DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS
OF THE
UNITED STATES

WATKINS GLEN-CATATONK FOLIO

NEW YORK

BY

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AND EDWARD M. KINDLE.

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GEOLOGIC ATLAS OF THE UNITED STATES.

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) inequalities 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 elevation of all parts of the area mapped, to delineate the outline 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 mean sea level, the vertical interval represented by each space between lines being the same throughout each map. These lines are called *contour lines* or, more briefly, *contours*, and the uniform vertical distance between each two contours is called the *contour interval*. Contour lines and elevations are printed in brown. The manner in which contour lines express altitude, form, and grade is shown in figure 1.

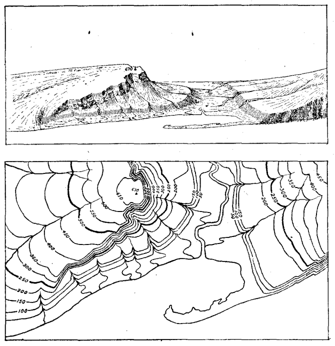


FIGURE 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay that is partly closed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle hill slope; that on the left is backed by a steep ascent to a cliff, or scarp, which contrasts with the gradual slope away from its crest. In the map each of these features is indicated, directly beneath its position in the sketch, by contour lines. The map does not include the distant portion of the view. The following notes may help to explain the use of contour lines:

1. A contour line represents a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contour lines are drawn at 50, 100, 150, and 200 feet, and so on, above mean sea level. Along the contour at 250 feet lie all points of the surface that are 250 feet above the sea—that is, this contour would be the shore line if the sea were to rise 250 feet; along the contour at 200 feet are all points that are 200 feet above the sea; and so on. In the space between any two contours are all points whose elevations are above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, and that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above the sea. The summit of the higher hill is marked 670 (feet above sea level); accordingly the contour at 650 feet surrounds it. In this illustration all the contour lines are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contour lines. The accentuating and numbering of certain of them—say every fifth one—suffices and the heights of the others may be ascertained by counting up or down from these.

2. Contour lines show or express the forms of slopes. As contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing around spurs or prominences. These relations of contour curves and angles to forms of the landscape can be seen from the map and sketch.

3. Contour lines show the approximate grade of any slope. The vertical interval between two contours is the same, whether they lie along a cliff or on a gentle slope; but to attain a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep ones.

A small contour interval is necessary to express the relief of a flat or gently undulating country; a steep or mountainous country can, as a rule, be adequately represented on the same scale by the use of a larger interval. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is in regions like the Mississippi Delta and the Dismal Swamp. For great mountain masses, like those in Colorado, the interval may be 250 feet and for less rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. For a perennial stream the line is unbroken, but for an intermittent stream it is broken or dotted. Where a stream sinks and reappears the probable underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are represented by appropriate conventional signs in blue.

Culture.—The symbols for the works of man and all lettering are printed in black.

Scales.—The area of the United States (exclusive of Alaska and island possessions) is about 3,027,000 square miles. A map of this area, drawn to the scale of 1 mile to the inch would cover 3,027,000 square inches of paper and measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and a linear mile on the ground by a linear inch on the map. The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to the inch" is expressed by the fraction $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; they are $\frac{1}{250,000}$, $\frac{1}{125,000}$, and $\frac{1}{62,500}$, corresponding approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale of $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale of $\frac{1}{125,000}$, about 4 square miles; and on the scale of $\frac{1}{250,000}$, about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three ways—by a graduated line representing miles and parts of miles, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map of the United States is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ represents one square degree—that is, a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ represents one-fourth of a square degree, and each sheet on the scale of $\frac{1}{62,500}$ one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, though they vary with the latitude.

The atlas sheets, being only parts of one map of the United States, are not limited by political boundary lines, such as those of States, counties, and townships. Many of the maps represent areas lying in two or even three States. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet are printed the names of adjacent quadrangles, if the maps are published.

THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic base map, the distribution of rock masses on the surface of the land and, by means of structure sections, their underground relations, so far as known and in such detail as the scale permits.

KINDS OF ROCKS.

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

Igneous rocks.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous*. Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or magma, within these channels—that is, below the surface—are called *intrusive*. Where the intrusive rock occupies a fissure with approximately parallel walls it is called a *dike*; where it fills a large and irregular conduit the mass is termed a *stock*. Where molten magma traverses stratified rocks it may be intruded along bedding planes; such masses are called *sills* or *sheets* if comparatively thin, and *laccoliths* if they occupy larger chambers produced by the pressure of the magma. Where inclosed by rock molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. Where the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive*. Lavas generally cool more rapidly than intrusive rocks and as a rule contain, especially in their superficial parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows also are usually porous, owing to the expansion of the gases originally present in the magma. Explosive action, due to these gases, often accompanies volcanic eruptions, causing ejections of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

Sedimentary rocks.—Rocks composed of the transported fragments or particles of older rocks that have undergone disintegration, of volcanic ejecta deposited in lakes and seas, or of materials deposited in such water bodies by chemical precipitation are termed *sedimentary*.

The chief agent in the transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits are then said to be mechanical. Such are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. Some of the materials are carried in solution, and deposits of these are called organic if formed with the aid of life, or chemical if formed without the aid of life. The more important rocks of chemical and organic origin are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the kinds of deposit named may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Another transporting agent is air in motion, or wind, and a third is ice in motion, or glaciers. The most characteristic of the wind-borne or eolian deposits is loess, a fine-grained earth; the most characteristic of glacial deposits is till, a heterogeneous mixture of bowlders and pebbles with clay or sand.

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

The surface of the earth is not immovable; over wide regions it very slowly rises or sinks, with reference to the sea, and shore lines are thereby changed. As a result of upward movement marine sedimentary rocks may become part of the land, and most of our land areas are in fact occupied by rocks originally deposited as sediments in the sea.

Rocks exposed at the surface of the land are acted on by air, water, ice, animals, and plants, especially the low organisms known as bacteria. They gradually disintegrate and the more soluble parts are leached out, the less soluble material being left as a *residual* layer. Water washes this material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it forms *alluvium*. Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. Their upper parts, occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a notable admixture of organic matter.

Metamorphic rocks.—In the course of time, and by various processes, rocks may become greatly changed in composition and in texture. If the new characteristics are more pronounced than the old such rocks are called *metamorphic*. In the process of metamorphism the constituents of a chemical rock may enter into new combinations and certain substances may be lost or new ones added. A complete gradation from the primary to the metamorphic form may exist within a single rock mass. Such changes transform sandstone into quartzite and limestone into marble and modify other rocks in various ways.

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressures, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structures may have been lost entirely and new ones substituted. A system of planes of division, along which the rock splits most readily, may have been developed. This structure is called *cleavage* and may cross the original bedding planes at any angle. The rocks characterized by it are *slates*. Crystals of mica or other minerals may have grown in the rock in such a way as to produce a laminated or foliated structure known as *schistosity*. The rocks characterized by this structure are *schists*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are many important exceptions, especially in regions of igneous activity and complex structure.

FORMATIONS.

For purposes of geologic mapping rocks of all the kinds above described are divided into *formations*. A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, an alternation of shale and limestone. Where the passage from one kind of rocks to another is gradual it may be necessary to separate two contiguous formations by an arbitrary line, and in some cases the distinction depends almost entirely on the contained fossils. An igneous formation contains one or more bodies of one kind, of similar occurrence, or of like origin. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics or origin.

When for scientific or economic reasons it is desirable to recognize and map one or more specially developed parts of a varied formation, such parts are called *members*, or by some other appropriate term, as *lentils*.

AGES OF ROCKS.

Geologic time.—The time during which rocks were made is divided into *periods*. Smaller time divisions are called *epochs*, and still smaller ones *stages.* The age of a rock is expressed by the name of the time interval in which it was formed.

The sedimentary 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.*

Inasmuch as sedimentary deposits accumulate successively the younger rest on those that are older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or superposed by faulting, so that it may be difficult to determine their relative ages from their present positions; under such conditions fossils, if present, may indicate which of two or more formations is the oldest.

Many stratified rocks contain *fossils,* the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are *characteristic types,* and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present. Where two sedimentary formations are remote from each other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first. Fossil remains in the strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

It is many places difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can in general be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it. Similarly, the time at which metamorphic rocks were formed from the original masses may be shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not that of their metamorphism.

Symbols, colors, and patterns.—Each formation is shown on the map by a distinctive combination of color and pattern and is labeled by a special letter symbol.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea, in lakes, or in other bodies of standing water. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations known to be of sedimentary or of igneous origin. The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system.

The symbols consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters.

The names of the systems and of series that have been given distinctive names, in order from youngest to oldest, with the color and symbol assigned to each system, are given in the subjoined table.

Symbols and colors assigned to the rock systems.

	System.	Series.	Symbol.	Color for sedimentary rocks.
Cenozoic	Quaternary	Recent Pleistocene	Q	Brownish yellow.
	Tertiary	Pliocene Miocene Oligocene Eocene	T	Yellow ocher.
Mesozoic	Cretaceous		K	Olive-green.
	Jurassic		J	Blue-green.
	Triassic		TR	Peacock-blue.
Paleozoic	Carboniferous	Permian Pennsylvanian Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Є	Brick-red.
	Algonkian		A	Brownish red.
	Archean		AR	Gray-brown.

SURFACE FORMS.

Hills, valleys, and all other surface forms have been produced by geologic processes. For example, most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; waves cut sea cliffs and, in cooperation with currents, build up sand spits and bars. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are inseparably connected with deposition. The hooked spit shown in figure 1 is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is first built and afterward partly eroded away. The shaping of a marine or lacustrine plain is usually a double process, hills being worn away (*degraded*) and valleys being filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wear them down, and streams carry the waste material to the sea. As the process depends on the flow of water to the sea, it can not be carried below sea level, and the sea is therefore called the *base-level* of erosion. Lakes or large rivers may determine local base-levels for certain regions. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the fairly even surface thus produced is called a *peneplain.* If the tract is afterward uplifted, the elevated peneplain becomes a record of the former close relation of the tract to base-level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—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 ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any particular formation, its name should be sought in the legend and its color and pattern noted; then the areas on the map corresponding in color and pattern may be traced out. The legend is also a partial statement of the geologic history. In it the names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology map.—The map representing the distribution of useful minerals and rocks and showing their relations to the topographic features and to the geologic formations is termed the *economic geology map.* The formations that appear on the areal geology map are usually shown on this map by fainter color patterns and the areas of productive formations are emphasized by strong colors. A mine symbol shows the location of each mine or quarry and is accompanied by the name of the principal mineral mined or stone quarried. If there are important mining industries or artesian basins in the area special maps to show these additional economic features are included in the folio.

Structure-section sheet.—In cliffs, canyons, shafts, and other natural and artificial cuttings the relations of different beds to one another may be seen. Any cutting that exhibits those relations is called a *section,* and the same term is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's *structure,* and a section exhibiting this arrangement is called a *structure section.*

The geologist is not limited, however, to natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface and can draw sections representing the structure to a considerable depth. Such a section is illustrated in figure 2.

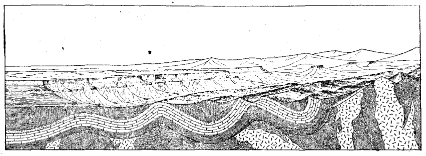
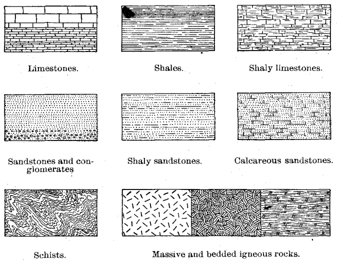


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground on a vertical plane, so as to show the underground relations of the rocks. The kinds of rock are indicated by appropriate patterns of lines, dots, and dashes. These patterns admit of much variation, but those shown in figure 3 are used to represent the commoner kinds of rock.



Limestones. Shales. Shaly limestones.

Sandstones and conglomerates. Shaly sandstones. Calcareous sandstones.

Schists. Massive and bedded igneous rocks.

FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

The plateau shown at the left of figure 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes. The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to the outcrops of a bed of sandstone that rises to the surface. The upturned edges of this bed form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shale.

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred. The direction of the intersection of a bed with a horizontal plane is called the *strike.* The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip.*

In many regions the strata are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines.* As the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets, the fact that they are now bent and folded is proof that forces have from time to time caused the earth's surface to wrinkle along certain zones. In places the strata are broken across and the parts have slipped past each other. Such breaks are termed *faults.* Two kinds of faults are shown in figure 4.

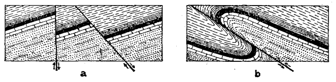


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not known by observation or by well-founded inference.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of sandstones and shales, which lie in a horizontal position. These strata were laid down under water but are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been uplifted. The strata of this set are parallel, a relation which is called *conformable.*

The second set of formations consists of strata that have been folded into arches and troughs. These strata were once continuous, but the crests of the arches have been removed by erosion. The beds, like those of the first set, are conformable.

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set shown at the left of the section. The overlying deposits are, from their position, evidently younger than the underlying deposits, and the bending and eroding of the older beds must have occurred between their deposition and the accumulation of the younger beds. The younger rocks are *unconformable* to the older, and the surface of contact is an *unconformity.*

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and traversed by eruptions of molten rock. But the pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that a considerable interval elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists were metamorphosed, they were disturbed by eruptive activity, and they were deeply eroded. The contact between the second and third sets is another unconformity; it marks a time interval between two periods of rock formation.

The section and landscape in figure 2 are ideal, but they illustrate actual relations. The sections on the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profile of the surface in the section corresponds to the actual slopes of the ground along the section line, and the depth from the surface of any mineral-producing or water-bearing stratum that appears in the section may be measured by using the scale of the map.

Columnar section.—The geologic maps are usually accompanied by a *columnar section,* which contains a concise description of the sedimentary formations that occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures that state the least and greatest measurements, and the average thickness of each formation is shown in the column, which is drawn to scale. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest being at the bottom, the youngest at the top.

The intervals of time that correspond to events of uplift and degradation and constitute interruptions of deposition are indicated graphically and by the word "unconformity."

GEORGE OTIS SMITH,
Director.

May, 1909.

DESCRIPTION OF THE WATKINS GLEN-CATATONK DISTRICT.

By **H. S. Williams, R. S. Tarr, and E. M. Kindle.**

INTRODUCTION.

By Henry S. Williams and Ralph S. Tarr.

LOCATION AND AREA OF THE QUADRANGLES.

The area mapped in this folio is included in the Watkins Glen and Catatonk 30-minute quadrangles. The Watkins Glen quadrangle, which includes the area mapped on the Watkins, Elmira, Ithaca, and Waverly 15-minute sheets, lies near the center of the southern tier of counties of the State of New York, between parallels 42° north, marking the southern boundary of the State, and 42° 30′ north, which crosses Cayuga Lake about 4 miles north of Ithaca. Its eastern and western boundaries are meridians 76° 30′ west, passing through the eastern part of the city of Ithaca, and 77° west, about 7 miles west of Watkins, at the head of Seneca Lake. It includes the whole of Chemung County, a narrow strip of eastern Steuben County, a narrow strip on the west side of Tioga County, and portions of Schuyler and Tompkins counties. (See fig. 1.) Its north-south length is about 34½ miles, its east-west breadth about 25½ miles, and its total area approximately 885 square miles. It is named for the picturesque Watkins Glen, situated west of Watkins, in a deep east-west gorge cut in the western hillside with precipitous walls and numerous waterfalls.

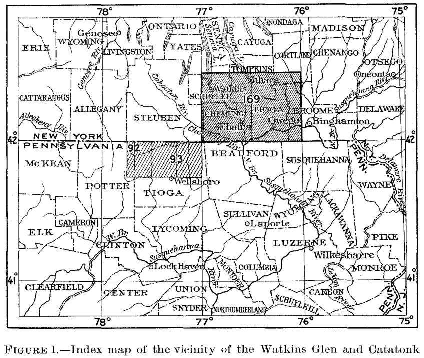


FIGURE 1.—Index map of the vicinity of the Watkins Glen and Catatonk quadrangles.

Darker ruled area, Watkins Glen-Catatonk folio. Other published folios indicated by lighter ruling as follows: Nos. 92, Gaines; 93, Elkland-Tioga.

The Catatonk quadrangle which includes the area mapped on the Dryden, Owego, Harford, and Apalachin 15-minute sheets, is directly east of the Watkins Glen quadrangle. Its northern boundary passes through the northern part of Dryden and cross Tioughnioga River about one-half mile north of Messengerville. Its western boundary is the eastern boundary of the Watkins Glen quadrangle. Its eastern boundary is the meridian of 76° west longitude, which crosses Susquehanna River between Owego and Binghamton. Near this boundary are the towns of Messengerville, Marathon, Lisle, Hooper, and Vestal Center. The quadrangle includes the southeastern quarter of Tompkins County, the southwestern quarter of Cortland County, the whole of Tioga County, and a strip about 5 miles wide in the western part of Broome County. Its dimensions and total area are the same as those of the Watkins Glen quadrangle. It is named for the town of Catatonk, situated on Catatonk Creek a few miles northwest of Owego.

GEOGRAPHIC AND GEOLOGIC RELATIONS.

These quadrangles lie entirely within the area of the Allegheny Plateau, which skirts the west side of the great Appalachian Valley from its south to its north end. The consolidated rocks of this plateau are all Paleozoic sediments, deposited in the sea which lay to the west of the ancient Appalachians during Paleozoic time. These sediments, consisting of essentially horizontal sheets varying in thickness and texture, were brought above the sea at the close of the Paleozoic era, when the ancient Appalachians were re-elevated and their area extended westward. Although this uplift caused mountain folds in the Appalachians proper, there was little disturbance of the sediments farther west. The strata of the plateau, therefore, though exhibiting minor folds, are in the main still in approximately horizontal positions. Since its uplift this plateau has been almost if not quite continuously exposed to denudation, with the result that throughout its area it is now profoundly worn and dissected. Among the latest events of the glacial period in the northern part of the plateau were two invasions by a continental glacier, the later being that of the Wisconsin stage, by which many changes in the surface features have been brought about. The rocks underlying the surface cover of Quaternary deposits of varying thickness in the Watkins Glen and Catatonk quadrangles are entirely of Devonian age.

There are many differences in the local geologic history of the various parts of the plateau province. Some of these differences present problems which may be solved by the study of a single quadrangle; but there are also many broader problems whose solution may be expected only after much larger areas of the Allegheny Plateau have been studied. This folio is therefore to be considered as only one of a number dealing with closely related problems.

TOPOGRAPHY.

By Ralph S. Tarr.

RELIEF.

ELEVATION.

The country comprised within the limits of these quadrangles is a deeply dissected, hilly plateau. The streams have cut steep-sided valleys in the plateau, but the interstream areas, though high above the valley bottoms, preserve a much more even surface, largely through the influence of the nearly horizontal strata of shale and sandstone. Viewed from the valleys the appearance is that of a rugged region of steep slopes; but from the hilltops the aspect is far less hilly and rugged. Many of the hills rise to elevations of 1700 or 1800 feet, and several are more than 2000 feet above the sea. The highest point in the quadrangles is a hill just west of East Virgil, which has an elevation of 2133 feet. So high and steep are some of the hills that they are locally known as mountains; for example, Mount Zoar, west of Elmira, where in a distance of less than a mile there is a difference in elevation of about 800 feet.

The lowest land exposed in the area is the shore of Lake Cayuga, which has an elevation of 381 feet above sea level; but the actual rock floor of the valleys, which would represent the lowest land if Quaternary deposits and lake water were absent, is much lower. A well boring at Ithaca reaches rock at a depth of 430 feet, so that the valley bottom here is at least 49 feet below sea level; and a boring at Watkins passed through 1080 feet of unconsolidated material, proving the hard rock in the lowest part of the Seneca Valley to be at least 637 feet below sea level. Therefore in the Watkins Glen quadrangle the maximum known relief between hilltop and valley floor is 2770 feet.

Considered in regard to elevation the Catatonk quadrangle may be divided into three belts. The largest of these, extending north of east, includes all of the southern half and, in the eastern part, a portion of the northern half of the quadrangle. In this belt the hilltops average from 1400 to 1600 feet in elevation. North of it and also extending in a direction north of east is a belt of higher land with hilltops averaging from 1600 to 1900 feet in elevation and a number of hills above 2000 feet, the highest reaching an elevation of 2133 feet. Still farther north is a much more level and lower area, whose elevation is nowhere above 1130 feet. This belt occupies only a small area in the northwestern part of the quadrangle. The two southern belts grade into one another; but the two northern are separated by an abrupt escarpment rising 400 to 700 feet, and followed at its northern base by Fall Creek. This escarpment coincides with a change in the bed rock, the uplands being of more durable shales and sandstones than the lower belt. In the Watkins Glen quadrangle these belts are less clearly defined.

THE UPLANDS.

Although the uplands are not rugged, they are far from level. Along many of the divides the hilltops preserve a moderate uniformity of level for several miles; but neighboring hills rise to decidedly different elevations, and all the hills slope rather steeply toward the minor upland valleys. If all the larger valleys were filled to the level of the minor upland valleys, the surface would still be hilly, though far more subdued than now and with a certain subequality of hilltops. (See fig. 28, illustration sheet II.)

Cirquelike upland valleys.—Owing to the influence of the nearly horizontal beds of shale and sandstone, the hills are commonly flat-topped and their upper slopes are usually smooth and well rounded. They vary greatly in shape but are typically curved, inclosing broad, moderately sloping, shallow, cirquelike areas above which they rise 100 to 200 feet. In places the more resistant layers have been etched by denudation into terrace forms, but these upland divides and hilltops are, on the whole, so mature in form and consequently so evenly sloping that they are almost uniformly cleared of timber, and are cultivated in spite of the fact that the soil is ordinarily thin, rocky, and infertile.

Upland valley slopes.—Below these mature uplands the slopes of the valley sides become much steeper, giving rise to a topography of much less mature appearance than that of the divide areas. These steeper slopes, which extend in places up to the very divide, are found here on one side only, there on both sides, in the latter case giving the valley the appearance of a broad gorge. Where one side is steeper than the other the steeper slope is generally on the side where the stream is flowing; but in valleys extending in an east-west direction, the steeper slope is more commonly on the south side than on the north side, a condition which may be due to the fact that the strata dip southward. Most of these valley sides are too steep for farming, and consequently are still wooded.

Rock terraces.—On the steeper slopes of the upland valleys, and to a less extent on the hilltops themselves, denudation has etched out minor topographic forms, dependent on the difference in resistance of the horizontal strata. The most common of these forms are rock terraces contouring the hill sides, and at the bases of many of them springs emerge, forming swampy patches. The emergence of the spring water in these situations suggests that the process of sapping, by which the terraces were formed, is still in progress.

Most of the rock terraces are horizontal, or approximately so; but in places they are inclined, and even broken into smaller sections. Indeed, some of the broken terraces are so confused that it has been difficult to determine whether they are rock or moraine. Such conditions prevail especially on the steeper slopes. This phenomenon has been interpreted as the result of downhill slipping of the terrace front prior to the glacial invasion, perhaps aided in some places by the shove of the ice. Residual clay, formed by the decay of shale layers beneath the cliff-forming sandstone beds, would afford good slipping planes, and in some localities the presence of such residual clay could be demonstrated. The fact that the glacial advance did not round and remove these rock terraces is evidence of its ineffectiveness as an agent of erosion on the uplands, a conclusion amply sustained by other evidence presented in the section on the Quaternary system. (See p. 16.) In the area occupied longest by the ice sheet rock terraces are few and imperfect, and usually have rounded edges.

Some of the best instances of the development of these rock terraces occur at the heads of short streams tributary to the deeper main valleys; for example, 2½ miles northwest of White Church. These streams were evidently actively gnawing at their divides when the ice last advanced over the region, and in the course of their work had formed gorges in the lower portions and an irregular, angular rock topography about the headwaters. In a number of such situations denudation has produced perfect though small buttes.

Difference from north to south.—There is a very decided difference between the upland topography of the northwestern portion of this area and that of the remainder. Even where the elevation above sea level is not greatly different, the surface in the north is far less rugged, the hilltops are broader, the mature divide areas are less distinct, rock terraces are less common, and the sides of the upland valleys are much more moderately sloping.

This difference coincides rather closely with a difference in rock structure and composition, weaker shales being characteristic of the north and more resistant shales and sandstones of the south. In a less perfect way it also coincides with a difference in the length of time that the two sections were glaciated during the Wisconsin stage; for the ice stood longer on the northern third of the area than on the southern two-thirds.

VALLEYS.

Through valleys.—These quadrangles include a part of the divide between the St. Lawrence and Susquehanna systems, and the valley pattern is very peculiar.

Two long, deep troughs, occupied in part by Lakes Cayuga and Seneca, extend nearly parallel to each other northward across the northern portion of the Watkins Glen quadrangle. These troughs carry the drainage of most of the northwest quarter of the area toward the St. Lawrence.

In the southern part of the Catatonk quadrangle is the Susquehanna Valley, rather narrow, moderately flat-floored, and with sides rising, usually with moderate steepness, though in places precipitously, to the upland a mile or two from the river and 500 or 600 feet above it. The river flows westward, leaving the quadrangle near Waverly, where it is joined by the Chemung from the west, the two forming a continuous valley near the southern margin of the quadrangles.

Most of the tributaries to these valleys are short, descending in a few miles from the high divide areas to the bottoms of the main valleys. This is especially true of the valleys tributary to the Cayuga and Seneca valleys and of the southern tributaries to the Susquehanna, but the larger valleys that enter the Susquehanna Valley from the north are long, deep, narrow, and of peculiar character.

In the western part of the area is a long, north-south trough connecting the Seneca Valley with the Chemung Valley at Horseheads, without a well-defined divide. East of this trough is the Cayuta Valley, long and narrow, with steeply rising walls, forming a continuous depression from Seneca Lake to the Susquehanna Valley at Waverly, also with no well-defined divide.

Still farther east is the similar Catatonk Valley, with steep, straight walls that are continued across the divides where a branch of Sixmile Creek rises to flow into Cayuga Lake. Near Candor is a broader, east-west valley which extends to Spencer, where it unites with the north-south Cayuga Valley, and still farther west to Van Etten, where it opens into the Cayuta Valley.

East of the Catatonk Creek valley are two similar valleys, those of the East and West branches of Owego Creek, both of which are continued across the divide of the St. Lawrence drainage basin, the West Branch heading near a branch of Sixmile Creek east of Slaterville Springs and the East Branch heading near an arm of Fall Creek northwest of Harford. In the northeast corner of the Catatonk quadrangle a similar valley is occupied by Tioughnioga River, a tributary to the Susquehanna, which enters the quadrangle from the north and leaves it at Lisle, on the eastern margin. In the Cortland quadrangle, just north of this, the Tioughnioga Valley also is continued across the divide of the St. Lawrence drainage area.

These valleys are all peculiar in character. They are very narrow, they do not progressively widen from head to mouth of the stream, their walls are steep, their sides are straight and show a marked absence of projecting spurs, and they have no pronounced divides at the heads of the streams, the present divides being on low morainic or other glacial deposits, and not in the narrowest parts of the valleys.

Valleys of the type just described may be called *through valleys* (a name suggested by Prof. W. M. Davis), because they extend uninterruptedly through from one drainage system to another. The narrowest part of the through valleys in this area is in that portion of the plateau which is highest and which may be considered to be the normal divide region between the St. Lawrence and Susquehanna systems; but the present divides of the larger streams are near the northern edge of this higher belt, not in the middle. For some reason this higher belt of upland has been trenched through by profound valleys, so deeply that old divides, presumably located where the through valleys are narrowest, were not reoccupied after the ice sheet left the region.

The through-valley condition is not confined to the main valleys. The headwaters of a large number of smaller streams are also situated in through valleys of less marked character, and there is every gradation from normal rock divides at the headwaters to the perfect through valleys of the larger north-south troughs. Examples will be found at Halsey Valley; at the head of Michigan Creek south of Danby; at the head of Danby Creek; at the head of Prospect Valley south of Slaterville Springs; at the head of Cascadilla Creek south of Ellis; in the valley west of Hunts Corners; in the valley south of Franks Corners; and at many other places in the area. Notched divides tending toward the through-valley condition form one of the most characteristic topographic features of this area and they are also present throughout the surrounding region. That this condition of notched divides was a general feature in the topography before the Wisconsin ice advance is proved in numerous places by the presence of drift-filled gorges tributary to the through valleys near the present divides.

Although the through-valley condition is due partly to the presence of deep drift deposits, which obscure the rock topography, it is mainly the result of the actual absence of definite rock divides. This condition may be best illustrated by calling attention to a few specific examples.

Near the western margin of the Watkins Glen quadrangle is the Post Creek valley, with steep rock walls rising above a flat-bottomed, drift-filled valley, and with so low and flat a divide, where it heads near Montour Creek, that the New York Central and Hudson River Railroad (Pennsylvania division) passes easily across it. A railway and a trolley line pass with easy grade across the divide between the Seneca and Chemung valleys. Through valleys extend from the Reynoldsville-Bennettsburg valley through Texas Hollow, and from the Taghanic Valley to the Cayuta Lake valley. It is possible to pass from the Cayuga Valley to Spencer and thence to the Cayuta Valley at Van Etten without encountering a well-defined divide; and likewise to pass up Pony Hollow and enter either the Newfield or the Butternut Creek valley. In each case, however, the valley walls rise high above the valley bottom, and, both at the present divides and at the narrowest part of the valley, the slopes of the valley sides are usually steep.

One of the most remarkable low divides in the area is that of Texas Hollow, between Odessa and Bennettsburg. At both the north and south ends this valley flares slightly and is drift-filled to an unknown depth; but near the middle there is rock in the valley bottom set deeply between steeply rising walls. For almost its entire extent this valley has straight walls, so steep that they are still wooded from top to base and no roads ascend them. Except at its north end the valley receives no tributaries other than those which head almost on the very edge of the inclosing steep valley slopes, and the walls are remarkably smooth and regular. The very word "hollow," in common use in this region, shows local recognition of the peculiarities of the steep-sided, straight-walled type of valley without definite divides. The straight, steep, smooth walls, which extend for a longer distance in Texas Hollow than elsewhere in the area, find their counterpart on a smaller scale in many other places; for example, south of West Danby, between Ithaca and Nina, south of Montour Falls, and in the Taghanic Valley south of Mecklenburg.

It is, in fact, true that not one of the large streams of this area heads against a definite rock divide; and this is true of east-west as well as of north-south valleys. To a less marked degree the tributaries of secondary size reveal the same characteristics. Besides those already mentioned, attention may be called to the divide at the head of Baldwin Creek just south of Breesport, the divide between Baker and Wyncoop creeks, and that between Johnson Hollow and Montour Creek. Even some of the still smaller tributaries have low divides with the valley sides rising high above them. Such is the case, for example, back of two hills about 2 miles southwest of Elmira and of a hill about 2 miles northeast of Horseheads.

A stream valley, in fairly uniform rock, normally broadens from head to mouth. A mere glance at the topographic maps of this region suffices to show that this normal condition is by no means uniformly present in the valleys of these quadrangles. The Cayuta Valley and its tributaries well illustrate this divergence from the normal. The headwaters, above Cayuta Lake, unite in the broad valley in which that lake lies and which extends southwestward toward Odessa; but, instead of following this trough into the Seneca Valley, the outlet stream of the lake flows through a narrow gorge past Alpine, and thence along a valley that rapidly narrows toward the southeast—that is, in the direction of the flow of the stream. At Cayuta the valley is joined by Pony Hollow, whose narrowest part does not coincide with the present divide. Between Cayuta and Rodbourn the Cayuta Valley is a deep, narrow gorge, but it broadens again toward the southeast, and at Van Etten turns sharply southward into a valley which also narrows and broadens before it reaches the Chemung Valley at Waverly. Normally there should be divides at these narrow parts; and their absence suggests that, through some cause, parts of several stream systems have here been united into one. The origin of this and other topographic peculiarities is considered in the section entitled "Physiographic record."

Where Chemung River enters the Watkins Glen quadrangle from the west it occupies a broad valley; but instead of following this valley the river passes south of Hawes Hill, through a narrow gorge which is broader at each end than in the middle. After passing through Elmira the river flows southeastward in a valley which is narrower than that at Elmira or that west of Big Flats. The Erie and Lackawanna railroads pass to the north of Hawes Hill along the broad valley which the Chemung leaves near Big Flats and which certainly must be considered the preglacial course of the river. It would not be a difficult task to divert the Chemung through this valley, or even northward into the Seneca Valley.

Other through valleys in the area show similar divergence from the normal condition of a valley broadening uniformly from the head toward the mouth.

Another normal characteristic of valleys is that the tributary streams enter at accordant grade; but there are innumerable broadly flaring valleys opening into these through valleys at levels high above the main valley bottom. These tributary hanging valleys have gorges sunk in their lower portions; and not uncommonly there are gorges of two ages, one postglacial, the other of earlier date and drift filled.

Valley filling.—The smaller valleys, away from the main streams, are not, as a general rule, deeply drift filled; but here and there wells reveal such a depth of drift as to indicate the presence of buried valleys. But the main valleys and the lower portions of the valleys tributary to them are deeply drift filled. This fact is indicated by the records of the following deep wells in various parts of the quadrangles: At Ithaca, 430 feet to rock; at Watkins, 1080 feet (no rock); at Cook Academy, Montour Falls, 436 feet (no rock); at Millport, 187 feet (no rock); at Horseheads, 350 feet (no rock); at Breesport, 195 feet (no rock); at Elmira Heights, 300 feet (no rock); in and north of Elmira, 100 to 125 feet (no rock). At Waverly rock was reached at depths of 64 to 72 feet. One mile northeast of Etna, in the Fall Creek valley, there is 170 feet of drift on the bed rock. At Ellis, in the Cascadilla Creek valley, a well 100 feet deep does not reach rock; at Brookton, in the Sixmile Creek valley, a well reaches rock at 170 feet; at Danby a well 80 feet deep does not reach rock; in the Owego Creek valley wells 60 to 70 feet deep fail to reach rock; in the Susquehanna Valley, south of Endicott, no rock is reached at 150 feet; and at several other points in this valley wells from 50 to 100 feet deep do not strike rock.

The general effect of this filling is to lessen the relief; but in many of the larger valleys it also forms a level floor, as the latest additions to the deposits were water laid. Nowhere in the quadrangles is this better illustrated than in and near Elmira, where the valley bottom is a flat gravel plain with a width of 2 or 3 miles. In consequence of such deposits the usual condition of the larger valleys is that of a flat floor from which steep valley walls rise abruptly. The chief exceptions to this condition are in those valleys where the ice stood and built moraines in the valley bottom. In such valleys the floor shows a confused hummocky topography, as may be seen southeast of Dryden, south of Brookton, and south of Seneca and Cayuga lakes.

Steepened main valley slopes.—Accompanying the condition of through valleys is the presence of a steepened slope, on both sides of many of the valleys where they are narrowest, but in others alternately on one side and on the other. In places the steepness is sufficient to make the valley wall a cliff, at the base of which talus is accumulating; but more commonly the slopes are not so steep as to be called cliffs, though too steep for farming. In such valleys, although both the valley bottoms and the uplands are cleared for farming, the valley sides are forest covered for miles and no roads ascend to the upland except along the tributary valleys. This condition is illustrated both east and west of Elmira, along the Cayuta Valley between Van Etten and Waverly, in Texas Hollow, in the Cayuga and Seneca valleys, and in many other places. Many of these steepened slopes rise to the mature upland, and even to the mature-upland divides, proving conclusively that there was a double stage in the history of the valley development of the region.

Hanging valleys.—The truncation of the uplands by the steep-sided valleys leaves many of the smaller valleys hanging 200 to 400 feet above the main valley bottom; and their small streams, after flowing along a moderate slope in the upland valleys, abruptly change in grade at the edge of the steepened slope and cascade down it in shallow gorges. It is evident that the deepening of the main valley and the steepening of the slopes have been accomplished so recently that the weaker tributaries have not yet had time to form valleys in harmony with the overdeepened main valley.

Many of even the larger streams tributary to the main valleys show a similar condition. (See fig. 27, illustration sheet II.) This is well illustrated in the Tioughnioga Valley above Marathon. Here the lower valley wall is steep and the upper slopes more moderate. Across the steeper slopes the tributary streams pass in rock-walled gorges cut in the beds of broad valleys whose bottoms hang a hundred feet or more above the river. The unnamed creek flowing from East Virgil to Messengerville is typical of these hanging valleys in the Tioughnioga region. Farther north, in the Cortland quadrangle, similar hanging valleys occur.

A very perfect hanging valley may be seen on the west side of Owego Creek, about 2 miles northwest of Owego, where a small stream occupies a mature valley nearly to its end and then, for over 100 feet, tumbles down the steepened slope in a gorge with several falls.

There are numerous other hanging valleys tributary to the larger valleys, and even to the smaller ones. Of the latter the hanging valleys tributary to Prospect Valley may be taken as a type. The tributary streams enter Prospect Valley through gorges sunk in the bottom of mature hanging valleys; and the main valley is bordered by a steepened slope with rock terrace remnants of the old valley floor. Some of the valleys tributary to the Susquehanna are hanging; for example, the valley of Hunts Creek at Lounsberry, whose lower course lies in a rock-walled gorge sunk in the bottom of a broad, mature valley. It would require a long list to refer specifically to all the hanging valleys in these quadrangles. They are present in scores of valleys, especially those extending approximately north and south, and show all stages of development. They occur, for instance, in Texas Hollow, in Pony Hollow, in Cayuta Valley, in the valleys of Sixmile Creek and of the inlets to Cayuga and Seneca lakes, and in many other valleys.

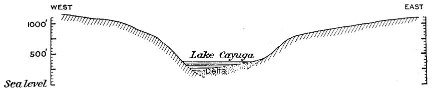


FIGURE 2.—Cross section of Lake Cayuga valley 2 miles north of Ithaca.
Horizontal scale, 1 inch=2 miles.

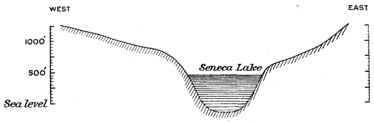


FIGURE 3.—Cross section of Seneca Lake valley 3 miles north of Watkins.
Horizontal scale, 1 inch=2 miles.

Nowhere, however, are the hanging valleys better developed than along the walls of the Cayuga and Seneca Lake valleys. Here the steepened slope extends from an elevation approximately 800 to 900 feet above sea level down to the rock floor in the valley bottom; that is, at least 850 feet in the Cayuga Valley and 1400 to 1500 feet in the Seneca Valley. (See figs. 2 and 3.) At Watkins there is a descent in the valley wall of 1400 feet in a little more than a mile on the steepened slope, but above this slope, toward the west, the surface rises only 700 feet in a distance of 5 miles. The upper slopes are mature in form; below them are straight, smooth-walled, gorgelike valleys in which the lakes lie.

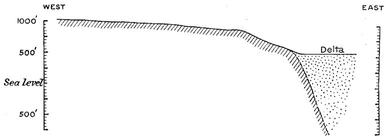


FIGURE 4.—Profile along bottom of Watkins Glen, in Seneca Valley.
Horizontal scale, 1 inch=2 miles. Well 1080 feet deep in delta did not reach hard rock.

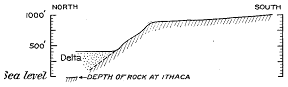


FIGURE 5.—Profile of Buttermilk (Tenmile) Creek 2 miles south of Ithaca
Horizontal scale, 1 inch=2 miles.

In harmony with this change in slope of the main valley walls there is, at approximately the same level (800 to 900 feet elevation), a change in the gradient of the tributary streams. To the edges of the steepened slopes these streams flow through valleys with moderate grade, but there the grade abruptly changes and the streams descend to the lake valleys in a series of cascades and falls. (See figs. 4 and 5.) This condition is found in all the tributaries to the Cayuga and Seneca valleys within the limits of these quadrangles. For example, Glen Creek flows through such a hanging valley before descending the steepened main valley wall in the picturesque Watkins Glen. Fall and Cascadilla creeks, which bound the Cornell University campus, have the same general characteristics. The plateau on which the campus is situated is the outer edge of the hanging valley of these two streams, and its rock floor at this point is at least 850 feet above the rock floor of the Cayuga Valley a mile and a half away. Sixmile Creek also flows in a gorge cut in the bottom of a hanging valley, whose rock floor is, however, between 150 and 200 feet lower than that of the neighboring valleys of Cascadilla and Fall creeks.

Gorges and falls.—Where these tributary streams tumble down the steepened slopes they have cut gorges, in which there are many picturesque cascades and falls. (See figs. 23 to 26, illustration sheet I.) Of these gorges the best known are Watkins and Havana glens, in the Seneca Valley, which are, however, only two of many. The massing of the contours on the map along Big Stream, Sawmill Creek, and Watkins Glen in the Seneca Valley, and along West Branch of Cayuga Inlet, Butternut Creek, Coy Glen, Buttermilk Creek, Sixmile Creek, and Fall Creek, in the Cayuga Valley, shows clearly the existence of these gorges in the course of the larger streams; but they are present also in the smaller ones. Many of these gorges are the result of postglacial erosion, and the streams are still busily at work deepening them. Weathering has not yet had time to broaden the gorges markedly, and consequently the walls rise as steep cliffs, many of which overhang where the stream is undercutting them on one side.

Much of the variety of form and picturesqueness of the gorges is due to the influence of the abundant joint planes which cleave the shales vertically and allow rock masses to fall away under the influence of weathering, giving rise to smooth rock faces and angular rock buttresses. The joint planes aid greatly in determining the direction of the streams in the gorges and also, in many places, the form of the falls. Far more commonly, however, the falls owe their origin and form to the variation in texture of the nearly horizontal shale and sandstone layers.

Gorges of a second type, with associated waterfalls, are found where drift deposits have turned the stream to one side of the preglacial valley and forced it to flow across the rock wall of one side of the valley. This condition is illustrated at two places on Sixmile Creek, at Brookton, where a great delta deposit has pushed the stream over to the south side of the valley, forming a fall that is utilized for power, and north of Slaterville Springs, where the creek is pushed over against its east wall by a massive drift deposit, associated in origin with a stand of the ice in this vicinity. Here a deep gorge has been cut. Rapids and falls in small gorge sections of diverted streams occur also in other parts of the quadrangle.

Older buried gorges.—Many of the streams tributary to the main valleys are flowing in gorges of earlier date than the postglacial gorges described above. As deposits made during the last ice advance partly fill these older gorges, they are known to antedate that advance; and as they are both broader and deeper than the postglacial gorges, it is evident that they required a longer period of time for their formation. In many places postglacial streams are engaged in removing the drift filling of the older gorges, with varying degrees of success. In some localities—for example, in Clark's Glen at Fitch Bridge, 3 miles west of Elmira—the present stream flows along the axis of the older gorge, which it is engaged in clearing out, revealing the old, much-weathered, and crumbling gorge walls where the stream swings against one side or the other. Many of the smaller streams flow between rock walls, partly drift covered and crumbling, and farther apart than would be possible as a result of postglacial work, even if the presence of drift did not preclude the possibility of assigning them to postglacial origin. In most places the postglacial stream work has not yet sufficed to clear out the drift and reveal the rock floor of these gorges. This is especially true of their lower ends, where the rock bottom evidently lies far below the level of the drift floor of the main valley, and therefore can not be reached until the main valley has had its drift filling removed.

That there is a system of older gorges associated with the hanging valleys is proved in many places. The best evidence is afforded by the buried gorges in the valleys tributary to Cayuga and Seneca lakes. Fall Creek, for example, crosses such a buried gorge just above the Cornell University campus, and there it broadens out and flows between drift walls in place of the rock walls which bound the stream above and below. The university has made a small lake by placing a dam across the postglacial rock gorge that has been formed where the stream passes out across the south wall of the older gorge. Cascadilla Creek also has a buried gorge, and Sixmile Creek crosses parts of such a gorge, its valley expanding to an amphitheater where it crosses the broad older gorge and narrowing to rock gorges, with falls, where it passes, in postglacial cuts, from one section of the older gorge to another.

This condition is illustrated also by Big Stream, Rock Stream, the part of Watkins Glen above the railroad, and upper Havana Glen, in the Seneca Valley, and by upper Buttermilk Creek, in the Cayuga Valley. These streams, as well as others, flow in alternate sections of narrow postglacial gorges, where they are turned aside by the drift, and broad gorges, or "amphitheaters," where their courses coincide with the older buried gorges. These older gorges have precipitous walls which, in many places, as in Havana Glen, may be seen extending out under the drift filling that has turned the postglacial streams aside.

The older gorges are much more clearly exhibited along the sides of the Cayuga and Seneca valleys than elsewhere in these quadrangles. There they are cut in the bottoms of all the hanging valleys and also trench the steepened main valley slopes. In some places the postglacial stream follows the older gorge down the steepened slope; but in others the thick deposits of moraine and delta, which occur at about the level of the edge of the steepened slope, have turned the stream completely aside from its older gorge and forced it to cut an entirely new postglacial gorge in the steepened slope.

Watkins Glen well illustrates this deflection. For 3 or 4 miles above the railroad bridge the stream flows alternately in postglacial and older gorges; but below the bridge it is in a narrow, precipitous gorge which it has cut since the Wisconsin ice left the region. At the elbow in the creek, just above the railroad bridge, the older gorge diverges from the present stream course, passing out under the railroad station and thence down the hill slope past the sanitarium. At the sanitarium a well boring carried to a depth of 105 feet found no rock, and just to the west no rock was found in a well 175 feet deep, apparently in the gorge; but wells both north and south of this locality, on the banks of the buried gorge, reach rocks at depths of 10 to 20 feet. The bottom of this older gorge is, however, above the level of Seneca Lake, for rock outcrops continuously above the lake level across the course of this gorge.

A similar condition exists on Buttermilk Creek south of Ithaca,[a] though here the older gorge is not so completely buried. Above the road which crosses Tenmile Creek near the 900-foot contour there are alternate sections of older and postglacial gorges; but below the road, down to the main valley floor, the creek flows in a postglacial gorge. Just north of Tenmile Creek the older gorge extends down the steepened slope as a distinct sag in the hillside, in reality a gorge with precipitous walls inclosing extensive drift deposits. It is much broader and deeper than the postglacial gorge of the present creek.

Similar buried gorges exist in the bottoms of the hanging valleys of the streams tributary to Tioughnioga River. For example, the creek between East Virgil and Messengerville occupies an old gorge in its lower portion; but at East Virgil the valley contracts decidedly, the older gorge continuing a little farther south under a great morainic pile and rejoining the creek a few hundred yards upstream. Similar conditions occur in a valley on the east side of Tioughnioga River farther north, in the Cortland quadrangle. That these older gorges were produced before the last ice invasion is proved by the fact that they are filled with drift of this invasion; and that they required a long period of time for their formation is demonstrated by the fact that they are deeper, broader, and less steep walled than the postglacial gorges. The bearing of these facts on the question of the origin of the overdeepening of the main valleys, which gave rise to the hanging-valley condition, is discussed in the section on "Physiographic record," page 30.

Minor valley peculiarities.—Tributaries naturally enter the main streams with an acute angle pointing downstream; where the angle points upstream it suggests that the main stream has had its direction reversed. Such "barbed" tributaries join the northward-flowing Catharine Creek near Pine Valley and Cayuta Creek near Van Etten.

Valleys exist in various places in these quadrangles where streams no longer flow, and some of these valleys lie on hill slopes where, under existing conditions, no such valleys could possibly be developed. Many of these valleys follow the contour of the hillside, and some of them have but a single bank. They are characteristic phenomena of ice margins where glacial streams flowed from the ice front or along its edge.

In still other places broad, flat-bottomed valleys are occupied by streams far too small to have formed them, indicating the former existence of larger streams along their courses. These valleys, most of which are too small to find expression on the topographic map, were made by marginal drainage and outflowing streams during the glacial occupation of the region. The sites of the more prominent valleys of this type are indicated on the surficial geology map, and a description of some of them will be found in the section on the Quaternary system.

MINOR TOPOGRAPHIC FEATURES.

The major features of relief of this region are the result of erosion of the nearly horizontal shales and sandstones; but many of the minor details of topographic form are due to the unconsolidated drift, or to the modification of this deposit by later erosion. The raising and leveling of the valley floors through drift deposition has already been mentioned, and a description of the moraines, deltas, alluvial fans, and other Quaternary deposits is presented in the section on the Quaternary system, pages 15–28. Except in a few places—as, for example, in the moraine areas south of Watkins and Ithaca—the relief of these deposits is not sufficiently marked to warrant expression on the topographic map; yet in the landscape they form conspicuous features of detail at many places.

DRAINAGE.

RIVERS.

Being in a headwater region, the streams of this area are mostly small. As the drainage of the area is tributary to two river systems, the Susquehanna and the St. Lawrence, it finds its way into the sea at two widely separated points. Fully two-thirds of it goes by way of the Susquehanna. The divide between these two systems is very irregular, swinging southward nearly to Horseheads south of Seneca Lake, and nearly to Spencer south of Cayuga Lake, whereas between these two lakes it extends northward nearly to the latitude of Ithaca, and east of the Cayuga Valley it passes northeastward across the northern boundary of the Catatonk quadrangle. Although for most of its extent this divide passes along the crests of the hills, it descends several hundred feet where crossing through each of the valleys between the larger tributaries of the two opposing systems.

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[a] Matson, G. C., Jour. Geology, vol. 12, 1904, p. 133.

From the divide it is a long journey to the St. Lawrence, but a very short one to the Susquehanna and Chemung, which extend entirely across the southern portion of the area. The Susquehanna, which here flows westward, enters the Catatonk quadrangle at an elevation of about 820 feet and leaves it at about 760 feet, everywhere having a moderate fall and flowing over glacial deposits. The volume of the river fluctuates greatly from the low-water stage of midsummer to the floods of spring; but it is not uniformly deep enough to be of importance for navigation.

In spite of the large volume of water in Susquehanna River, it has accomplished a surprisingly small amount of erosion in postglacial time. Kames and eskers extend up to its very banks; the outwash gravel plains are only slightly trenched; its current is still divided around a small drift island (Hiawatha Island, near Owego), which it has not removed; and, except in one or two places, it is not attacking the adjoining hills. It is true that its valley presents alternate cliffs and more moderate slopes, and that the river is in many places flowing close to the base of the steeper slopes; but these cliffs are in the main inherited from an earlier stage of river erosion, for glacial deposits are banked up against them, notably at the cliffs west and southwest of Barton.

As the Susquehanna swings southward near the center of the Catatonk quadrangle, the country south of the river forms in part a roughly triangular area with the river on two sides; and as the tributary streams flowing northward and those flowing westward are in competition for the drainage of this area, they can not be of great size. It is evidently because of this fact that the streams tributary to the Susquehanna from the south in this quadrangle are all so small.

The largest tributary to the Susquehanna system from the north in the Catatonk quadrangle is Tioughnioga River, which cuts across the northeast corner of the quadrangle and joins the Chenango, a tributary of Susquehanna River, in the Binghamton quadrangle, just to the east. The Tioughnioga heads far to the north and brings to the Susquehanna Valley waters which normally would be tributary to the St. Lawrence but have been diverted by glacial interference. Owego Creek, entering the Susquehanna at Owego, is formed by the convergence of two branches, which unite not far north of Owego. A few miles south of the junction it receives the waters of Catatonk Creek. Each of these three streams heads in a broader portion of the valley, and flows toward and through a narrow portion, which broadens slightly downstream. Evidently the narrower portion represents an old divide, and each of these streams, like the Tioughnioga, has received accessions of headwaters formerly tributary to the St. Lawrence. Other smaller streams, like Danby and Michigan creeks, have also received headwater additions; and the sum total of these additions, in this and neighboring quadrangles, has materially increased the volume of the Susquehanna.

The largest stream in the Watkins Glen quadrangle is Chemung River, which is navigable by canoes and small rowboats. Just below Waverly this river joins the Susquehanna. None of the tributaries of the Chemung are large enough to deserve the name river, and, with the exception of Cayuta Creek, they all head within a few miles of their junction with the main stream. The headwaters of Cayuta Creek lie within 5 miles of the northern edge of the Watkins Glen quadrangle, and the creek unites with the Chemung near Waverly, on the southern border, being thus the longest stream in the quadrangle. Yet, notwithstanding its length, Cayuta Creek is not an especially large stream, because all its tributaries are short and small. None of them exceed 6 miles in length and the majority are not more than 2 to 4 miles long. For much of its length, including the entire distance from Van Etten to Waverly, the divide is within 2 or 3 miles of Cayuta Creek. In the section from Van Etten to Alpine, the streams on the south side are short, but those on the north side are several times as long, and the tributaries on the south side head against much longer southward-flowing creeks that are directly tributary to the Chemung.

The St. Lawrence drainage is carried northward along two main lines, the Cayuga and Seneca valleys, whose outlet streams unite farther north. The southern divide of the Seneca Valley is farther south than that of the Cayuga, but the divide between the Cayuga and Seneca valleys is much nearer the latter.

Several of the streams tributary to these main valleys have had their volumes diminished by glacial diversion of their headwaters; for example, the stream in Havana Glen by diversion to Cayuta Creek; Sixmile Creek by diversion to both Willseyville Creek and the West Branch of Owego Creek; and Fall Creek by diversion into both Tioughnioga River and the East Branch of Owego Creek—all diversions from the St. Lawrence to the Susquehanna system. As has been stated, the tributaries to these two main troughs in this area descend the steepened lower slopes as a series of falls and cascades in gorges cut in the shale. The water power which these streams of steep grade provide is utilized in several places, as at Montour Falls and Ithaca; but the small and variable volume of the streams renders this source of power of limited value. The grades of all the larger streams are moderate, and they consequently possess little value as sources of water power.

LAKES AND SWAMPS.

The south ends of the larger two of the Finger Lakes, Cayuga and Seneca, lie within the Watkins Glen quadrangle. Seneca Lake extends farther south than Cayuga Lake, but does not reach so far north. It has a length of 35 or 36 miles; Cayuga Lake is 36 or 37 miles long. Both these lakes occupy long, winding valleys, though that of Cayuga Lake is much more winding than the Seneca Valley, and both are bounded by smooth valley slopes, steepened near the lower portion. Both the lakes broaden toward the north, where, in one section, they attain a width of 3¼ miles each; but within the area of this quadrangle the width nowhere exceeds 1½ miles. Both are very deep, Seneca Lake, the deeper, having a sounding of 618 feet, while the deepest known point in Cayuga Lake is 435 feet. The bottom of Seneca Lake is 175 feet and that of Cayuga Lake 54 feet below the level of the sea; but as the valley bottoms have been raised by drift deposits, these figures do not represent the actual depth of the rock floors of the valleys. Both lakes occupy river valleys that have been decidedly enlarged and deepened by ice erosion.

These lakes are of sufficient size to have an important influence on the local climate, making possible the extensive growth of grapes and other fruits along their shores. They are also the seats of many summer homes, which are rendered all the more attractive by the presence, near by, of many picturesque gorges and falls. The heat of the summer nights is tempered by the valley breeze which flows down the gorges from the hanging valleys above the steepened slopes. The effect of the hanging valleys in causing the convergence of air currents is the prime cause for the notoriously treacherous winds of the lakes. Squalls are frequent, and they often drop down upon the lake at some distance from the shore, making sailing at such times unsafe. The winds sweep down the high hanging tributary valleys and, reaching the ends of these valleys well above lake level, descend upon the water surface without warning of their approach.

The lakes serve also as important highways of navigation and in earlier days were used as pathways of exploration and settlement. They are both connected by canal with the Erie Canal system, and at one time Seneca Lake had canal connection with the Susquehanna, though this canal is now abandoned. Owing to their large size and great depth, these lakes are never completely frozen over except in the coldest of winters.

Next in size to these two lakes is Cayuta Lake, east of Watkins, a shallow lake less than half a mile wide and 2 miles long. This lake is formed behind morainic accumulations, deposited across the broadly open valley at the southwest end of the lake. Spencer Lake, just north of Spencer, on the eastern edge of the Watkins Glen quadrangle, is the only other lake in this area worthy of special mention. It lies in an outwash gravel plain, occupying a kettle probably formed by the melting out of a buried ice block. Just south of it is a morainic area rising above the outwash plain and serving as a partial dam. Scores of smaller ponds and swamps occupy kettles in the morainic belts, but most of them are too small even to have a place on the map. There are also a number of small ponds made by artificial dams for water power and for municipal water supply. Dryden Lake, southeast of Dryden, occupies a kettle in the moraine. It was at one time enlarged by a dam, but this has been destroyed, greatly reducing the size of the lake, whose shores are now surrounded by a swamp on the site of the old lake.

Most of the surface of this region is well drained, though there is slack drainage in small areas, forming small swamps and wet places. The largest swamps are on the deltas at the heads of Cayuga and Seneca lakes. There is also a swamp east of Slaterville Springs, on an outwash gravel plain behind a moraine built by an ice tongue in the Sixmile Creek valley.

INFLUENCE OF PHYSIOGRAPHY ON SETTLEMENT.

Throughout these quadrangles the relation of settlement, industries, and commerce to topography is striking. The rugged topography unfits much of the land for agriculture, and consequently there is a large percentage of forest-covered land, especially on the steeper slopes. In places lumbering is still an important industry.

The larger valleys are mainly cleared and occupied by prosperous farming communities, but the smaller valleys are in the main too steep walled and too narrow bottomed for the most successful agriculture and the bottom lands are in many places strewn with stony débris brought by the torrential tributary streams. The uplands are mainly cleared, but the poor soil, much of which is thin and stony, the remoteness from markets, and the hilly and usually bad roads have been unfavorable to the highest development of agriculture. Consequently farming on the uplands is on the decline, many houses are deserted, and even some farms and roads are abandoned. The population is steadily decreasing in practically all the hill towns Much of the upland might well be allowed to return to the forest condition; for the remainder dairying and sheep raising seem the natural industries.

On the uplands roads can be built almost anywhere, though locally they are bad and have steep grades; but in ascending from the larger valleys to the uplands there are many places where roads can not be made except at great expense. Some of the roads ascend from the valleys, by steep grades, diagonally up the hillside; but most of them follow the minor valleys.

Because of the ruggedness of the topography travel across country is difficult; but the well-graded through valleys have furnished a series of excellent highways, mainly along north-south lines, several of which are followed by railways. This is well illustrated by the main line of the Lehigh Valley Railroad, which passes up the graded Cayuta Valley and across the lips of two hanging valleys, one at Odessa, the other at Burdett, without serious grades, and, being above the edge of the steepened slope, without the necessity of numerous bridges across the gorges.

The ease of railroad building along the major valleys contrasts strikingly with the difficulty in crossing the uplands. It is possible to go with little grade from Elmira to Van Etten, via Waverly; but the more direct route of the Elmira and Cortland branch of the Lehigh Valley Railroad requires the ascent of a steep slope to reach the long Newtown Valley. To travel by rail from Ithaca to Watkins it is necessary to go by way of Van Etten and Horseheads. A shorter route via Van Etten and Odessa passes within 2 or 3 miles of Watkins well above the Seneca Lake level because of the fact that the railroad comes into that valley through a hanging tributary valley. The only important east-west highway is along the Susquehanna and Chemung valleys, which are followed by two trunk lines, the Erie and the Delaware, Lackawanna and Western, and, from Owego westward, by a branch of the Lehigh Valley Railroad. The Tioughnioga through valley is followed by a branch of the Delaware, Lackawanna and Western Railway; the East Branch of Owego Creek by a branch of the Lehigh Valley Railroad, which crosses the divide of the through valley near Harford by an easy grade; the Catatonk Creek through valley is occupied by the Elmira and Cortland branch of the Lehigh Valley Railroad which has practically no grade across the divide. The divide of the through valley of Willseyville Creek is also crossed by the Elmira and Cortland branch, with moderate grade, and by a branch of the Delaware, Lackawanna and Western Railway extending northward from Owego to Ithaca. The latter descends the steepened slope of the Cayuga Valley by means of a switch back and a very steep grade; but the former does not attempt to descend to Ithaca, keeping instead in the hanging valley of Cascadilla and Fall creeks, 470 feet above the Cayuga Valley.

As the travel is along the valleys, which are also the most fertile portions of the area, these are the most densely settled parts of the quadrangles, the seat of numerous villages and of several cities and large towns. Two of the larger places, Ithaca and Watkins, are at the head of lake navigation and both have felt the influence of trade by the Erie Canal. Waverly, near the junction of the Chemung and the Susquehanna and at the mouth of the Cayuta Creek valley, is closely related to Sayre and Athens, Pa., two much larger places with which Waverly shares some of the advantages of position on a broad outwash plain at the junction of important valleys. Elmira, the largest city in the two quadrangles, also on a fertile outwash plain, is at a natural junction of routes, toward which roads and railroads converge. Its situation on Chemung River and on a canal now abandoned was of early importance.

One of the best known cities in the quadrangles is Ithaca. It is situated at a convergence of highways, being at the junction of two large converging valleys (Fall and Sixmile) with the north-south Cayuga Valley; but the effect of this convergence on the growth of Ithaca is lessened by the hanging condition of the tributary valleys, which interfere with the entrance of traffic to the city. The hanging valleys have, however, given rise to a moderate water power, but not enough to cause great development. The value of Lake Cayuga as a highway, formerly of marked importance, has decreased with the decrease in importance of the Erie Canal; and Ithaca owes a large part of its present importance to the location of Cornell University there instead of to its position as a natural industrial center.

Most of the smaller towns and villages of the area owe their position and present importance to their situation at the convergence of highways—notably Owego and Spencer and smaller places like Lisle, Nichols, and Union. Most of these smaller places lie in the large valleys at or near the mouth of a tributary valley up which a main highway passes. In early days many of these highways were important as stage routes, and the villages were located at junctions of such routes. A few, like Brookton and Marathon, have water power, and at least one, Slaterville Springs, has some reputation as a health resort. Some of the villages are busy and growing, but most of them are sharing in the decline of the uplands. Everywhere in the area the influence of physiography on location and development is evident.

DESCRIPTIVE GEOLOGY.

The surface rocks of these quadrangles are of three classes, as follows: (*a*) The outcropping edges of the solid, stratified rocks may be seen in ravines, along the shores of lakes, and in artificial cuttings which have penetrated through the soil. These stratified rocks are argillaceous shales, thin-bedded sandstones and flags, and a few thin bands of impure limestone, belonging to the Devonian system. Over the whole area the strata are nearly horizontal, but have a general gentle slope to the south. (*b*) A few small dikes of igneous rock cut through the Devonian sedimentary rocks, but no metamorphic rocks have been discovered. (*c*) Unconsolidated deposits of sand, gravel, till, etc., of glacial and river origin and belonging to the Quaternary system, constitute the general soil of the region.

DEVONIAN SYSTEM.

By Henry S. Williams.

GENERAL RELATIONS.

The southern half of the State of New York, from its western boundary on Lake Erie to a point within a few miles of Hudson River on the east, is underlain by rocks of the Devonian system. On account of the gentle southward inclination of the strata the formations outcropping in the southern counties of the State are younger than those farther north. The formations exposed in the Watkins Glen and Catatonk quadrangles belong to the upper part of the Devonian, and the highest rocks exposed in the southern part of the Catatonk quadrangle are near the top of the system. Formations of the Carboniferous system appear in the adjoining counties of Bradford and Tioga, Pennsylvania, but nothing of that system is certainly identified within these quadrangles.

The sedimentary rocks of the Watkins Glen and Catatonk quadrangles are classified into formations, members, and lentils, the description of which is summarized in the columnar section forming figure 6.

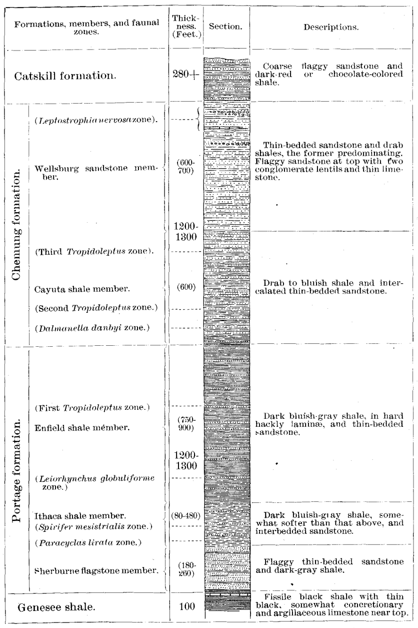

Figure 6.—Generalized columnar section for the Watkins Glen and Catatonk quadrangles.

LITHOLOGIC CHARACTERS OF THE STRATA.

The rocks of the Genesee shale are, when unweathered, massive brownish-black shales, weathering into thin fissile flakes. The surfaces of fracture are smooth and the texture is extremely uniform. The shale is very fine grained and predominantly siliceous rather than argillaceous. This shale is distinguished from the dark fissile shale which appears at numerous higher horizons by its greater uniformity of grain and texture, and by the general smoothness of the surfaces of the fissile flakes into which it weathers; in the unweathered massive rock this feature is expressed by its smooth, laminate stratification. The similar dark fissile shale that is found above the Genesee weathers into thicker flakes with rougher surfaces and of lighter color (a grayish black) than the typical Genesee shale. The Portage formation is also of softer texture than the Genesee, owing to its greater percentage of argillaceous matter, and on weathering rapidly turns into a clay soil.

There are several distinctly calcareous horizons near the top of the Genesee shale, expressed by several series of concretions in which the calcareous matter is moderate in amount, or, where richer in lime, by calcareous beds varying from a few inches to a foot or more in thickness. These calcareous beds are argillaceous limestone in the outcrop at Firtree Point and appear to represent the limestone at Lodi of the section farther north. In the section at Esty Glen, on Cayuga Lake, there are several zones of concretions situated between two slightly calcareous sandstone beds capping the Genesee. Here the excess of siliceous matter makes sandstone instead of limestone, the calcareous element being relatively small.

Above the Genesee the strata exposed in these quadrangles consist of a succession of thin-bedded, fissile shales and thin flagstones with some beds of sandstone 8 or 10 to 20 inches thick. In the lower or Portage formation the tough flags, formed of thin-bedded, hard, arenaceous layers, separated by fissile argillaceous bands, predominate. In the succeeding Chemung formation the lower 600 feet (the Cayuta shale member) is predominantly argillaceous, though including many sandstone beds 8 to 10 inches thick, rarely thicker. In the upper portion (the Wellsburg sandstone member) the sandstone beds are more numerous and conspicuous. In weathering, the rocks of the Portage break up into uneven, irregular, splintery pieces, and many of the flags are wave marked and have uneven surfaces. The Chemung rocks display a tendency to break vertically across the strata and when reduced to fragments make rectangular blocks with square edges. There is also a difference in the general color of the two formations. The rocks of the Portage are in general of a dark blue-gray color; the Chemung rocks, when weathered, are lighter and brownish. These characteristics are general, yet in each formation there appear some beds more typical of the rocks of the other formation.

The above description applies in general to the rocks of both quadrangles, but the lithologic characteristics distinguishing the Chemung rocks from the Portage appear at a lower horizon in the Catatonk than in the Watkins Glen quadrangle, and in neither is the transition a sharp one. On account of this earlier appearance (in relation to faunal succession) of the Chemung lithologic characters, there is shown on the map a transitional zone between the Portage and Chemung formations in the Catatonk quadrangle. The horizon of first appearance of the typical Chemung fauna is shown by a colored line, and the transitional lithologic zone is drawn as beginning with the first strata of typical Chemung character. These strata appear nearly on meridian 76° 15′ west longitude and come in lower and earlier eastward to longitude 76°, where they are 600 feet below the typical Chemung faunal line. The rocks of the Ithaca shale member of the Portage present a strong resemblance to those of the Chemung, and this fact, in addition to the resemblance of their fossils, may have led to the classification of the Ithaca as part of the "Chemung group" in the early surveys of the State.

At several horizons in the Portage, ranging in position from bottom to top of the formation, there is a uniform, thin-bedded, dark-colored fissile shale, ranging in thickness generally from 10 to 20 feet, but locally reaching 100 feet. Illustrations of these beds are seen at the base of the Ithaca (the "Ithaca *Lingula* shale"); a few hundred feet above the Ithaca, as at a point west of Newfield; and near the base of the Chemung, as at Van Etten, at the base of the first *Tropidoleptus* zone. It was thought, on first noting these horizons of fissile shale, that they might be of value as definite markers. But the attempt to trace them from place to place proved unsatisfactory from the fact that the thin bands of sandstone separating the fissile shales were found to change rapidly in thickness. In the passage of a few miles many heavy-bedded sandstones and flags may appear in the midst of the fissile shales, by thickening and running together of the thin beds, entirely changing the complexion of an exposed section. The fact that the fossils occurring in the fissile shale, are very similar, at whatever horizon they were found, also detracted from the value of the shale for marking horizons. It was concluded, therefore, to indicate on the map only those shale masses which contained some independent fossil evidence of their particular horizon.

DIVISION LINES BETWEEN FORMATIONS.

As will be seen in the columnar section (fig. 6) four divisions of formation rank are represented in these quadrangles—the Genesee, Portage, Chemung, and Catskill. Heretofore these formations have been defined by their lithologic character and contents, and the limiting horizons have been left indistinct. Though their names have appeared in literature and on geologic maps for over fifty years, the chief difficulty experienced in mapping them arises from uncertainty as to the nature of the marks by which two contiguous formations can be separated. From the Genesee upward the general character of the rocks is monotonous, and above the Genesee, in the Sherburne flagstone member of the Portage, bands of black fissile shale appear, closely resembling the Genesee rocks. Very rarely does any single stratum, or series of like strata, preserve such constancy laterally as to furnish the sole basis for tracing a geologic horizon entirely across a quarter of a quadrangle. Although slight differences mark the successive horizons of the column, the lithologic changes are too gradual to serve for defining masses of less than about a hundred feet in thickness. The gradual lithologic changes do not proceed uniformly in any one direction for the whole area of a quadrangle. Where lithologic changes are thus indefinite, fossils, and particularly the composition of the successive fossil faunas, have been used and found reliable in determining continuous horizons to a remarkable degree of accuracy. The conspicuous lithologic characteristics of the Genesee shale have furnished the chief criteria for drawing the line between the Genesee and the Portage. For the line between the Portage and the Chemung the faunal and the lithologic changes agree in the Watkins Glen quadrangle, but diverge in the Catatonk quadrangle; accordingly both lines have been shown on the map, as already described. The Ithaca shale member of the Portage, though marked in some sections by diagnostic initial or terminal beds, is discriminated and its limits defined by the range of the Ithaca fauna. The Sherburne flagstone member is recognized as belonging to the Portage formation by its fossils, and stratigraphically its limits are determined by the Genesee shale below and the Ithaca shale member above. The Enfield shale member is also recognized as part of the Portage formation by its fossils, but stratigraphically it consists of the beds lying between the Ithaca shale member and the Chemung formation.

In the eastern part of the Watkins Glen quadrangle the first *Tropidoleptus* faunal zone appears near the top of the Portage. This paleontologic zone is typically represented at railroad level and for 200 feet above it at Van Etten. It is composed of thin-bedded, blocky argillaceous shale with some sandstone bands in the higher parts, not materially differing from the Chemung rocks above, and contains a fauna whose genera are similar to the Hamilton and Ithaca faunas but which lacks typical Chemung species. Some traces of the Portage fauna are also to be seen in this zone. The fauna marking this zone appears east of the Watkins Glen quadrangle and is strongly developed in the Catatonk quadrangle. It is well represented by its characteristic species at the east side of the Catatonk quadrangle, but not so distinctly on the west side. On account of the absence of distinctive Chemung fossils this fossiliferous zone has been included at the west in the Enfield shale member of the Portage formation.

The Chemung formation in the Watkins Glen and Catatonk quadrangles is divided into two members, the Cayuta shale and the Wellsburg sandstone, the distinction being based on the presence and observed range of five well-marked facies of the general Chemung fauna. The base of the Cayuta shale member is indicated by the fossils of the *Dalmanella danbyi* zone; its termination by the fossils of the third *Tropidoleptus* zone. The space between is occupied at the west by the typical Chemung fauna. For 500 or 600 feet above the third *Tropidoleptus* zone the Wellsburg facies of the Chemung fauna is seen. Near the top of the Wellsburg sandstone member is the *Leptostrophia nervosa* zone. For local classification these paleontologic zones are convenient means of subdividing the Chemung, where lithologic characters fail to be sufficiently diagnostic. The sandstone at Watkins Glen near the base of the Sherburne member, the sandstone on Cascadilla Creek near the middle of the Ithaca member, and the conglomerate at the top of the *Leptostrophia nervosa* zone in the Chemung formation are each local lentils discriminated primarily by their lithologic characters.

Variation in thickness.—On crossing the quadrangles from west to east considerable difference is observed in the thickness of the several formations and members. The total thickness between the top of the Hamilton and the base of the Catskill decreases, and the black shale and dark-colored thin-bedded sandstones characteristic of the Genesee and Portage formations range through a much less thickness on the east side than on the west side of the quadrangles. It is also observed that the light-colored ferruginous shales and sandstones which rather sharply mark the passage from Portage into Chemung in the western part of the Watkins Glen quadrangle are, in the eastern part of the Catatonk quadrangle, the prevailing type for 600 feet below the typical Chemung fauna. The Chemung formation is reduced in thickness, however, on the east side by being cut off at the top at an earlier stage by the Catskill sedimentation.

These facts are represented in the accompanying diagram (fig. 7). The chart is drawn to show the relation of the fossiliferous zones to the formational lines as drawn on the map. The relations shown for the Chenango Valley are based on the already reported Chenango Valley section. The chart is drawn as if a horizontal line across the middle of the diagram represented a horizontal plane at the time of deposition. The line representing the top of the Tully limestone declines toward the right, to express the eastward thickening of the sediments above. The line marking the boundary between the Cayuta and Wellsburg members rises toward the right, and the boundary is represented as cut off in the Chenango Valley by the Catskill sediments, the diagram thus expressing the thickening of the Cayuta shale member of the Chemung formation but the decrease in the thickness of the whole formation, resulting from the replacement of the Wellsburg sandstone member by the Catskill sediments to the east.

In the Chenango Valley the sediments from the top of the Oneonta sandstone to the base of the Catskill correspond lithologically to the Cayuta and Wellsburg members of the Chemung, and the sediments below the Oneonta sandstone represent lithologically the Portage sediments of the Watkins Glen area.

The successive paleontologic horizons are indicated by the thirteen columns on the right of the list of names, marked at the top by the initial letter of the horizon, as follows:

A. Chemung formation.—Wellsburg sandstone member, *Leptostrophia nervosa* zone.
W. " " Wellsburg sandstone member, *Spirifer disjunctus* uncommon.
S. " " Cayuta shale member, third *Tropidoleptus* zone.
O. " " Cayuta shale member, second *Tropidoleptus* zone.

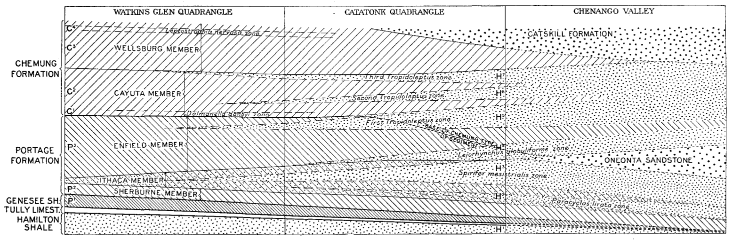

Figure 7.—Faunal chart, showing the eastward invasion of the Portage and Chemung faunas and the westward invasion of the recurrent Hamilton fauna in the Watkins Glen and Catatonk quadrangles.

FAUNAL ZONES.

Changes in character of sedimentation are proved by tracing the faunal zones across the region. These faunal zones are seen to consist of two sets alternating in their occupation of the region. Their distribution is shown diagrammatically in figure 7. The first set, coming from the west and occupying the typical Portage and Chemung formations, is marked P^1, P^2, P^3, C^1, C^2, C^3, and C^4; the second set, coming into the region from the east and thinning out westward, represents successive mutations of the Hamilton fauna and is marked H^1, H^2, H^3, H^4, H^5, H^6, and H^7. The first set is expressed by abundance of fossils in definitely successive zones in the Watkins Glen quadrangle, is less abundantly expressed in the Catatonk quadrangle, and is for the most part absent from the extreme Chenango sections, though represented locally by a few species. The second set of faunas is well defined in the Chenango Valley, occupies distinct zones in the Catatonk quadrangle, and is almost completely lacking in the sections on the west side of the Watkins Glen quadrangle.

The first set consists of the faunas of the following zones:

P^1. *Orbiculoidea lodiensis* zone; Genesee shale.
P^2. First *Reticularia lævis* zone; Sherburne flagstone member.
P^3. *Buchiola-Manticoceras* zone; general in Portage formation.
C^1. *Dalmanella danbyi* zone; base of the Cayuta shale member.
C^2. *Spirifer disjunctus* zone; Cayuta shale member as a whole.
C^3. An upper Chemung zone; containing many of the typical Chemung species but lacking *Spirifer disjunctus* and marked by the infrequency or total absence of any species of the genus *Dalmanella*; Wellsburg sandstone member.
C^4. *Leptostrophia nervosa* zone; near the top of the Wellsburg sandstone member.

The second set contains the following faunal zones:

H^1. *Spirifer pennatus* zone; Hamilton formation.
H^2 *Paracyclas lirata* zone; entering the lower part of the Ithaca shale member from the east, and not apparent in the Watkins Glen quadrangle.
H^3. *Spirifer mesistrialis* zone; Ithaca shale member; this fauna prevails throughout the Ithaca in the eastern sections, but is restricted to not more than 25 feet in the center of the Ithaca shale member of the Ithaca section.

The Ithaca fauna as a whole may be called the *Spirifer pennatus posterus* fauna, which on passing eastward is separable into three distinctive paleontologic zones: H^2, *Paracyclas lirata* zone; H^3, *Spirifer mesistrialis* zone; H^4, *Leiorhynchus globuliforme* zone.

H^4. *Leiorhynchus globuliforme* zone; above the Oneonta sandstone in the Chenango Valley, typically expressed in the Kattel Hill section and thinning out westward; not recognized in the Watkins Glen quadrangle.
H^5. First *Tropidoleptus* zone; upper part of the Enfield shale member in the Catatonk quadrangle, invading the eastern part of the Watkins Glen quadrangle, and thickening eastward.

The *Spirifer disjunctus* and *Dalmanella danbyi* zones are above H^5, wherever seen together in the same section.

H^6. Second *Tropidoleptus* zone; a second stage of the recurrent Hamilton fauna invading the lower part of the typical Cayuta fauna in the Catatonk quadrangle and the eastern part of the Watkins Glen quadrangle, but not traced into the Chenango Valley.
H^7. Third *Tropidoleptus* zone; entering the region at the top of the Cayuta shale member, not recognized specifically in the general succession of Chenango Valley, but theoretically considered as representing with H^6 the undivided general Hamilton fauna of the Upper Devonian of eastern New York.

PALEONTOLOGIC TABLE.

The accompanying table comprises a list of 102 species of fossils found in the rocks of the Watkins Glen and Catatonk quadrangles and shows the stratigraphic horizons at which they are conspicuous. The list is not exhaustive, and described species only are inserted in it. It is prepared by selecting from the total number of fossils collected those species which are sufficiently abundant and general in distribution in this particular region to serve the geologist as a means of discriminating in the field the horizons described and mapped in this folio.

C. Chemung formation.—Cayuta shale member, *Spirifer disjunctus* zone.
D. " " Cayuta shale member, *Dalmanella danbyi* zone.
V. Portage formation.—Enfield shale member, first *Tropidoleptus* zone.
K. " " Enfield shale member, *Leiorhynchus globuliforme* zone.
E. " " Enfield shale member, *Buchiola-Manticoceras* zone.
I. " " Ithaca shale member, *Spirifer mesistrialis* zone.
P. " " Ithaca shale member, *Paracyclas lirata* zone.
S. " " Sherburne flagstone member, first *Reticularia lævis* zone.
G. Genesee shale.—*Orbiculoidea lodiensis* zone.

Opposite each specific name are inserted the initial letters for the zones in which the species has been discovered. The mark + is inserted when either the horizon or the identification of the species is in doubt. The mark ? is used to indicate probability without certain evidence.

As is explained elsewhere in the text the mapping of this region is based in places on evidence of change in fossil contents rather than change in lithologic composition, though any conspicuous lithologic change has been made use of wherever practicable.

The zones holding the faunules G, E, D, C, and W thicken toward the west and contain two sets of species; the first set (G, E) constitutes the general *Manticoceras* fauna characteristic of the Portage formation; the second set (D, C, W) contains the general fauna of the Chemung formation. The zones holding the faunules P, I, K, V, O, and S thicken toward the east; their several faunules are homeotopic, and they are strongly dominated by species common in the Hamilton of central New York or closely related to such species. They may thus be regarded as successive mutating facies of the general fauna of the Hamilton appearing above the stratigraphic Hamilton formation. The Chemung fauna is known to be closely related to the general Upper Devonian fauna of northern Europe, also well developed in northern British America and in Iowa, Arizona, and Idaho. The Hamilton *Tropidoleptus* fauna, on the other hand, is conspicuously dominant in the Devonian of the southern hemisphere. It seems reasonable to infer, therefore, that the alternating fossiliferous zones here observed represent successive stages of invasion and occupation of the region by faunal groups whose centers of distribution were at widely diverse points on the globe, the Chemung fauna reaching this region from the west and north and the Hamilton coming from the south and east.

The sharpest faunal contrast is observed between the *Manticoceras* fauna and either of the others (see zones G, S, and E); but the change requiring the closest scrutiny is that from the successive mutants of the Hamilton fauna to the typical Chemung fauna—the boundary between V and D.

In discriminating horizons, disappearance of species formerly common is as important a fact as appearance of species not occurring before; hence zone E becomes important in the Watkins Glen quadrangle in separating zones I and D. To the east zone V and then zone K enter the upper part of E, reducing the thickness of the relatively barren zone E, and the special fauna of D withdraws, throwing the actual beginning of the Chemung fauna up to the base of C.

It is believed that the table will enable the geologist to locate the horizons discussed in the folio with a greater degree of precision than would be possible on any basis of lithologic definitions alone.

Paleontologic table of the Watkins Glen and Catatonk quadrangles.

[Hamilton species are shown by an *. Horizon or specific identification in doubt, +.]

	Genesee.	Portage.						Chemung.					
	G	S	P	I	E	K	V	D	C	O	S	W	A
Lingula spatulata*	G	S			E	K	V		C				
Lingula complanata			P	I		K	V			O	+		
Orbiculoidea lodiensis	G												
Craniella hamiltoniæ *	G			I		K	V		C	O	S		
Stropheodonta demissa				I		K							
Leptostrophia interstrialis (Van.)		+	P	I		K		D	C				
L. nervosa (Hall)									C			W	A
Douvillina mucronata (Con.)									C			W	A
Schuchertella chemungensis *			+	+			V	D	C			W	A
Chonetes lepidus	G	S	+	I									
C. scitulus*			P	I		K	V		C			W	
Productella truncata Hall*	G	S	+	I									
P. speciosa				I		K	V						
P. spinulicosta						K	V	D					
P. lachrymosa et vars						?	V		C		S	W	
P. hirsuta						+	V		C	O	S		
P. costatula									C		S	W	A
Dalmanella danbyi								D					
D. tioga, elmira, et carinata									C	O	S	W	
Rhipidomella vanuxemi et vars *			+			K	V			O	S		
Schizophoria striatula			?	I		K	+		C	O	S	W	
Camarotœchia eximia			P	I		K	V						
C. stepheni			P	I		K							
C. sappho*							V	D	C	O	S		
C. contracta									C	O	S	W	
Pugnax altus (Calvin)				I		K		D					
Leiorhynchus quadricostatum	G												
L. multicosta*							V			O			
L. mesicostale		+	P	I					C				
L. globuliforme						K							
L. sinuatum							V	+	C		S	W	
Cryptonella eudora				I		K			C			W	
Tropidoleptus carinatus*			P				V			O	S		
Atrypa reticularis*			P	I		K	V	D			S		
A. spinosa									C	O	S	W	
A. hystrix									C			W	
Cyrtina hamiltonensis*		S	P	I		K							
Spirifer tullius*													
S. mesistrialis et mut			P	I					C		S	W	
S granulosus*			+										
S. marcyi*							V			O	S		
S. pennatus*													
S. pennatus posterus													
S. disjunctus				I		K		D	C				
Delthyris consobrinus*													
D. mesicostalis et mut						K	V		C	O	S	W	A
Reticularia fimbriata*			P				V						
R. lævis		S		I		K	V	D					
Ambocœlia umbonata et mut.*		+			E	K	V		C	O	S	W	A
Grammysia arcuata*													
G. subarcuata		S	P	I		K	V		C			W	
G. bisulcata*						+							
G. elliptica				I		K							
Buchiola speciosa et vars.*	G	S		+	E		V						
Paracardium doris	G	S		I	E		V	+	+				
Pinnopsis acutirostra		S			E								
Nucula corbuliformis*			P	+		K							
Palæoneilo constricta et mut*		S	P	+									
P. plana*		S	+			K	V						
P. brevis				I	E	K	V	D	C				
P. filosa		S	P	I		+		+					
P. emarginata*			P										
P. bisulcata									C			W	
Leptodesma rogersi et vars.*			P	I		K	V						
L. spinigera et vars						K	V		C		S	W	A
L. extenuatum											S	W	
Pterinea consimilis						?		D	C			W	
P. chemungensis								D	C			W	
P. (Vertumnia) reproba				I									
P. (V.) reversa									C			W	
Actinopteria boydi*			P	I									
A. epsilon, perstrialis, etc			P	I		K							
Lyriopecten tricostatum						K			C				
Pterochænia fragile et var	G	S		+	E		V	?	?				
Mytilarca chemungensis				I		+			C		S	W	
Modiomorpha subalata et vars.*		+	P	I		K	V			O	S		
Goniophora carinata*			P			K							
G. chemungensis									C				
Paracyclas lirata*			P										
Schizodus chemungensis				I					C			W	
Cypricardella bellistriata*			P	+		+	V			O	S		
C. gregaria*				I					C			W	
Spathella typica				I					C			W	
Pleurotomaria capillaria et mut.*		S	P	I	E	K	V	D	C				
Porcellia nais		S							C				
Bellerophon natator	G			I									
B. incisum	G			I			V						
B. ithacensis				I									
B. triliratus juvenis								D					
B. triliratus									C			W	
B. mœra						?			C				
Euomphalus hecale								?	C	O	S		
Palæotrochus præcursor		+		+	E		V	D					
Loxonema delphicola et mut.*			P			K	V						
L. styliola							V		C	O	S		
L. terebra									C		S		
Bactrites (Coleolus) aciculum	G	S		I	E		V						
Manticoceras pattersoni	G	S		I	E			D	?				
Probeloceras lutheri		S		I	E				?				
Sandbergoceras chemungensis									C				
Phacops rana*			P	+			V			O			
Plumalina plumaria		S		I									

DESCRIPTION OF FORMATIONS.

GENESEE SHALE.

Character and thickness.—The Genesee shale outcrops in the extreme northeast corner of the Watkins Glen quadrangle at Esty Glen and on the opposite side of Cayuga Lake at Glenwood; it also appears on the west shore of Seneca Lake at Firtree Point and for a short distance northward; it shows no outcrops in the Catatonk quadrangle. At neither of the outcrops above mentioned is the base exposed. A typical exposure of the formation is shown in figure 14, illustration sheet I. From measurements made a few miles north of the Watkins Glen quadrangle in the valley of Cayuga Lake at Taghanic Ravine, the formation is estimated to be 135 feet thick. The terminal beds are well exhibited at Firtree Point, where the following section is seen:

Section of Genesee shale at Firtree Point.

				Ft.	in.
Nodular limestone					0–8
Fissile black shale				13	
Impure shaly limestone.	Dove-colored shaly limestone	2	5	7	4
	Calcareous shale	1			
	Dove-colored shaly limestone	1	5		
	Calcareous shale		2		
	Dove-colored shaly limestone	1	2		
	Calcareous shale		6		
	Nodular limestone		8		
Fissile black shale to water level				10	
				30	12

The top of the formation is placed above the upper nodular limestone in the Firtree Point section for the following reasons: The upper 13 feet of black shale present lithologic characters of the typical Genesee shale below; they carry in abundance a characteristic Genesee fossil, *Leiorhynchus quadricostatum;* and, finally, the original description of this black shale where it outcrops along Seneca Lake distinctly specified as a part of the formation a "regular course of septaria in the upper part of the black shale," becoming "a continuous stratum 3 or 4 feet in thickness."[a] This limestone lentil, both by its position and by its fossils, is correlated with the limestone at Lodi, on the east shore of the lake, described by J. M. Clarke.[b] The limestone at Lodi differs faunally from the Genundewa or *Styliola* limestone described by Clarke and Luther[c] as terminating the Genesee shale in the Firtree Point section.

The section at Esty Glen on Cayuga Lake presents the following details:

Section of Genesee shale at Esty Glen.

	Ft.	in.
Calcareous sandstone		8
Dark fissile shale with three layers of calcareous concretions	5	6
Calcareous sandstone	1+	
Black shale	1	
Massive calcareous sandstone	2	2
Black fissile shale to lake level	58	
	68	4

In this eastern outcrop of the Genesee shale the calcareous matter is scanty, and the weathered edges of the beds appear more like tough sandstone than limestone, but examination shows them to be distinctly calcareous when unleached. The top of the Genesee is here drawn at the top of the 8-inch calcareous sandstone, 68 feet above the lake.

This definition is a revision of the boundary line between the Genesee and Portage formations as originally drawn by Williams in 1884 for this section. In the absence of any trace of Genesee fossils above the typical black shale, the massive calcareous sandstone capping it was then considered the base of the Portage.[d] Close comparison of the two sections now leads to the conclusion that these calcareous beds in Esty Glen are to be correlated with the limestone at Lodi and with the limestone and interbedded shale of the Firtree Point section. The calcareous bands contain transitional faunas, as was noted by Clarke in the footnote above cited; but the abundance of *Leiorhynchus* in the overlying black shale leaves no doubt as to the continuance of the Genesee sediments and fauna above these bands in the Firtree Point section. So far as examination shows the calcareous bands do not recur at any higher horizon and therefore they may be regarded as features of the Genesee. In both sections similar dark, fissile shales occur within a hundred feet above the top of the Genesee, but nowhere do the higher shales show characteristic brown-black color and uniform, even-bedded structure of the typical black shale of the Genesee. Wherever fossils appear in these higher beds, the difference is made apparent by the absence of the characteristic Genesee species and by the appearance of other forms diagnostic of the Portage.

The calcareous beds at the top of the Genesee contain the genus *Cladochonus*, which is also a common form in some of the zones of lower Portage—thus expressing the initiation of the Portage fauna before the entire cessation of the Genesee sedimentation or of its characteristic fauna. The exposures of the Genesee are so few in the Watkins Glen quadrangle as to be useless for purposes of mapping the geologic horizons, except at the extreme northern border of the quadrangle.

Fauna.—The Genesee shale is notable for the meagerness of its fauna. Only a few fragile-shelled brachiopods and pteropods are commonly seen. The beds near the middle of the formation as a rule contain no fossils. Near the upper and lower limits of the Genesee shale fossil-bearing zones appear in places. The species commonly found in these zones, and generally regarded as diagnostic of the Genesee, are *Lingula spatulata* Vanuxem, *Orbiculoidea lodiensis* Vanuxem, *Chonetes lepidus* Hall, *Leiorhynchus quadricostatum* Vanuxem, *Styliola fissurella* Hall, and *Tentaculites gracillistriatus* Hall.

The pteropods and lingulas are likely to occur both above and below the Genesee shale wherever sediments like the Genesee appear. Thin beds of fissile black shale of local extent, appearing at various horizons above the Genesee, contain many *Lingula spatulata*. The species *Orbiculoidea lodiensis* and *Leiorhynchus quadricostatum* are more limited in range; they have not been observed higher than the transition beds at the top of the Genesee. The fauna is named the *Orbiculoidea lodiensis* fauna from the fossil which appears to be a characteristic species.

Distribution.—The Genesee shale in these quadrangles is limited to the shores of Cayuga and Seneca lakes. It is below lake level on the south limb of the Ludlowville anticline 2 miles north of the head of Cayuga Lake and does not reappear above drainage level south of that exposure. In the Seneca Lake basin the Firtree Point anticline brings the uppermost beds of the Genesee shale above the surface of the lake for a short distance, south of Glenora and Peach Orchard. The lower limit of the Genesee is sharply marked by the Tully limestone throughout the Finger Lake region.

GENESEE-PORTAGE BOUNDARY.

At the top of the Genesee shale is a well-defined lithologic transition zone in which the lower rocks consist of black shale characterized by a definite assemblage of fossils of the Genesee. In the Seneca Lake outcrop the upper part of the Genesee is marked by calcareous beds, a short distance above which *Leiorhynchus quadricostatum* and other Genesee fossils continue to appear in black shale similar to that below. In the Cayuga Lake outcrops there are some concretionary nodules, less marked and of smaller size near the top. The calcareous layers at the top are more like sandstone than limestone, and have been so called. Above the Genesee the rocks are not made up of the typical black shale but appear as rough, uneven thin-bedded strata, and the fossils (wherever discovered) belong to the Portage fauna. The boundary is therefore drawn at the top of the calcareous beds, wherever they are evident, including the finely laminated black shales with the *Leiorhynchus quadricostatum* fauna if discovered above the calcareous beds. In the Cayuga Lake basin the line is drawn at the top of the upper calcareous band, about 10 inches thick, above which shale of a typical Portage character appears without the *Orbiculoidea lodiensis* fauna.

PORTAGE FORMATION.

GENERAL STATEMENT.

Definition.—Following the Genesee, and conformable with it, are the beds of the Portage formation. In this are included those beds which have generally been referred to by the term Portage, or Portage group. The term Portage group was originally defined by Hall[a] and applied to the sandstones lying above the Gardeau flagstones of Genesee Valley and distinct from the Gardeau, Ithaca, and Cashaqua groups which were named in the same report. Two years later Vanuxem[b] applied the term Portage or Nunda group to the rocks between the Ithaca group and the Genesee black shale of the third district, supposing them to be the equivalent of Hall's Portage, Gardeau, and Cashaqua groups of the fourth district.

In the year following Vanuxem's report Hall[c] adopted Vanuxem's usage, erroneously supposing the Ithaca to be the equivalent of the lower part of the Chemung, and some later authors, finding in this final report the definition of species under the name Portage or Nunda, have adopted the name Portage group in this wrong sense. It is important to correct this error in the use of the name Portage. The "Portage sandstone" of Hall has not been traced as far east as the Watkins Glen quadrangle. There the Portage consists of three members, the Sherburne flagstone, Ithaca shale, and Enfield shale. The name Nunda has recently been applied to this widespread formation occupying the place between the Genesee and Chemung formations of this and other States, in accordance with the early usage by Vanuxem.

In this folio the rocks between the Genesee and Chemung are called the Portage formation, in accordance with the usage adopted by most later writers.

Lithologic characters.—The Portage formation as a whole may be characterized as a series of thin beds of alternating sandy shale and sandstone. (See figs. 15–19, illustration sheet I.) The layers have usually a thickness of 2 to 10 inches. At not a few places either the shale or the sandstone constituent is largely absent and the formation comprises a continuous bed of shale, usually very dark in color, or a series of thin-bedded gray sandstones. One thin limestone zone has been recognized. The bedding is very regular and the planes of contact between adjacent strata are usually parallel. Only one occurrence of cross-bedded strata in the Portage formation has been observed in these quadrangles. This appears in a quarry 2 miles southwest of Ithaca. Wave marks and fragments of driftwood are common on the sandstones. The Portage formation has a maximum thickness of about 1300 feet in the Watkins Glen quadrangle.

COMPOSITION.

This formation (in the Watkins Glen quadrangle) is composed of (1) a lower member, corresponding to the Sherburne flags of the early surveys, approximately 188 feet thick on the west side and 260 feet on the east side of the quadrangle; (2) the Ithaca shale member, 80 feet thick on the west side in the Seneca Lake basin and 460 feet at Ithaca, and (3) the upper or Enfield shale member, 800 feet thick on the west side of the quadrangle. The space occupied by the Enfield member alone on the west side of the quadrangle is represented near the meridian of Ithaca first by 550 to 600 feet of characteristic Enfield shale containing a few fossils (but those discovered are of the common *Buchiola-Manticoceras* fauna), above which for 150 to 200 feet the rocks become more strongly argillaceous and contain a brachiopod fauna called the first *Tropidoleptus* fauna, which includes several Hamilton species.

Eastward across the Catatonk quadrangle the lower or Sherburne flagstone member continues of about the same thickness and is represented by thin-bedded flags and intercalated shales. The Enfield member loses its *Buchiola-Manticoceras* fauna and in the lower part, above the normal Ithaca fauna, is marked by the *Leiorhynchus globuliforme* fauna of Kattel Hill for 200 feet or more. After an interval of about 200 feet of completely barren sandstones the first *Tropidoleptus* zone characterizes the upper 300–400 feet immediately underlying the base of the Chemung.

Thus the Portage at the extreme western border of the Watkins Glen quadrangle is represented by about 1200 feet of flagstone and dark shale, containing scarcely any fossils except those of the *Buchiola-Manticoceras* fauna. At the extreme eastern border of the Catatonk quadrangle it is dominated throughout by rich brachiopod faunas of four well-marked stages called the *Paracyclas lirata*, the *Spirifer mesistrialis*, the *Leiorhynchus globuliforme*, and the first *Tropidoleptus* faunas, from their dominant species.

The fossiliferous Ithaca member increases in thickness toward the east. Near Watkins the total thickness of the zone in which the Ithaca fossils have been detected is about 80 feet; and in several examined sections only a few fossils, or a fossiliferous stratum a few inches thick, were discovered. In the sections at Ithaca fossils are abundant for a thickness of 300 feet.

The lower limit of the Portage formation is drawn at the top of the typical Genesee shale and its *Orbiculoidea* fauna. The Portage–Chemung line in the western half of the Watkins Glen quadrangle is recognized where the first traces of the Chemung *Spirifer disjunctus* fauna appear. This is indicated here and there in the western half and at many places in the eastern half of the quadrangle by the *Dalmanella danbyi* fauna. Across the Catatonk quadrangle and the eastern half of the Watkins Glen quadrangle the first *Tropidoleptus* fauna is seen in the rocks below the *Dalmanella* zone, containing some species which are common above but lacking the typical species of the *Spirifer disjunctus* fauna.

On account of the similarity of the beds below the actual faunal zone to the typical Chemung rocks above, a transition zone between Portage and Chemung is shown on the map of the Catatonk quadrangle. The position of the base of this transition zone is indicated on figure 7 as starting in the middle of the Catatonk quadrangle, at the base of the *Dalmanella danbyi* zone, and running diagonally downward to the top of the *Leiorhynchus globuliforme* zone at the east border of the Catatonk quadrangle. Still farther east this line reaches the top of the Oneonta sandstone. The base of the typical Chemung fauna, however, lies above the first *Tropidoleptus* zone.

The Portage formation, which in the typical region of the Genesee Valley is composed of the Cashaqua, Gardeau, and "Portage" members, consists in the Watkins Glen quadrangle of the Sherburne, Ithaca, and Enfield members. In the Chenango Valley the Ithaca member is overlain by the Oneonta sandstone.

DISTRIBUTION.

The formation comprises the surface rocks over most of the northern third of the Watkins Glen and Catatonk quadrangles except where the higher hills and ridges reach up into the overlying Chemung. In the southwest quarter of the Watkins Glen quadrangle it extends much farther south than elsewhere. Reaching down the broad Catherine Creek valley, it passes below drainage level about 2 miles north of Horseheads. At Elmira, over a small area on the east side of the valley, it is brought to the surface again by the Elmira anticline.

In the Ithaca Valley, on the east side of the quadrangle, the main mass of the upper Portage reaches southward nearly to the southern boundary of Tompkins County and down the Cayuta Creek valley to a point about 3 miles south of Cayuta. The Van Etten anticline brings it again above drainage level for a few miles east, west, and south of Van Etten.

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[a] Fourth Ann. Rept. New York Geol. Survey, 1840, pp. 422-423.

[b] Lincoln, D. L., Geology of Seneca County: Forty-eighth Ann. Rept. New York State Museum, 1895, p. 101, footnote.

[c] Clarke, J. M., and Luther, D. D., Geology of the Watkins and Elmira quadrangles: Bull. New York State Mus. No. 81, 1905, p. 5.

[d] Bull. U. S. Geol. Survey No. 3, 1884, p. 10.

[a] Fourth Ann. Rept. Geol. Survey New York, 1840, p. 391.

[b] Final Rept. Third District, 1842, p. 171.

[c] Final Rept. Fourth District, 1843, p. 224.

FAUNA.

The fauna affords the most reliable means of distinguishing the Portage formation from the Chemung. The species most commonly appearing in the outcrops of the Portage formation of the Watkins Glen quadrangle are given in the following list:

Diagnostic species of the Buchiola-Manticoceras fauna of the Portage formation.

Lingula complanatum.
Reticularia lævis.
Buchiola speciosa.
Paracardium doris.
Lunulacardium (Pterochænia) fragile.
Pinnopsis ornata.
P. acutirostra.
Porcellia nais.
Bellerophon natator.
Styliola fissurella.
Hyolithes aclis.
Orthoceras pecator.
Manticoceras pattersoni.
Rhodea pinnatum.
Psilophyton princeps.
P. robustum.
Plumalina plumaria.

The dominant species of the fauna are its lamellibranchs, and these belong almost entirely to a single family—the Præcardiidæ of Neumayr. The shells are thin in structure and exhibit a very slight amount either of structural elaboration of the hinge margin into teeth, or of markings on the interior to indicate muscular or pallial attachment. Thin-shelled goniatites (*Manticoceras*, etc.) are also abundant, as well as small pteropods and a few genera of gasteropods. This Portage fauna is distributed throughout the formation, though appearing only in scattered beds. The species are generally few in any particular faunule, and in general they are only sparsely distributed anywhere in the formation. In two prominently fossiliferous zones (the Ithaca member and the first *Tropidoleptus* zone) the more abundant appearance of other faunas gives to the fossil contents a different complexion, and it is the dominant representation of these other faunas which has furnished the basis of discrimination for the several members into which the Portage is divided.

In general the Portage or *Buchiola-Manticoceras* fauna prevails wherever the tough, thin-bedded flagstones constitute the bulk of the beds, although the fossils themselves are more frequently found in the argillaceous partings between the flags. In the Ithaca *Spirifer pennatus posterus* zone and the first *Tropidoleptus* zone the soft argillaceous beds, with only local sandstone bands, are the characteristic type of strata. In those zones the sandstone beds are softer and more argillaceous than the typical flags. Wherever the beds, for 20 or 30 feet vertically, are chiefly composed of thin fissile shale, lingulas are apt to appear. Until the region was thoroughly explored these lingula zones were believed to be definite horizons; fuller study showed them to be recurrent zones and suggested the conclusion that the lingulas are characteristic of the kind of sedimentation rather than of stratigraphic horizon. They are likely to be discovered anywhere in the Portage in this particular type of shale, irrespective of local position in the series. The same species of *Lingula* occur in the shale at the base of the Ithaca member, at the base of the first *Tropidoleptus* zone, and at other places in similar local beds of shale, above, between, and below these particular zones.

In the Catatonk quadrangle the typical or western Portage is supplanted by the eastern Portage or Ithaca fauna. This fauna continues in a modified form up to the Chemung fauna in the Tioughnioga Valley.

SHERBURNE FLAGSTONE MEMBER.

The lowest member of the Portage formation is the Sherburne flagstone member. It is composed of a mass of flagstones and shales varying from 180 to 260 feet in thickness. The name is applied on account of the similar position and lithologic resemblance of these rocks to the thin-bedded, flaggy sandstones so conspicuous in Chenango County, to which the name Sherburne flagstone was applied by Vanuxem. Their flaggy character is well exhibited a few miles north of the Watkins Glen quadrangle in the quarries of Trumansburg and neighborhood and above Taghanic Falls, the capstone of which is one of the heavy sandstone beds at the base of the Sherburne member. In the sections about Ithaca, in addition to the general Portage fauna, the *Reticularia lævis* subfauna is conspicuous at several horizons in the Sherburne member. It is typically exhibited at the foot of the falls on the south side of the Fall Creek gorge, and below the falls opposite the Hull mill. The conspicuous species of this subfauna are *Reticularia lævis*, *Palæoneilo filosa*, and *Cyrtina hamiltonensis*. In addition to these *Chonetes*, *Leiorhynchus*, *Leptostrophia*, *Orthoceras*, *Manticoceras*, and other species of the Portage fauna may occur in the limited *Reticularia lævis* zone. The general Portage or *Buchiola-Manticoceras* fauna prevails throughout the Sherburne member, as it does above the Ithaca in the Enfield member.

In the outcrops of the Sherburne member at the head of Seneca Lake a heavy-bedded sandstone lentil appears at about 60 or 70 feet above the top of the Genesee. This sandstone bed is 4 or 5 feet thick. It generally consists of one massive layer of purplish-brown sandstone about 20 inches thick, of fine-grained, uniform texture, and a few thinner sandstone beds separated by shaly layers. The sandstone outcrops on the west shore, a little north of Salt Point, near the level of the lake; passing southward it rises to an elevation of 30 feet just north of the village of Watkins; on the east side of the valley it appears at a level about 10 feet lower; and it occurs again in several outcrops on both sides of the southward extension of the lake valley.

SHERBURNE-ITHACA BOUNDARY.

The *Reticularia lævis* beds, outcropping at the foot of Fall Creek, Ithaca, may be taken as the upper boundary of the Sherburne member for the Ithaca section. The fauna of these beds was described and figured in the final report on the geology of the State of New York and was there referred to the "Portage or Nunda group" by Hall. The fossil now described under the name *Plumalina plumaria* Hall was noted by both Vanuxem and Hall as coming from Ithaca; and in Vanuxem's report its appearance in the rocks from the tunnel of Fall Creek (which were referred to the "Ithaca group") furnishes precedent for including the "Ithaca *Lingula* shale" of Williams in the Ithaca member.

The famous "*Lycopodites vanuxemi* beds" are in this "Ithaca *Lingula* shale" on the west side of the valley of Ithaca, above the engine house of the Lehigh Valley Railroad. The name *Lycopodites vanuxemi* was applied to the species by Dawson in 1862.[a] The base of the Ithaca member is therefore now drawn below these shale beds in which *Lingula complanatum* Williams and *Lycopodites vanuxemi* Dawson (*Plumalina plumaria* Hall) are abundant, and above the *Reticularia lævis* beds, at the foot of Fall Creek, which were originally referred to the "Portage or Nunda group" by Hall In the Fall Creek section a sandstone about 21 inches thick forms the top of the *Reticularia lævis* zone and may therefore be taken as the uppermost stratum of the Sherburne of this region. At Fall Creek it is approximately 400 feet above sea level.

Although a few Ithaca fossils appear immediately above the fissile shales (Ithaca *Lingula complanatum* zone), it is not until a horizon nearly a hundred feet higher is reached that the characteristic Ithaca fauna is at all conspicuous in these rocks. The Ithaca fauna proper is restricted in range at Ithaca to not over 300 feet of strata, and in the sections about Watkins, so far as observed, to not over 80 feet of strata.

ITHACA SHALE MEMBER.

Limits.—In the typical Ithaca region, at the head of Cayuga Lake, the Ithaca shale member is mapped as beginning lithologically at the base of the *Lingula complanatum* zone (already described as the "Ithaca *Lingula* shale") and paleontologically at the top of the zone of *Reticularia lævis.* Its upper boundary is the zone of the transition from the Ithaca brachiopod fauna back to the sparser pelecypod fauna of the upper Portage, or Enfield member. In this upper zone, which appears in the Fall Creek section in the rocks near the bridge at Forest Home, *Schizophoria striatula* is abundant and the second appearance of *Reticularia lævis* is noted.

Lingula complanatum zone.—In the sections at Fall Creek and other places near Ithaca a well-defined blackish shale (originally referred to under the name "Ithaca *Lingula* shale") forms a conspicuous fossiliferous zone at the base of the Ithaca member. The upper part of this zone is seen at the mouth of Cascadilla Creek, at a level with the upper windows of the Cascadilla Mills. This shale crosses the Fall Creek section immediately below the brink of the Ithaca Falls and is just above water level in Sixmile Creek under the Cayuga Street Bridge, in the south part of the town. This *Lingula complanatum* zone is a finely stratified fissile shale, of dark, not black color, breaking up by weathering into thin flaky fragments, which become reddish brown on exposure to air. It is crossed here and there by lens-shaped sandstones which have been described as "channel fillings." These "channel fillings" are narrow bands of hard siliceous sandstone, lying in the midst of finely laminated shales. In cross section many of them are limited to less than 10 feet in width, thickening in that distance from a knife-edge to a massive sandstone a foot thick at the center and again thinning out on the opposite side. These sandstone beds run along the line of their axes for hundreds of feet without appreciable change of character. The direction of their axes is generally northeast and southwest. The fissile shales lie above them in a series of strata fairly continuous and parallel with those below. A few feet away from them, laterally, the section comprises a continuous uninterrupted mass of thin-bedded fissile shale.

The termination of this *Lingula* zone is marked by bands of sandstone of the ordinary character, from 6 to 8 or 10 inches in thickness, separated by shaly beds. The shaly layers predominate for several hundred feet, but they are interrupted by some thin-bedded sandstone layers. For the first hundred feet above the *Lingula* zone the fossils are rare; above that they are more numerous and many layers filled with fossils occur, constituting the typical Ithaca fauna.

In the Watkins Valley the first distinct traces of the Ithaca fauna appear from 125 to 150 feet above the thick sandstone bed which is seen at the foot of the cliffs at the entrance to Watkins Glen. No particular sandstone bed, nor any change in the general character of the sediments, nor any sudden change in the fossil contents can be traced continuously along the outcrops of this valley as a Sherburne-Ithaca boundary. To the east of Ithaca the faunas change so that the limits of the Ithaca member at the Tioughnioga Valley are not distinguishable by the same signs as at Ithaca.

Eastern phase.—The upper limit of the Ithaca member in the Tioughnioga Valley is drawn at the top of a rather heavy sandstone bed which locally terminates the *Spirifer mesistrialis* fauna and is conspicuous at Marathon. The modified Ithaca of that region is called the eastern phase of the Ithaca member. From fossil evidence it is believed that this terminal sandstone at Marathon is to be correlated with the sandstone at Cascadilla Creek. In the Chenango Valley the Oneonta sandstone is believed to be the eastern extension of this same type of sediment, and there the Oneonta overlies the Ithaca.

Fauna.—Some of the characteristic species of the *Spirifer pennatus posterus* fauna of the typical Ithaca member are given in the following list:

Arthrocantha ithacensis.
Leptostrophia interstrialis Vanuxem.
Productella speciosa.
P. hallana.
Schizophoria striatula.
Camarotœchia eximia.
Cryptonella eudora.
Spirifer mesistrialis.
Leiorhynchus mesicostale.
Pugnax pugnus var. altus Calvin.
Spirifer pennatus posterus.
Palæoneilo filosa.
Actinopteria boydii.
A. perstrialis.
A. epsilon.
Orthoceras bebryx.

For practical purposes of identifying the horizon in the field the most important species are *Leptostrophia interstrialis*, *Productella speciosa*, *Leiorhynchus mesicostale*, *Spirifer pennatus posterus*, and *Palæoneilo filosa*. The occurrence of all five of these species together in a single stratum is good evidence of the presence of the Ithaca fauna, wherever the limits of the Ithaca member are placed. In the Ithaca sections the thickness of this fossiliferous zone is approximately 300 feet. The total thickness of the Ithaca member from the top of the *Reticularia* zone of the Sherburne member to the terminal *Reticularia* zone of the Ithaca is approximately 460 feet.

The eastern phase of the Ithaca member in the northeast quarter of the Catatonk quadrangle is defined by the presence of the *Paracyclus lirata* and *Spirifer mesistrialis* faunas, which become more dominant than in the typical region of the member.

In the Watkins region, at the head of Seneca Lake, the Ithaca *Spirifer pennatus posterus* fauna is greatly restricted both in species and in vertical range of appearance in the section. Close scrutiny has, however, located several calcareous bands in which typical Ithaca species occur in the lower portion of the Portage formation. The greatest thickness through which traces of the fauna have been observed to range in any one section of this valley is about 80 feet.

The chief quarry zone in the sections about Ithaca is the zone of sandstone of the McCormick quarry noted in the old state reports. It is also referred to by Williams[a] as the university quarry. As a lentil in the Ithaca member it is distinguished by a massive sandstone layer in the university quarry a few feet above Stewart avenue, in the old quarries along Quarry street, and in the old McCormick quarries. It crosses Cascadilla Creek about halfway up. It crosses Fall Creek back of the present university electric power plant; the same beds cross Williams Ravine at the southwest corner of the lake between 600 and 650 feet above sea level. In the last-named outcrop these beds include two massive layers separated by a foot or so of shale, which are very fossiliferous. These beds have a calcareous and arenaceous composition. This sandstone when fresh from the quarries is of a dark-purplish hue. In several of the quarries massive layers, over a foot in thickness, have been quarried. In other places the mass breaks up into thinner layers. In addition to the more common Ithaca species the sandstone contains great numbers of *Spirifer mesistrialis* and *Cryptonella eudora* and at many places has *Gomphoceras tumidum*. Some of the shells are pyritized. In the Ithaca section the three species named above rarely occur below or above a zone 25 feet thick, including this sandstone lentil. The sandstone is near the middle, about 260 feet above the base, of the Ithaca shale member of the Portage formation.

ITHACA-ENFIELD BOUNDARY.

The boundary between the Ithaca and Enfield members is drawn across the Watkins Glen quadrangle at the point where the Ithaca fauna ceases to appear in the upward succession. This horizon is more or less distinctly expressed by the passage from soft argillaceous beds into tough, thin-bedded flags. Many of the flagstones are conspicuously wave marked, and for scores and locally for several hundred feet above the boundary fossils are extremely rare. This transition from the Ithaca into the upper Portage (Enfield member) is seen below the Delaware and Lackawanna Railroad switch on South Hill. Few fossils are to be discovered in the 50 feet immediately below the level of the switch (760 feet above the sea); in the shale at that level *Buchiola* and associated species of the Portage fauna are seen here and there. The last distinct trace of the Ithaca fauna occurs locally in a very fossiliferous calcare-

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[a] Quart. Jour. Geol. Soc., vol. 18, 1862, p. 314.

[a] Williams, H. S., On the fossil faunas of the Upper Devonian: Bull. U. S. Geol. Survey No. 3, 1884, p. 17.

ous sandstone bed which, from the abundance of the fossil shells, assumes the character of an impure limestone; such a zone is seen in Coy Glen, on the west side of the Inlet Valley, at an elevation of about 815 feet. In several sections on the east side as well as on the west side of the valley *Reticularia lævis* has been found among the last fossils of the Ithaca fauna. A small variety of the species also appears in the Enfield member in the northeastern portion of the Catatonk quadrangle, and again in the *Dalmanella* zone at the base of the Chemung in the vicinity of Ithaca.

On the east side of the Catatonk quadrangle the boundary between the eastern phase of the Ithaca member and the Enfield member is marked by a massive sandstone which is quarried at Marathon and along the Tioughnioga Valley, and this terminates the local *Spirifer mesistrialis* fauna.

ENFIELD SHALE MEMBER.

General description.—The Enfield shale member of the Portage formation is a fissile, shaly, and flaggy mass with few fossils in the northwest quarter of the Watkins Glen quadrangle. It occupies the interval between the Ithaca member and the base of the Chemung formation and is observed to contain only species of the general *Buchiola-Manticoceras* fauna. In the northeast quarter of the quadrangle its upper 100 feet or more contains the first *Tropidoleptus* fauna. The flaggy rocks predominate in the Watkins region, and the argillaceous shales are more conspicuous near Ithaca. The fossils are those of the normal Portage fauna and are extremely rare and associated with fewer outside species in the western than in the eastern section. The lithologic characters of the Enfield member, in general, throughout the Watkins Glen quadrangle are a repetition of those of the Sherburne flagstone below the Ithaca. Thin-bedded fissile shale may dominate for a hundred feet or more, or tough, wave-marked flags may prevail for similar thicknesses; but the general character is an alternation of these two kinds of rock in irregular order. Paleontologically, however, this typical Enfield member of the Portage can be distinguished by the general absence of brachiopods, such as *Spirifer*, *Stropheodonta*, *Orthis*, and the rhynchonellids. Small Productellas are occasionally seen. *Lingula* and a few specimens of *Ambocœlia*, *Palæoneilo*, *Buchiola*, *Lunulicardium*, and *Leptodesma* may be found, but all these forms are of rare occurrence throughout the typical Enfield member of the Portage, and generally are not abundant where discovered. Nevertheless, near the eastern boundary of the Watkins Glen quadrangle an Ithaca species appears here and there in the upper part of the Enfield member. In several of the more typical sections of the northwest quarter of the Catatonk quadrangle, a few miles east of the Watkins Glen boundary, the upper 200 or 300 feet are dominated by a fauna composed mainly of such species as have already appeared in the Hamilton and Ithaca zones, associated with a few other species or varieties indicating a later stage of evolution than the Ithaca.

First Tropidoleptus zone.—Traces of the fauna just mentioned are seen in the rocks exposed along the railroad cuts at Van Etten, an occurrence which has led to their distinction from the normal Enfield as a special fossiliferous zone. In the sections on the east side of the Watkins Glen quadrangle and in the adjoining western part of the Catatonk quadrangle the uppermost 150 to 200 feet of the Enfield member is composed of thin-bedded, fissile argillaceous shale with some sandstone beds from 6 to 18 inches thick. Though representing no sharp lithologic contrast with the beds below, the sandstone beds are less abundant in the shale. They contain a characteristic fauna which is of special importance as an expression of the return into the region of representatives of the Hamilton fauna. This fauna becomes more important toward the east. In the Catatonk quadrangle the fauna is conspicuous and appears stratigraphically lower down in the Enfield member than it does in the Watkins Glen quadrangle. In the cliffs about Van Etten, extending from the railroad level up for nearly 200 feet, the zone occurs with its typical aspect. Throughout the zone *Lingula complanatum* and *Productella spinulicosta* are abundant, also the first representative (since the Hamilton) of a true *Delthyris mesicostalis*. Near the base and distributed upward for a distance of 50 feet or more occurs *Tropidoleptus carinatus*, also *Rhipidomella vanuxemi*, *Spirifer marcyi*, and *Cypricardella bellistriata*; the genus *Leptodesma* occurs locally in abundance and is represented by several species, and there are a considerable number of rarer associated species. In several sections where the strata can be continuously examined this particular fauna is observed to lie distinctly 100 to 150 feet below the *Dalmanella danbyi* zone which ushers in the Chemung formation.

The estimate of the thickness of the first *Tropidoleptus* zone is based on the relations of this *Tropidoleptus* fauna to the *Dalmanella* zone seen near White Church, and confirmed by other sections to the west and east of that point in the Catatonk quadrangle. In the White Church region the *Dalmanella* fauna begins to appear in force at about 150 or 200 feet stratigraphically above the first *Tropidoleptus* zone. The total thickness of strata from the top of the Ithaca member to the zone of first incursion of the *Dalmanella* fauna (which is there taken as the base of the Chemung formation) varies from 750 to 900 feet.

PORTAGE-CHEMUNG BOUNDARY.

The general transition from the Portage to the Chemung formation is marked, lithologically, by the passage from thin-bedded, rather barren, generally tough and flaggy lead-gray shales of the Portage, to thicker-bedded shales, generally soft and argillaceous, drab colored, weathering into brown, blocky fragments and a clay soil. With these shales (the lower 500 feet at least) are intercalated beds of sandstone, varying from 2 to 10 inches in thickness, which on weathering break down into small brown blocks with vertical rather than splintery fractures.

At the west the paleontologic transition from the Portage to the Chemung is sharply defined in typical sections, and the boundary is drawn at the horizon of lowest appearance of the characteristic species of the *Spirifer disjunctus* fauna. In defining this boundary in 1884 Williams[a] considered the transition from the sparse Portage *Buchiola-Manticoceras* fauna composed chiefly of pelecypods and cephalopods to a returning brachiopod fauna as evidence of the incoming of the Chemung formation. The species observed at that stage of transition were *Schizophoria striatula*, *Ambocœlia umbonata*, *Atrypa reticularis*, *Delthyris mesicostalis*, and Productellas of later types than those of the Ithaca member. A fuller knowledge of this *Schizophoria striatula* fauna has, however, shown it to be not the typical Chemung, but a facies of the fauna of the Ithaca member mingled with some more pronounced representatives of the still older Hamilton *Tropidoleptus* fauna. The species *Delthyris mesicostalis* first enters the region at this stage of progress. That species is seen to be a very slightly modified representative of the typical Hamilton *Spirifer ziczac*, which has lately been identified with the European species *Delthyris consobrina*.

On account of fuller knowledge of the composition of this fauna and the discovery of its intimate relationship with the Hamilton fauna, this faunal zone (the first *Tropidoleptus* zone) is now recognized as not belonging to the Chemung formation.

A typical exhibition of the succession from this *Tropidoleptus* zone to the *Dalmanella danbyi* zone of the Chemung is seen in the White Church section, on the west side of the Catatonk quadrangle. The discovery of this sequence explains the stratigraphy at the base of the Chemung, which heretofore has been obscure. This first appearance above the Genesee shale of a *Dalmanella* fauna furnishes a reliable paleontologic guide for distinguishing the base of the Chemung formation in the northwestern part of the quadrangle. The first *Tropidoleptus* fauna is strictly intermediate between the Ithaca and Chemung faunas. In the Ithaca zone, *Spirifer pennatus posterus* and *S. mesistrialis* occur without *Delthyris;* in the first *Tropidoleptus* zone *Delthyris mesicostalis* appears without *Spirifer pennatus posterus* and *Spirifer mesicostalis* of the Ithaca member and without *Spirifer disjunctus* of the Chemung, but it contains *Tropidoleptus carinatus* and *Spirifer marcyi* and other species well known in the Hamilton shale. In the *Dalmanella* zone, at the base of the Chemung, *Spirifer disjunctus* appears for the first time accompanied by *Reticularia lævis* and *Dalmanella danbyi*, both small in size. It was difficult to define sharply the Portage-Chemung boundary on any paleontologic basis until this order of sequence in the faunas was definitely established. Heretofore the presence of *Delthyris* Microspirifer with this first return of the brachiopod species in abundance in the upper part of the Portage was generally regarded as indicative of the incoming of the Chemung fauna. This was the basis of Williams's interpretation in 1884; and later Prosser and Clarke drew the Portage-Chemung boundary below this zone in Chenango County. A close scrutiny of its composition, however, demonstrates that the fauna of the first *Tropidoleptus* zone represents a phase in the evolution of the Hamilton fauna distinctly later than the one at the base of the Ithaca, and stratigraphically earlier than the incursion of the typical Chemung fauna into the basin. A still later stage of that same general fauna appears in force in the third *Tropidoleptus* zone at the top of the typical *Spirifer disjunctus* fauna of the Cayuta member. The third *Tropidoleptus* fauna almost completely displaces for a few feet the whole Chemung fauna and is there represented by an abundance of characteristic species. In the sections about Van Etten the fissile shales continue upward to an altitude of more than 1100 feet, where they are interrupted by coarser beds and sandstone. At an altitude of about 1120 feet a heavy-bedded sandstone 10 inches thick occurs, above which the sandstone beds are more numerous and the shales coarser than below. In these Van Etten sections the *Dalmanella danbyi* fauna has not been detected in place below an altitude of about 1300 feet, above which the typical Chemung *Spirifer disjunctus* fauna occurs wherever fossils have been discovered up to the top of the Cayuta member. The first traces of the *Dalmanella* fauna are seen in the sections west of West Danby at an altitude of 1250 feet, but without any marked lithologic change in the strata.

The genera which, in the Watkins Glen quadrangle, first appeared above this zone are *Dalmanella*, *Douvillina*, and *Spirifer*, of the *S. disjunctus* type; also several other genera and species characteristic of the typical Chemung fauna. The lowest phase of the general Chemung fauna is one in which the species *Dalmanella danbyi*, *Productella spinulicosta*, and *Schuchertella chemungensis* are common; here and there *Spirifer disjunctus* appears with them in a single zone in the midst of the 100 feet of strata through which *Dalmanella danbyi* ranges. Drawing the lower boundary of the Chemung formation below this *Dalmanella danbyi* zone gives to the Chemung fauna a definite faunal composition that is maintained in the formation at the west and separates it from the Hamilton-Ithaca combination which toward the east crowds it out and replaces it. A similar displacement of the Chemung fauna by the Catskill from above finally shuts out paleontologic evidences of both Portage and Chemung formations from the section. This has brought a still later phase of the Hamilton fauna up into contact with the sediments of the Catskill type above, as may be seen in the southeast portion of the Catatonk quadrangle.

In mapping the formations of the Catatonk quadrangle it becomes important to recognize the horizon of the Oneonta sandstone, which is conspicuous in the Chenango Valley and farther east, though it has no clear expression in the rocks of the Catatonk quadrangle.

Faunally the rocks immediately underlying the Oneonta sandstone are correlated with the Ithaca member. The rocks above it in the Chenango Valley region contain faunas which in the Catatonk quadrangle follow the typical Ithaca fauna and underlie the typical Chemung fauna. These faunas, however, differ greatly from those of the Enfield member in the Watkins Glen quadrangle, which represent the general fauna of the Portage formation. They are homeotopic with the Ithaca and Chemung faunas and in general aspect intermediate between them.

CHEMUNG FORMATION.

DEFINITION.

Without here discussing the literature of the Chemung formation, it may be stated simply that the numerous excellent exposures in the southern part of the Watkins Glen quadrangle, around the sides of Narrow Hill, at Chemung Narrows west of Chemung, and along the banks of Chemung River offer the typical and standard exhibition of the Chemung formation. This is the locality referred to in the original definition of the Chemung: "Between Elmira and Chemung they [the rocks of this formation] are seen at numerous points, but nowhere in the county so well as at the Chemung Upper Narrows about 11 miles below Elmira."[a] The fauna found in these rocks at the Chemung Upper Narrows is therefore regarded as the typical Chemung fauna; and the downward and upward extension of that fauna is taken as evidence of the limits of the formation.

LITHOLOGIC CHARACTERS.

In attempting to define the boundaries of the formation stratigraphically, although it is possible to describe the lithologic characters of the formation as a whole, it is not possible to draw a uniform boundary line, either below or above, where particular lithologic characters cease and other characters take their place.

The Chemung formation is composed almost entirely of sandy shales and thin-bedded sandstones of drab or very light gray color. Somewhat rarely heavy-bedded sandstones appear in the sections. (See fig. 20, illustration sheet I.) Near the top there are at many places fine pebble conglomerates. These appear to be of no more than local significance where they are found, but are probably expressive of an approach to shore conditions. Layers of concretions, locally developed, characterize the strata at various horizons. These concretions are composed largely of fine-grained, very hard sandstone.

A notable difference is recognized in the character of the transition from the Portage to the Chemung formation between the east and west sides of the Watkins Glen quadrangle. On the Watkins side the transition is abrupt and the comparatively barren flagstone and shale of the Enfield member of the Portage there change into blocky argillaceous shale and sandstone with characteristic Chemung fossils. The line of transition can be readily drawn. On the east side of the Watkins Glen quadrangle there are several hundred feet of similar strata below the base of the Chemung in which traces of a fauna having affinity with the Ithaca fauna appear mingled or alternating with Portage fossils. This fauna, where best shown, is seen to contain recurrent Hamilton species. It is in the first *Tropidoleptus* zone. Not only is this zone not recognized in the southwest quarter of the Watkins Glen quadrangle (a Hamilton recurrent faunule does appear higher up in the section), but the first Chemung faunule recognized there shows evidence of a later stage of evolution of the

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[a] Williams, H. S., Bull. U. S. Geol. Survey No. 3, 1884, pp. 20-21.

[a] Third Ann. Rept. New York Geol. Survey, 1839, p. 323.

Chemung fauna than is expressed by the first Chemung faunule of the east half of the Watkins Glen quadrangle. It is thus estimated that the line drawn between the Portage and Chemung represents actually a somewhat more recent point of time on the west than on the east side.

The Chemung formation comprises the surface rocks of nearly all the southern half of the quadrangle. In the northern half it caps the higher hills and ridges extending, on the high divide between Lakes Cayuga and Seneca, to the northern margin of the quadrangle.

SUBDIVISIONS OF THE CHEMUNG FORMATION.

In the Watkins Glen quadrangle there are two well-defined members of the Chemung formation, named the Cayuta shale member and the Wellsburg sandstone member. The basal 100 feet of the Cayuta shale member is characterized by the fossils of the *Dalmanella danbyi* zone, and the top by those of the third *Tropidoleptus* zone. The Wellsburg sandstone member includes about 600 feet of strata lying above the third *Tropidoleptus* zone. In the upper part of the member is the *Leptostrophia nervosa* zone, with a thin conglomerate lentil near its top. The three above-mentioned fossiliferous zones contain specialized portions of the general Chemung fauna.

The limits of the several zones may be sharply defined in any section where they appear, and the succession of the three is always the same; but the thickness of rock strata dominated by each is not strictly uniform over the whole of the Watkins Glen and Catatonk quadrangles. The *Dalmanella danbyi* zone is from 100 to 150 feet thick; the third *Tropidoleptus* zone is rarely over 5 feet in thickness and may be less; the *Leptostrophia nervosa* zone is recognized in more than one calcareous bed near the top of the Wellsburg member within about 50 feet of the upper conglomerate, and loose slabs indicate that the same fauna may be associated with the pebbly conglomerate.

CAYUTA SHALE MEMBER.

Limits.—The Cayuta shale member includes the *Dalmanella danbyi* zone at the bottom and the third *Tropidoleptus* zone at the top. The fossiliferous zone between contains the typical Chemung *Spirifer disjunctus* fauna. The species which are diagnostic of this fauna are listed under "Paleontologic characters;" the species more conspicuous and more commonly encountered are not all restricted in range to the Chemung formation. Common species in this main part of the Cayuta member are *Spirifer disjunctus, Schizophoria striatula, Delthyris mesicostalis, Ambocœlia umbonata, Productella boydi, P. hirsuta, P. lachrymosa, Schuchertella chemungensis, Dalmanella tioga, D. elmira, Douvillina mucronata, Spirifer mesistrialis, Atrypa spinosa, Pterinea consimilis, P. chemungensis, Mytilarca carinata, Lyriopecten tricostatus, Palæoneilo brevis,* and *P. bisulcata.*

Dalmanella danbyi zone.—The lowermost 100 feet of the Chemung formation contains a peculiar fauna, the species of which are generally small in size; several of them do not appear higher up in the section where the typical Chemung species are abundant. This fossiliferous zone is typically represented in the West Danby section on the east side of the Watkins Glen quadrangle. The most significant species in its fauna is *Dalmanella danbyi,* which occurs at many places in great abundance and ranges through about 100 feet of strata. With this species are found, not uncommonly, *Leptostrophia interstrialis, Productella spinulicosta, Spirifer disjunctus, Reticularia lævis, Palæoneilo brevis,* and *Pterinea chemungensis. Dalmanella tioga* and *Douvillina mucronata,* though both of common occurrence in the following strata of the Cayuta member, do not appear in this zone; nor has *Delthyris mesicostalis* been seen associated with *Dalmanella danbyi,* though it is common both below in the first *Tropidoleptus* zone of the Portage formation and higher in rocks of both the Cayuta and Wellsburg members of the Chemung.

Third Tropidoleptus zone.—At the top of the Cayuta shale member in many places is a fossiliferous zone a few inches or feet in thickness, in which the species are almost entirely different from those in the rocks below and above. Among the more common of these peculiar species is *Tropidoleptus carinata,* with which are locally associated *Rhipidomella vanuxemi, Cypricardella bellistriata, Spirifer marcyi,* and *Schizophoria striatula,* with scattered representatives of the genera *Pleurotomaria, Loxonema, Delthyris, Leptodesma, Chonetes,* and *Camarotœchia.*

The third *Tropidoleptus* zone is important as separating the more fossiliferous portion of the Chemung (the Cayuta shale member) from the Wellsburg sandstone member, in which some though not all of the common Chemung species locally appear but are sparsely scattered through the rocks. It is desirable to give this zone a distinct designation in order to separate it from the first *Tropidoleptus* zone, which contains several of the same species but lies 700 feet lower.

In the lower part of the Cayuta member of the Chemung there is another zone containing *Tropidoleptus carinatus* and, here and there, *Spirifer marcyi,* but as a fossiliferous zone this is not very sharply separated from the general Chemung fauna. It is called the second *Tropidoleptus* zone.

WELLSBURG SANDSTONE MEMBER.

Above the third *Tropidoleptus* zone few fossils are seen for 500 or 600 feet, but those that do appear indicate the Chemung formation. The strata occupying this interval are called the Wellsburg sandstone member. *Spirifer disjunctus* is very uncommon; but *Douvillina mucronata, Schuchertella chemungensis, Spirifer mesistrialis, Delthyris mesicostalis,* and, toward the top, *Leptostrophia nervosa* are occasionally seen. Productellas and Dalmanellas are rare or absent. The rocks of the Wellsburg member are more arenaceous than those below, and the thin slablike sandstones, characteristic of the overlying Catskill, are present in places. The tops of the hills running up into these rocks are very stony where not covered with drift, with great numbers of thin, tough sandstone slabs an inch or so in thickness scattered over the surface.

Locally the higher beds of the Wellsburg sandstone are distinctly flaggy. Loose fragments of hard gray flagstone appear on the higher slopes of some of the hills. The flags do not appear to be confined to a single horizon, but are developed at many levels through 200 feet or more of the upper part of the Chemung. In the southwestern part of the Watkins Glen quadrangle heavy beds of greenish-gray flags appear in the hills between Hendy and Seely creeks at an elevation of about 1700 feet. The high ridge northwest of Bigflats, including Martin Hill and Quackenbush Hill, shows a gray flagstone horizon which appears persistently throughout that ridge at an elevation of 1700 to 1800 feet. The Chemung fauna continues above these gray flags, but no red flags appear. The flaggy beds are of rather finer material than the Catskill flagstones of contiguous quadrangles.

Large concretions in the sandstone characterize the lower beds of the Wellsburg at some localities A layer of sandstone concretions may be seen in the section at Chemung Narrows. The quarry at Rosstown, southwest of Elmira, exposes a bed of concretions which shows some unique features. (See fig. 21, illustration sheet I.) At the end of the quarry there is a fine-grained, massive sandstone, entirely free from concretions. This sandstone bed changes toward the middle of the quarry into a mass of arenaceous concretions of various sizes. These vary from less than a foot in diameter to masses 5 or 6 feet across, the larger sizes predominating. Their shape is extremely variable and includes a great variety of irregular forms, a common type among the larger masses being roughly quadrilateral in cross section. They agree in most of their general features with the characters of arenaceous concretions which have been observed in many other concretionary bands in the Chemung, save in one particular. The unusual feature is the remarkable position which a band of fossils assumes with reference to the concretions. Fossils are not generally distributed through the concretionary bed and appear to be absent except in a thin seam, 4 to 6 inches thick, belonging near the bottom of the concretionary zone. This band is composed almost entirely of common Chemung fossils; but instead of retaining the horizontal position characterizing the underlying strata it has assumed a sinuous course, corresponding to the base and sides of the larger concretionary masses. Where this band is present it separates the lower sides of the concretions sharply from the inferior beds, bearing much the same relationship to them that the outer shell of a nut bears to the inner. Not only does this fossil band follow the irregular basal outline of the concretions, but at many places it bends abruptly upward and, taking a vertical direction, follows the side of a concretionary mass. In at least one concretion the fossil band, after having followed the base and side, has been reflexed at the top, following for a few inches the horizontal upper outline of the mass. The abnormal position of the zone of fossils, filling the rôle of an outer shell to a concretionary mass, does not seem to be adequately explained by the commonly accepted theory of chemical segregation.

In the upper part of the Wellsburg member local beds of impure calcareous sandstone at different horizons appear at several points. They are composed largely of fossil shells and many of them extend only a short distance. In the southwest corner of the Watkins Glen quadrangle, between Hendy and Seely creeks, such a bed of calcareous sandstone, more persistent than usual, appears a little below the 1600-foot contour. This bed has a thickness generally of 1 to 2 feet and may be found on most of the hills in that region.

Leptostrophia nervosa zone.—On Ashland Hill, 4 miles south of Elmira, the upper 50 feet of the Wellsburg sandstone member is marked by several very fossiliferous calcareous layers containing an abundance of *Leptostrophia nervosa* Hall. These are also found in several other places.

CONGLOMERATE LAYERS.

The *Leptostrophia* zone is terminated by a layer of coarse sandstone and quartz pebbles. Loose slabs of this rock lie on the high hills in the southern half of the Watkins Glen quadrangle, but it was seen in place in the Ashland Hill sections at an altitude of about 1670 feet. The conglomerate is supposed to represent the Fall Creek conglomerate outcropping in Bradford County, Pa. It is composed of coarse sandstone and quartz pebbles, usually not larger than beans but locally much as 1½ inches in diameter. Chemung fossils and scanty traces of a fish fauna are associated with it. On many of the hills east of Elmira no trace of conglomerate appears. On most of the hills between Shoemaker Mountain and Lockwood, however, loose fragments of conglomerate may be found at elevations of 1400 to 1600 feet. In the high hill just east of Shoemaker Mountain two or more such conglomerate layers are present; the higher is about 200 feet above the lower and occurs at an elevation of about 1600 feet. The upper of these layers is supposed to represent the Fall Creek conglomerate of Pennsylvania. The higher layer has not been actually seen in place.

A considerable change in the composition of the faunas takes place at about the horizon of the conglomerates, apparently being associated with the appearance of the flaggy layers. The fauna is there characterized by an abundance of *Schuchertella chemungensis* and large, coarse forms of *Leptostrophia nervosa,* and by less numbers of *Strophonella cœlata* and *Douvillina mucronata.* This is one of the highest faunas seen in the Watkins Glen quadrangle; the highest beds are not, however, above the range of familiar Chemung species.

PALEONTOLOGIC CHARACTERS.

In deciding upon the limits of the Chemung formation, great consideration has been given to the vertical range of the fossil fauna typically expressed in the rocks at Chemung Narrows. In Bulletin 210 of this Survey an attempt was made to describe the essential elements of this Chemung fauna as completely as the facts then in hand would permit. Since the publication of that report, in preparing the maps of this folio, the faunal details have been studied with particular regard to the vertical range of the species. It has been ascertained that the lower limit of the Chemung formation at Chemung Narrows may be expressed almost entirely in terms of genera and subgenera of organisms which are diagnostic of the Chemung fauna. Below that limit the genera are either entirely lacking or are represented very sparingly through more than a thousand feet of strata.

This analysis of the fossil fauna in the sections at Chemung Narrows, and in those south of the river running up to the conglomerate in the southern part of the Watkins Glen quadrangle, shows the genera, subgenera, and species named below not only to be found at numerous horizons in the successive strata but to be abundant in many zones and thus to represent the dominant bionic characteristics of the typical Chemung fauna. Among the most conspicuous fossil genera appearing in the Chemung formation of the Watkins Glen quadrangle are *Dalmanella, Douvillina, Schuchertella, Pterinea, Spirifer* (of the species *S. disjunctus* and *S. mesistrialis*), *Delthyris* (of the species *D. mesicostalis*), *Atrypa, Productella, Mytilarca, Schizodus, Edmondia, Sphenotus,* and *Spathella.* There are many other genera represented, most of which occur also below the base of the Chemung. Nowhere else in the geologic column, however, are so many of the genera above named so conspicuous and abundant as in the Chemung. Although, therefore, they may not all be called characteristic genera, their presence is strongly indicative of the Upper Devonian series, and of the Chemung formation if they appear to the exclusion of any other genera.

In the original lists of species from the typical Chemung rocks of Chemung Upper Narrows given by Hall and Conrad in the early reports of the New York State Geological Survey the following 20 species were named, the modern nomenclature being used here:

1. Phacops nupera (Hall).
2. Pterinea chemungensis (Hall).
3. Leptodesma spinigerum (Conrad).
4. L. protextum (Conrad).
5. Avicula multilineata (Conrad).
6. Goniophora chemungensis (Conrad).
7. Mytilarca chemungensis (Conrad).
8. Schizodus chemungensis (Conrad).
9. Schuchertella chemungensis (Hall).
10. Productella lachrymosa (Hall).
11. P. lachrymosa var. lima (Hall).
12. Stropheodonta (Douvillina) mucronata (Vanuxem).
13. Leptostrophia (? perplana) delthyris (Conrad).
14. Dalmanella carinata (Hall).
15. D. tioga (Hall).
16. Spirifer disjunctus (Sowerby).
17. S. mesistrialis (Hall).
18. Delthyris mesicostalis (Hall).
19. Atrypa spinosa (Hall).
20. Atrypa recticularis (Linnæus).

Of this list Nos. 1, 5, 8, 9, 13, 17, 18, 19, and 20 can not be taken as strictly diagnostic of the part of the column included in the Chemung formation. The remainder may be regarded as diagnostic species of the typical Chemung fauna of the Chemung Narrows section. They are *Pterinea chemungensis, Leptodesma spinigerum, L. protextum, Goniophora chemungensis, Mytilarca chemungensis, Productella lachrymosa, P. lachrymosa* var. *lima, Stropheodonta* (*Douvillina*) *mucronata* (Vanuxem), *Dalmanella carinata, D. tioga,* and *Spirifer disjunctus.* The presence of these species may be regarded as evidence of the Chemung fauna; and in mapping the Chemung formation in the Watkins Glen quadrangle the lowest range of this fauna has been taken as the criterion for locating the boundary.

Of these forms *Spirifer disjunctus* has been generally regarded as one of the most characteristic Chemung species. The careful study of the range of the species has shown all species of the genus *Dalmanella* to be absent from the faunas below the Portage-Chemung boundary for a thickness of at least 2000 feet of strata, but above that line for a distance of 1000 feet the genus is found at many horizons in one or other of the common species *Dalmanella danbyi*, *D. tioga*, or *D. carinata*. For these reasons specimens of this genus found in the rocks of the Upper Devonian of New York, and in all neighboring areas which may be regarded as in the same geologic province, are indicative of the Chemung formation. In the Watkins Glen quadrangle the first appearance of the genus is in a small variety of the species *Dalmanella danbyi*. A closely allied form, *Dalmanella leonensis*, characterizes the Chemung in the western counties of New York. The forms described as *Dalmanella tioga* and *D. elmira* average larger than the average size of the forms of *D. leonensis* or *D. danbyi* and prevail throughout the central part of the Chemung in the Watkins Glen quadrangle. The prevailing representatives of the genus in the higher Chemung formation are either large-sized specimens of *Dalmanella tioga* and *D. elmira* or typical *D. carinata*. Small specimens of *Dalmanella* are therefore in general significant of the lower Chemung in this central New York region, and the larger forms are characteristic of the upper Chemung. In the central part of the Chemung the smaller and the larger extremes can rarely be found, though here and there young specimens are present with the ordinary-sized *Dalmanella tioga* and *D. elmira*. In the southwestern part of the Watkins Glen quadrangle the first representatives of the genus to appear in ascending the strata are larger than the specimens first seen on the east side of the quadrangle and in the adjacent part of the Catatonk quadrangle.

In the eastern part of the Catatonk quadrangle the representatives of the genus are rarely seen anywhere in the sections of Portage and Chemung rocks, though other species of the Chemung fauna appear. In that same region there is an increasingly strong representation of species having affinity, if not identity, with species of the Hamilton shale high up in rocks which stratigraphically belong to the Upper Devonian.

CATSKILL FORMATION.

The base of the Catskill type of sediments appears at a progressively lower stratigraphic level when followed eastward from Susquehanna River near the New York–Pennsylvania boundary. These rocks are absent from the sections in the Watkins Glen quadrangle but are present in the southeastern part of the Catatonk quadrangle, where they occupy a horizon which is the tratigraphic equivalent of the highest beds of the Chemung in the southwestern part of the Watkins Glen quadrangle.

The beds of this formation occur in the upper portion of the high hills of the southeast corner of the Catatonk quadrangle, in the town of Vestal, and comprise coarse sandstones, with some fine-pebbled conglomerate bands, cross-bedded sandstone strata, and chocolate-colored shale.

The total thickness of these beds is about 200 feet. The shaly beds do not have the bright red color which so often characterizes the shales of the Catskill where typically developed. Instead they show dull shades of red, usually brown or chocolate colored, and are at many places gray. Some of the sandstones, however, show the most typical features of the Catskill type of sandstone as seen to the east and south of this area. Good examples of this characteristic Catskill type of sandstone may be seen on the high hill west of Tracy Creek. Here the coarse gray sandstone shows the peculiar thin shingle-like laminæ so characteristic of the Catskill. The Catskill of this area corresponds to that of the adjacent portions of Susquehanna County, Pa., where it is the principal surface formation, in being composed of alternating belts of shale and sandstone. The shales, however, are invariably duller in color and nowhere show the bright reds and olive green commonly seen in the Catskill of Pennsylvania.

Fossils are rare and are limited almost entirely to fish bones. Those which have been observed probably belong to *Holoptychius*.

Marine fossils occur up to the thin conglomerate bands that lie at or near the base of the Catskill but were not seen above them. In one of the conglomerate beds *Tropidoleptus carinatus* occurs. This fact and the relation to the faunas below indicate that the brackish-water sedimentation of the Catskill formation replaced the marine Chemung sedimentation at a stratigraphic horizon lower in that region than in the southern half of the Watkins Glen quadrangle. The strata lying above the last traces of marine Chemung fossils in the Catatonk quadrangle are therefore mapped as the Catskill formation.

CORRELATIONS.

PRELIMINARY STATEMENT.

On account of the fact that the classification and mapping of the formations and members in these quadrangles have been based largely on paleontologic evidence, special importance attaches to a comparison of the results with previous classifications. It is quite true that an observer can select particular division planes which, locally, seem sharply differentiated, both lithologically and paleontologically. Few of them, however, will bear the same lithologic definition for a distance of 10 miles in these quadrangles.

The three formations, Genesee, Portage, and Chemung, have been adopted as primary divisions largely on the evidence of the distinct faunas characterizing them. The boundaries between these faunas are recognizable in every section observed in the Watkins Glen quadrangle and the western part of the Catatonk quadrangle in which the strata are visible.

The boundary between the the Genesee and Portage formations is drawn, locally, at the top of a thin limestone stratum overlying the highest bed of black shale carrying the Genesee fauna.

The Portage-Chemung boundary is drawn, as already explained, immediately below the first appearance of the diagnostic Chemung fauna.

The Ithaca "group" of Williams is reduced to the rank of a member of the Portage formation, because of the appearance of the Portage fauna in hundreds of feet of strata both above and below its limits. The boundary between the Sherburne and Ithaca members is drawn at the top of the first *Reticularia lævis* fauna, originally defined as characteristic of the "Portage or Nunda group" at the heads of Seneca and Cayuga lakes. The upper boundary of the Ithaca member is drawn where in the section the Ithaca fauna ceases and the general Portage fauna reappears. In its extension across the northeastern part of the Catatonk quadrangle, however, this member is terminated by a sandstone believed to be the western extension of the Oneonta sandstone, and on account of this difference in boundary it is called in that area the eastern phase of the Ithaca member.

The original division of the "Portage or Nunda group" into Cashaqua shale, Gardeau shale and flagstone, and "Portage sandstones" is not recognizable in the Watkins Glen quadrangle, where the three members defined are the Sherburne flagstone, the Ithaca shale, and the Enfield shale members.

The Sherburne flagstone member is the Sherburne flagstone of Vanuxem, lying between the "Black shale" and the Ithaca. It was originally described as "extending from Cayuga Lake through the district." [a]

The Ithaca shale member is part of the original "Ithaca group" of Hall.[b] Its limits are determined by the range of the fauna characterizing it It is found to be preceded and succeeded by the general Portage fauna.

The Enfield member constitutes the upper part of the Portage formation in the Watkins Glen quadrangle, where it contains only the Portage or *Buchiola-Manticoceras* fauna. The name is suggested by that of the township of Enfield, whose surface rock consists chiefly of this member.

In the northeastern portion of the Watkins Glen quadrangle the upper part of the Enfield contains a brachiopod fauna which appears at first like a return of the Ithaca fauna with some modifications. The zone containing this fauna is called the first *Tropidoleptus* zone, from the fossil by which it is characterized.

In the eastern part of the Catatonk quadrangle the Enfield member gradually loses its Portage fauna, and the modified Ithaca fauna is found higher and higher in the sections. This is the *Leiorhynchus globuliforme* fauna. Also from the base of the Chemung downward the upper half of the Enfield is more and more dominated by the expanded first *Tropidoleptus* fauna. On account of this changed expression of the Enfield fauna the member in this area is called the eastern phase of the Enfield.

Westward from Ithaca the fauna of the Enfield becomes more strongly that of the typical Portage and the zone of range of the Ithaca fauna becomes restricted, goes lower down in the section, and finally disappears. In this direction also boundaries based on prominent lithologic changes differ from the boundaries of the formation based on faunal changes.

CORRELATION WITH THE CANANDAIGUA LAKE FORMATIONS.

In 1905 a map with definitions was published by Clarke and Luther [c] in which the detailed classification originally established for Canandaigua Lake (section B) was extended eastward, as shown in section C, figure 8.

Section A in figure 8 was reported by Clarke and Luther in 1908 [d] as representing the sequence of formations in the Genesee Valley. The thicknesses are generalized from the various measurements given in that report.

In the treatment by Clarke and Luther of the transition from Genesee to Portage at the Firtree Point section a different interpretation has been made from that adopted in this folio. According to the list of species reported by them for the Watkins and Elmira quadrangles their West Hill flags and shales and High Point sandstone should both be included in the Chemung formation as here defined. On the same basis their Hatch shale and flags appear to include the upper part of the Ithaca fauna and to run up into the Enfield member. The division made by them between the High Point sandstone and the Prattsburg shale, according to the fossils cited, corresponds nearly with the upper boundary of the *Dalmanella danbyi* zone in the midst of the typical Chemung fauna of the Cayuta member.

The High Point sandstone and the upper part of the West Hill flags and shales of Clarke and Luther represent the basal portion of the Chemung as the lower limit of this formation is drawn in this folio. In the stratigraphic classification of Clarke and Luther, however, the High Point sandstone is placed below the Chemung and separated from it by the Prattsburg shale.[a]

This results in a considerable discrepancy between the base of the Chemung as drawn on the map of this folio and the map of the Watkins and Elmira quadrangles by Clarke and Luther. The explanation of this difference is found in the discussion of the Portage-Chemung boundary in the area west of these quadrangles by Clarke and Luther. These authors state that the stratigraphic continuity of the "Nunda" ("Portage") sandstone of the Genesee section with the High Point sandstone of the Naples section is beyond question. They report, however, that this sandstone carries in some places at the west a Portage fauna, while in others at the east it has a Chemung fauna. On this ground they refer the same stratigraphic unit in one section to the Chemung age and in another to the Portage age, according to the fauna which predominates. The base of the Chemung of this folio is drawn where the Chemung fauna first appears and not where the Portage fauna ends, as in the classification of Clarke and Luther. These points of equivalence are brought out on the correlation chart (fig. 8).

According to the general faunal character and stratigraphic position assigned to them by the authors cited, the divisions called West Hill shale, Cashaqua shale, Parish limestone, Rhinestreet black shale, and Hatch shale and flags are to be correlated with the Portage formation of this folio. These divisions amount to less than 600 feet. The total thickness of the Portage is estimated herein to be about 1100 feet in the western part of the Watkins Glen quadrangle. Thus it is extremely difficult to recognize in the Watkins Glen quadrangle the particular horizons to which these names apply. It is believed, however, that the definitions of these divisions apply accurately to the Canandaigua section, for which they were originally designed.

CORRELATION BETWEEN THE TIOUGHNIOGA AND CHENANGO RIVER SECTIONS.

Toward the east the modification of the faunas presents as many difficulties as it does in the opposite direction. The farther west one goes the more prominent he finds the characteristics of the Portage faunas for the whole formation. Toward the east, however, the Hamilton and Chemung faunas are stratigraphically nearer to each other, and the Portage fauna almost vanishes. In the Catatonk quadrangle the strata which, on a stratigraphic and structural basis, correspond to the Portage formation of the Genesee River section carry fossils that in other regions are found separately in Hamilton, Ithaca, and Chemung faunas.

It becomes necessary, therefore, to trace the faunal modifications step by step across the quadrangles and to draw the lines separating the members and define the members themselves, on characters which can be examined in the field for each typical section.

The Oneonta sandstone is a conspicuous lithologic member in the Chenango Valley section. It is ascertained, however, that the limits of the Oneonta, which are in the main founded on lithology, do not agree with the limits of either of the members of the Portage in the Watkins Glen quadrangle. The fauna occupying the 500 feet below the Oneonta is, however, correctly correlated with the Ithaca fauna of Ithaca, as interpreted by Prosser.[b]

In Cascadilla Creek near Ithaca a similar sandstone occurs more than 100 feet below the top of the Ithaca member. This sandstone contains the only known *Spirifer mesistrialis* zone in the Portage of that section—this species being there limited to about 25 feet of strata. In the Tioughnioga Valley the sandstone at Marathon marks the upper limit of the range of *Spirifer mesistrialis* for that particular part of the section; the species, it should be noted, also reappears with a different fauna several hundred feet higher up. The sandstone shows in several massive beds in the section at Marathon, at an elevation of about 1150 feet. The strata for several hundred feet below are more or less fossiliferous, but for 50 feet above the base of the thick sandstone beds fossils are rare and few species can be found. Above this 50-foot zone other species appear and the fauna changes. These sandstones are in this eastern

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[a] Fourth Ann. Rept New York Geol. Survey, 1840, p. 381.

[b] Third Ann. Rept. New York Geol. Survey, 1839, p. 318.

[c] Geology of the Watkins and Elmira quadrangles: Bull. New York State Mus. No. 81, 1905.

[d] Geologic map and description of the Portage and Nunda quadrangles: Bull. New York State Mus., No. 118, 1908.

[a] Bull. New York State Mus. No. 81, p. 4.

[b] Fifteenth Ann. Rept. State Geologist, New York, pt. 1, 1895, p. 16.

part of the Catatonk quadrangle made the upper limit of the Ithaca member.

Below the range of the distinctly *Spirifer mesistrialis* fauna the *Paracyclas lirata* fauna occurs, and was recognized in 1886 as the "*Paracyclas lirata* stage of the Middle Devonian fauna."[a] This fauna is also seen in the 500-foot zone lying immediately below the Oneonta sandstone of the Chenango Valley section. It is correlated with the recurrent Hamilton fauna, at "Station 14," near the base of the Ithaca shale member in the Ithaca section.[b]

Below the *Paracyclas lirata* fauna the rocks are flaggy, contain Portage fossils, and are referred to the Sherburne flagstone member. The point of transition from the sparsely fossiliferous zone of the Sherburne member to the first reappearance of the recurrent Hamilton fauna (*Paracyclas lirata* zone) is adopted as the base of the Ithaca member for the Tioughnioga Valley sections. In the region about Ithaca the member is marked at its base by the *Reticularia lævis* bed, and its top is indicated by the transition from the Ithaca fauna back to the nearly barren rocks in which only Portage species are discovered.

In the Chenango section the marine fauna showing next below the Oneonta sandstone is the *Spirifer mesistrialis* zone. Hence the 500+ feet of the Chenango section lying between the Sherburne flagstone member and the Oneonta sandstone represents the eastern phase of the Ithaca member.

FAUNA OF THE EASTERN PHASE OF THE ITHACA MEMBER.

The *Paracyclas lirata* fauna is more purely developed in the sections of the Chenango Valley and farther east than it is in the Catatonk quadrangle. Its typical expression may be seen in these eastern faunules. Dominant species in the faunules of Chenango Valley and eastward are *Paracyclas lirata*, *Atrypa reticularis*, *Spirifer pennatus posterus*, *Chonetes scitulus*, *Tropidoleptus carinatus*, *Spirifer mesistrialis*, *Leiorhynchus mesicostale*, *Actinopteria eta*, *Palæoneilo emarginata*, *Cyrtina hamiltonensis*, *Cypricardella bellistriata*, and *Nucula corbuliformis*. Other species associated with them at many places are representatives of the genera *Modimorpha*, *Camarotœchia*, *Stropheodonta*, *Orthoceras*, *Grammysia*. This combination of species unites elements of both the Hamilton and the Ithaca faunas, and traces of it are seen in the Ithaca section, but they are there relatively inconspicuous.

In the upper part of the eastern phase of the Ithaca *Paracyclas* is rarely found, but *Spirifer mesistrialis* is locally very abundant, and *Leptostrophia*, *Grammysia*, *Palæoneilo* of several species, *Actinopteria* of several species, *Modiomorpha*, and *Cypricardella* are not uncommon. The above lists of species demonstrate clearly a phase of the Ithaca fauna in which the infusion of Hamilton species is stronger than in the local sections at Ithaca. The prominence of *Spirifer mesistrialis* at the top supports the correlation of the eastern phase with the *Spirifer mesistrialis* zone in the sandstone at Cascadilla Creek in the western phase of the Ithaca member. At present the lithologic evidence points to the equivalence of the sandstones at Cascadilla Creek and at Marathon; but the fact that the *Spirifer mesistrialis* fauna runs down below but not above the sandstone at Marathon in the Tioughnioga River section is paleontologic evidence for placing that sandstone at the top of this phase of the Ithaca member. A little farther east, where the Oneonta sandstone appears in the sections, the marine fauna coming in above the Oneonta belongs distinctly above the Ithaca member as paleontologically limited in the Ithaca sections.

ZONE OF MERGING BETWEEN PORTAGE AND CHEMUNG.

In the sections of the lower part of the Chenango River region the first trace of the *Spirifer disjunctus* fauna is seen at about 800 feet above the top of the Oneonta sandstone.[c] In the east half of the Catatonk quadrangle there are about 900 feet of strata lying between the sandstone at Marathon and the first trace of a diagnostic Chemung fauna. In this zone between the top of the Oneonta and the first detected *Spirifer disjunctus* the most conspicuous fauna is the one originally called the *Leiorhynchus globuliforme* stage of the Middle Devonian fauna.[d] This fauna is seen in its typical development in the Kattel Hill section, 2½ miles south of Chenango Forks. Prominent species in this fauna are *Leiorhynchus globuliforme*, *Stropheodonta demissa*, *Pugnax pugnus*, *Delthyris mesicostalis*, *Productella speciosa*, *Cyrtina hamiltonensis*, *Camarotœchia stevensi*, *Schizophoria striatula*, *Palæoneilo constricta*, *Cypricardella bellistriata*, and *Lyriopecten tricostatus*.

In other faunules of the same fauna *Spirifer pennatus posterus* and *Atrypa reticularis* are also seen. This fauna occupies the lower 200 or 300 feet of the strata following the Oneonta sandstone, and it is the same fauna which appears above the sandstone at Marathon. Higher in the section *Delthyris mesicostalis* and *Spirifer mesistrialis* reappear, associated with *Ambocœlia*, *Chonetes*, *Tropidoleptus carinatus*, *Nucula corbuliformus*, *Palæoneilo brevis*, and some other species. When traced westward both of these facies of the fauna are found to occupy the horizon of the Enfield member and to lie below the typical Chemung fauna. This zone, therefore, stratigraphically represents the Enfield member but because it is composed of rocks of the Chemung type it is here classed as a transition zone between the Portage and Chemung. There is little lithologic contrast to mark the upper Portage from the lower Portage rocks of this region, but the *Leiorhynchus globuliforme* fauna is diagnostic of the upper member. In the higher strata the fauna assumes a modified facies of the first *Tropidoleptus* fauna of the Watkins Glen quadrangle, and the rocks gradually assume the Chemung lithologic expression.

The correlation thus established by the range and distribution of the faunas in the strata is represented on the accompanying chart (fig. 8).

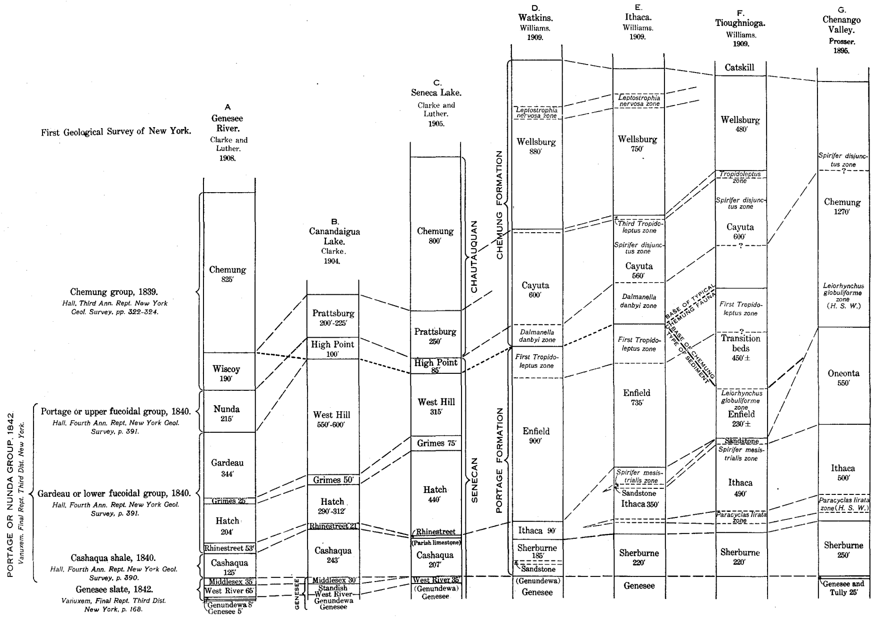

FIGURE 8.—Correlation chart showing relations between the classification and nomenclature used in the Watkins Glen-Catatonk folio and that of previously published reports.

CORRELATION CHART.

The correlation chart is prepared to exhibit the relations between the nomenclature and classification proposed in the Watkins Glen-Catatonk folio and previous published interpretations of the rocks under discussion. Seven geologic columns are given in the chart, drawn to a common scale. A maximum thickness of about 2500 feet is represented.

At the left is given the general nomenclature and classification of the First Geological Survey of New York State, 1839-1842, with the date and a reference to the original definition of each named division. The sections are as follows:

A. Genesee River section by J. M. Clarke and D. D. Luther, 1908.

B. Naples or Canandaigua Lake section, by J. M. Clarke, 1904.

C. Watkins section, Watkins and Elmira quadrangles, by J. M. Clarke and D. D Luther, 1905.

D. Watkins section, representing the western part of the Watkins Glen quadrangle as published in the present folio, by H S. Williams.

E. Ithaca section of this folio, by H. S Williams.

F. Tioughnioga section, representing the section across the eastern part of the Catatonk quadrangle as given in this folio, by H. S. Williams.

G. Chenango Valley section of C S. Prosser, 1895, including location of two fossiliferous zones, by H. S. Williams

It will be noted that the divisions called "Portage," Gardeau, and Cashaqua in the list at the left of the chart were named and defined in 1840, and were bracketed together to form the "Portage or Nunda group" in 1842.

The lines connecting columns A, B, and C, are based on the statements made by J. M. Clarke and D. D. Luther in the various papers describing these sections. On the right of column C is shown the use of the terms Senecan and Chautauquan as proposed by J. M. Clarke (1905). Columns D, E, and F express generalized sections of the western, middle, and eastern parts of the Watkins Glen-Catatonk area, in which are indicated the chief fossiliferous zones on which the classification is based.

The lines drawn connecting columns C and D express the relations supposed to exist between the interpretation of the rocks of this area given by Clarke and Luther in 1905 and the interpretation given in the present folio.

The heavy dashed line, drawn between columns E and F, expresses the lower limit of the transition zone between the Portage and Chemung formations as mapped in the Catatonk quadrangle. The lines connecting columns F and G express the relation supposed to exist between the rocks of the Catatonk quadrangle and the Chenango Valley section of Prosser. The Oneonta sandstone of the latter section is supposed to be represented by the sandstone at Marathon, in the Tioughnioga Valley, and the sandstone on Cascadilla Creek; and the *Leiorhynchus globuliforme* fauna is regarded as an upward continuation of the general Ithaca fauna of the west. Such an interpretation of the expansion of the Ithaca fauna on passing eastward would bring the top of it to the top of the *Leiorhynchus globuliforme* zone of the Tioughnioga and Chenango sections. However, on account of the prominence of the Oneonta sandstone in the Chenango Valley and eastward, the top of the Ithaca is drawn in the Catatonk quadrangle up to the sandstone at Marathon, which is believed to be the western equivalent of the Oneonta.

The comparison of the several sections of the chart has shown that the correlation of horizons may be established by study of the faunules with a precision and refinement not hitherto attained. The intrinsic evidence of the fossils themselves furnishes a reliable means of determining the stratigraphic position of a fossiliferous stratum. The discrepancies in formation limits brought out by these comparisons should not be regarded as reflecting on the accuracy of either the field observations or the records made by other observers. If the scarcity of fossils, the infrequency of outcrops, and the disturbing effect of slight dips on calculations of altitude are taken into account, it would not be surprising to find divergences of 20, 30, or even 100 feet in correlating a common horizon for these uniform rocks without the help of fossils.

IGNEOUS ROCKS.

By EDWARD M. KINDLE.

MICA PERIDOTITE.

General occurrence.—More than twenty-five small dikes of mica peridotite occur in the vicinity of Ithaca, cutting the Devonian rocks about the head of Cayuga Lake. Some of these dikes are in the adjacent quadrangles. The northernmost observed occurrences of the group lie north of the Watkins Glen quadrangle, at Ludlowville and Taghanic Falls. Groups of similar dikes occur at Syracuse and Little Falls, 40 and 90 miles, respectively, to the northeast.

The intrusive rocks of this quadrangle all outcrop in the area of the Portage formation. They follow joint planes of the north-south system and depart only a few degrees from north and south in direction. The thickness of the sedimentary rocks cut by these dikes is presumably more than 6500 feet. The dikes are as a rule only a few inches in width and occur both singly and in groups including two or more parallel dikes, separated by a few inches or a few feet of shale.

Character and outcrops.—The intrusive dikes known in this area occur at three localities, on the west side of Cayuga Lake, in the eastern part of Ithaca, and in the valley of Sixmile Creek. The northernmost of them is in Glenwood Creek. At

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[a] Proc. Am. Assoc. Adv. Sci., vol. 34, 1886, p. 225.

[b] Bull. U. S. Geol. Survey No. 3, 1884, p. 15.

[c] Prosser, C. S., Fifteenth Ann. Rept. New York State Geologist, 1897, p. 160.

[d] On the classification of the Upper Devonian: Proc. Am. Assoc. Adv. Sci., vol. 34, 1886, p. 226.

an elevation of about 760 feet the Ithaca shale member is cut by a dike 8 feet in width. The outcrop of this dike, owing to the relative ease of disintegration of the igneous rock, is marked by a shallow trench in the shale. The dike strikes N. 5°–7° E. The shale is slightly altered for a few inches on each side and is traversed by closely spaced north-south joints.

On fresh surfaces the dike material is a nearly black rock, with a sprinkling of grayish minerals throughout the mass. It weathers to a dull yellowish-green color. The clay residual from its decomposition is yellowish in color and contains a large amount of mica. Where weathering has been in progress its unequal rate among the constituent minerals leaves the rounded surfaces of the more resistant ones projecting like pebbles above the general surface. The covering of till entirely conceals the position of the dike beyond the bed of the stream which it crosses.

Two large igneous masses are exposed in the bed of the stream near the head of a small ravine three-fourths of a mile southeast of the Glenwood dike. The upper or western mass is exposed for a width of 13 feet; it is separated from the eastern one by a covered interval of 110 feet. The eastern mass is exposed for a width of 25 feet; along its east side is an irregular border of highly baked shale and sandstone and its west side is masked by a mantle of till that extends to the upper intrusive mass, whose eastern edge is likewise concealed. The western mass terminates sharply against a joint plane in the shale and sandstone bearing N. 15° W. The stream above and below these intrusive outcrops is generally confined between rock walls; but between these two igneous masses no rock outcrops are visible on either side of the stream. The abrupt termination of the rock walls of the stream at this point and the mantle of till concealing the interval between the two intrusive masses leave some uncertainty as to whether there are two dikes, 13 and 25 feet across, or whether the outcrops represent a single dike 160 feet across. The material comprising the two masses is similar. It contains a large quantity of shale and many crumbling limestone inclusions.

On Indian Creek, at an elevation of 720 feet, two dikes 20 feet apart cut the shale. They follow joint planes bearing N. 8° W. These dikes are 2 inches and 2 feet in width. Where exposed to the weather their outer portions are decomposed, forming a mass of greenish-yellow residual clay containing mica, which fills the interval between the axis of the dikes and their containing shale walls. The shale near the smaller dike appears to be considerably altered and is cut by numerous small veins of calcite.

The largest of the dikes exposed in Ithaca is in the Cascadilla Creek gorge, 60 feet east of the Central Avenue Bridge. It has a thickness of 3 feet and bears N. 3° E. The drift conceals it beyond the outcrop on the south side of the gorge. It is probable, however, that the dike in Driscoll's quarry, one-fourth mile south of Cascadilla Creek, may be the continuation of this dike. A large loose block of igneous rock which was observed in an excavation on the Cornell campus, one-fourth mile north of Cascadilla Creek, may be a fragment from the northern part of this dike. The rock is greenish black in color. Weathering attacks most rapidly the fine-grained groundmass, leaving the large rounded olivine crystals, now altered to serpentine, standing out on the surface like the pebbles of a conglomerate. A few yards below this dike and 10 feet east of the bridge a small dike 2 inches in width, superficially weathered to clay, traverses the north wall of the gorge.

Two other dikes cross the Cascadilla gorge, being exposed in the north wall just north of Cascadilla gate. They are 3 and 6 inches in width and 30 inches apart, and bear N. 8° E. The material composing these closely associated dikes is similar and consists of a dark olive-green material inclosing bits of shale.

One small dike is exposed on the north side of the campus, in the south wall of the Fall Creek gorge. It is about 100 yards above the tunnel in the deep notch near the foot of the old ladder. This intrusion has a width of 4 to 5 inches, and may be seen bearing within a few degrees of north and south for 50 feet above the bottom of the gorge. It does not appear to cross to the north side of the gorge.

In the southeastern part of Ithaca a dike occurs on the west side of Driscoll's quarry. Its decomposition has proceeded so much more rapidly than that of the inclosing sandstone and shale that a fissure filled with yellowish-brown micaceous clay is the only visible representative of it. Apparently there are two dikes 3 and 8 inches wide separated by 3 inches of shale. Their direction is N. 2° E.

A dike 6 to 10 inches in width cuts the north wall of Sixmile Creek 200 yards below the waterworks dam in Ithaca. Unlike most of the intrusions, which generally occupy vertical joints, this one is inclined at 7° from the vertical and bears N. 2° to 3° E. The rock is dark olive-green and contains considerable mica. Although much harder than the inclosing shale, it has been disintegrated and removed to a depth of several inches.

About $1\frac{1}{2}$ miles southeast of Ithaca, near the head of a pool above Green Tree Falls, is a small dike bearing N. 1° W. From a maximum thickness of $1\frac{1}{4}$ inches it pinches to less than one-eighth of an inch before disappearing. The rock is ashen gray, resembling in color and texture the big dike south of Glenwood Creek in the Watkins Glen quadrangle. Unlike the previously described intrusions, this dike does not disintegrate more rapidly than the inclosing shale and it therefore fills the fissure to the surface.

About three-fourths of a mile above Green Tree Falls, at the extensive outcrop below the wagon bridge, another small dike occurs in a joint bearing N. 4° to 5° E. It has a maximum thickness of $2\frac{1}{2}$ inches. It extends across about 100 feet of the sandstone and shale exposure and thins to one-fourth of an inch before disappearing. The rock is ash-gray in color and holds numerous inclusions of shale fragments.

Age.—Perhaps the most striking fact concerning the occurrence of the dikes is their close approximation to a north-south direction, corresponding with the direction of the north-south system of joints. The greatest amount of variation from a north-south course shown by any of the nine dikes in the Ithaca and Sixmile localities which have been described is only 5°. More than twenty-five dikes are known in this and adjacent quadrangles within a few miles of Ithaca, but not one of them is associated with the east-west system of joints. This fact suggests that the dikes were probably intruded into the north-south joints before the east-west system was developed. It seems scarcely probable that dikes, some of which pinch down to a thickness of less than one-eighth of an inch, should have failed to penetrate the east-west fissures if both systems had been in existence at the time of the intrusion. The east-west system of joints was probably developed at the same time as the gentle easterly and westerly undulations of the sedimentary beds of this region, which are correlated in age with the Appalachian uplift. If this hypothesis of the origin of the east-west joints is correct, the presence of the dikes in the north-south joints and their absence in the other system suggests that the former system is older than the Appalachian uplift, and consequently dates from a period between the Portage and the close of the Carboniferous. This seems to limit the time of the intrusion of the dikes to the interval between the Portage and the early Permian.

The evidence of the age of the intrusion of the dikes as stated above rests on the assumption that the east-west joints could not have been so tightly closed by east-west pressure as to prevent the intrusion of the peridotite into them. This, however, though possible, is apparently not a probable explanation of the absence of the dikes from the east-west joints, so that the conclusion as to the late Devonian or Carboniferous age of the dikes must be regarded as probable but not demonstrated.

Petrographic description.—The petrographic description of the intrusive rocks which follows has been prepared by Albert Johannsen:

> A microscopical study of the basic rocks occurring in dikes about the head of Lake Cayuga, in the Watkins Glen and Catatonk quadrangles, shows all of them to be similar in character. The specimens examined are much decomposed, serpentine and calcite being the principal alteration products, but there is considerable difference in the degree of alteration in the different dikes. The texture of the rocks is holocrystalline-porphyritic, with phenocrysts somewhat subordinate to groundmass.
>
> The phenocrysts are rounded and vary in size from 0.25 to 6.0 millimeters. While all were originally olivine, and in the large dike from Cascadilla Creek cores of olivine remain fresh and unaltered, in most of the dikes little or none of the original mineral remains. The olivine exhibits the usual characters and its alteration to serpentine follows the common course, proceeding from cleavage cracks. The other essential mineral in the rock is a dark mica which fills up the greater portion of the space between the crystals of olivine and thus forms the groundmass. This mica is much paler than biotite and its pleochroism is much less than is usual in that mineral, with which it agrees in other particulars; it is probably the magnesian mica, phlogopite. It is possible that one or two of the altered phenocrysts were originally augite but the occurrence of this mineral is very rare.
>
> Besides olivine and phlogopite, there are as accessory minerals perofskite, iron oxide, and apatite. Calcite, serpentine, and part of the iron oxide are secondary. The perofskite is very abundant and is of a bright yellowish-brown color. It occurs generally in small, well-formed octahedrons from 0.02 to 0.15 millimeter in diameter, many of which have dark borders; it usually exhibits optical anomalies. The iron oxide is much less abundant than perofskite and its grains are about the size of the smaller ones of that mineral. It is opaque and unaltered, generally has rectangular outlines, and is, therefore, magnetite. Some ilmenite may occur. Apatite is rare and occurs in rather large crystals.
>
> In appearance the fresher specimens from these dikes agree closely with the rock described by Darton and Kemp from Dewitt, near Syracuse, N. Y., which was called a limburgite by Kemp. Augite, however, is rare or perhaps entirely absent from these rocks, and as there is no evidence of the former presence of a glassy base they should be called mica peridotites. In general appearance, under the microscope, the Cayuga Lake dike rocks are very similar to the mica peridotite from Crittenden County, Ky., which is one of a group occurring in western Kentucky and southern Illinois. A mechanical analysis made of the Cascadilla Creek dike indicates that that rock is very similar in chemical composition to the rocks from Kentucky and from Dewitt, the composition of which is known.
>
> The big dike south of Glenwood Creek, which shows fragments of the country rock in a mass of decomposition products, is similar in appearance, under the microscope, to some of the other rocks, though it now consists almost entirely of calcite. The areas of the former olivine crystals are distinct and the alteration rims of what was once serpentine now seem to be further altered to talc.

GEOLOGIC STRUCTURE IN DEVONIAN ROCKS.

By Edward M. Kindle.

GENERAL DESCRIPTION.

The rock strata in much of the area depart so little from the horizontal position that the amount of dip can not be recognized except by the very careful use of clinometer or level. Dips high enough to be conspicuous, ranging from 8° to 55°, have been noted in various parts of the quadrangles, but nearly all these high dips are associated with small anticlines or faults, extending only a few rods and possessing only local interest.

A detailed study of the low dips characterizing the rocks in most of the area has shown them to have an important structural significance. They have been found to be features of a series of low, approximately parallel arches having the same general easterly strike as the great mountain flexures immediately south of them in Bradford County, Pa. The gradual extinction of these flexures east of the Susquehanna County boundary corresponds with the dying out of the New York folds toward the east and occurs not far from the same meridian. The folds that cross the western part of the Watkins Glen quadrangle are low, flattened arches from 3 to 6 miles across, separated by synclinal depressions which are as a rule almost or quite flat near the middle. Toward the sides of these folds the strata show dips of 1° to 10°. Northerly dips are absent in the eastern part of the Watkins Glen quadrangle, so that folds are not recognizable. The southerly dips are nearly everywhere more pronounced than the northerly dips, so that the beds involved reach progressively lower levels on crossing the folds from north to south. (See fig. 9.)

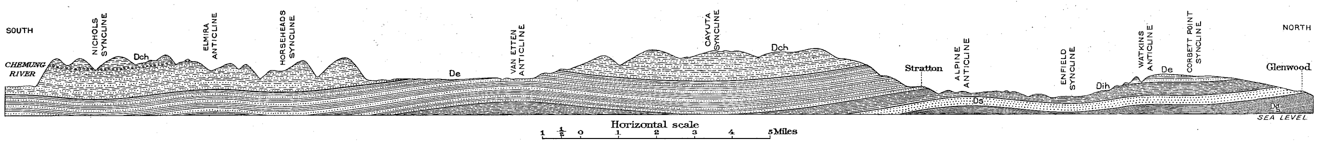

FIGURE 9.—North-south cross section along the line A-A on the Watkins Glen areal geology map.

Vertical scale 5 times the horizontal.

There are two main groups of structural features, a general southward monocline and a series of low arches impressed upon it. While the primary tectonic relationship of these low arches is with the Allegheny folds, they also lie on the southern border of the great Canadian uplift which elevated the Paleozoic rocks of northern New York and southern Canada. This northern uplift with its center in southern Canada gives a general southerly dip to the Paleozoic rocks of New York south of Lake Ontario. It brings to the surface successively older and older beds northward from the northern border of these quadrangles to the shore of Lake Ontario. The total thickness of the beds thus exposed is more than 6000 feet. The gently folded beds under consideration lie near the southern border of this uplift. Their anticlinal structure appears to have been superimposed upon the older monoclinal structure. The general southerly declination of the beds of these quadrangles is thus the result not only of the greater inclination of the southern limbs of the anticlines but of the earlier monoclinal inclination toward the south as well.

ANTICLINES AND SYNCLINES.

Very gentle dips ranging from half a degree to 5°, locally increasing to 10° or more, characterize these folds. Although very low, they belong to anticlinal structures, which are rather persistent. Six of these anticlinal folds and their intervening synclines have been recognized. Beginning at the north, they are designated the Firtree Point, Watkins, Alpine, Van Etten, Elmira, and Sabinsville anticlines. The position of these minor folds in relation to the nearest of the grander Allegheny folds south of the New York–Pennsylvania line is shown by the accompanying sketch map, figure 10.

Firtree Point anticline.—Where cut by the valley of Seneca Lake the Firtree Point anticline has a width of $5\frac{1}{2}$ miles. Its axis bears a little north of east and crosses the lake at Firtree Point, $2\frac{1}{2}$ miles south of the northern edge of the Watkins Glen quadrangle. The crest of the anticline rises about 115 feet above the troughs of the synclines on each side, as measured along the nearly continuous exposures at the lake shore. This anticline therefore brings to view 115 feet of strata which are below lake level at the northern border of the quadrangle.

The uplifted beds include about 75 feet of typical Portage sandstone and shale, above about 40 feet of black and dark-gray shales representing the highest beds of the Genesee.

This axis is probably continuous with one which crosses Cayuga Lake about 3 miles northwest of the north line of the Watkins Glen quadrangle, between Shurger Point and Ludlowville. From 6° at Shurger Point the southerly dip lessens to about 2° at the northern border of the Watkins Glen quadrangle. The southerly dip diminishes still further in approaching the southeast corner of Lake Cayuga, but appears not to be reversed by the Corbett Point syncline and Watkins anticline, which were recognized on the west side of the inlet valley. The synclinal axes appear to fade out at Ithaca, the Watkins anticline being transformed into a monocline on the east side of the valley. At Forest Home the southerly dip is about 1 foot in 100. South of the Cornell campus the dip is accentuated, reaching 2½° to 3° at some points. Southerly dips continue nearly to the axis of the Enfield syncline, which crosses Sixmile Creek about one-half mile south of Green Tree Falls.

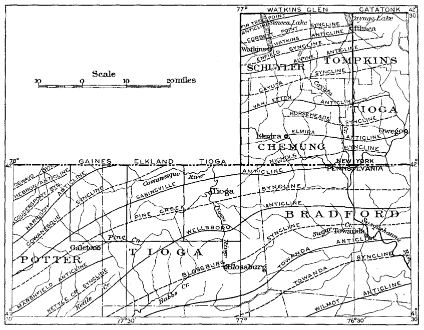

FIGURE 10.—Sketch map of the Watkins Glen and part of the Catatonk quadrangles and adjacent portions of Pennsylvania, showing location of anticlinal and synclinal axes.

The locations of the axes in Pennsylvania are determined from maps published in folio 93 of the Geologic Atlas of the United States and reports of the Second Geological Survey of Pennsylvania, supplemented by reconnaissance observations in Bradford County.

The axis of the Corbett Point syncline to the south of the Firtree Point fold crosses Seneca Lake just north of Corbett and Cottage points, 3 miles south of the anticlinal axis. The amounts of northerly and southerly depression on this fold are practically the same along Seneca Lake.

Watkins anticline.—Six miles south of Firtree Point a second low fold crosses the south end of Seneca Lake. Its axis crosses the lake just north of Watkins. Continuing east by northeast, it is indistinctly recognizable in the Cayuga Inlet valley at Ithaca. In the Seneca Lake basin the maximum height of the fold above the synclinal trough on the north is about 35 feet. A band of heavy-bedded sandstone, outcropping at the foot of the cliffs just below the entrance to Watkins Glen, affords a convenient datum plane from which to determine the height of the Watkins fold. In a small ravine just north of the village it reaches nearly its maximum elevation of 30 feet above the lake. From the point of its disappearance below lake level northward to the axis of the Corbett Point synclinal trough, the total depression of the strata does not exceed 10 feet. The total amplitude of this fold is therefore not over 40 feet. On the east side of the lake the maximum elevation of the sandstone (which is about 10 or 12 feet less than on the west side) is attained at the quarry just north of Excelsior Glen.

At Ithaca a very slight northward dip appears to represent this fold along the west side of the inlet valley from the south edge of the town nearly to the lake. On the east side of the valley it is manifested only by a much accentuated southward dip which appears in South Hill. This low anticlinal swell passes thus into a monocline. The southward dip of this fold both at Ithaca and Watkins greatly exceeds the northward dip. The synclinal axis between this fold and the next to the south passes a little north of Montour Falls and south of Cayuga Lake, through the village of Enfield and across into the Catatonk quadrangle at a point east of the upper dam in Buttermilk Creek.

Alpine anticline.—The strongest fold in these quadrangles is the Alpine anticline, the one next south of the Watkins fold, with which it is parallel. Its anticlinal axis enters the Watkins Glen quadrangle nearly west of Beaverdams. It passes thence in an easterly by northeasterly direction across the Watkins Glen quadrangle and into the Catatonk quadrangle as far as Slaterville Springs. The axis crosses Catharine Creek valley about 5 miles south of the head of Seneca Lake, Cayuta Creek 1 mile north of Alpine, and Cantor Creek 1½ miles north of Pony Hollow, and passes midway between Bessemer and Brookton. Northeast of Harford low northerly dips and near Harford Mills heavy southerly dips suggest the probable continuation of this axis beyond Slaterville Springs, through Harford as far east as Lapeer. In the hill just south of Brookton the southerly dips range from 5° to 10°. Exposures along the valley 2½ miles southeast of Brookton show southerly dips of 5° to 6°. The northerly dips of this fold, which may be seen northeast of Slaterville Springs along Sixmile Creek and 1 mile east of Bessemer, are much lower than the southerly dips, ranging from 1° to 3°. This fold raises the top of the Ithaca member to 980 feet at Brookton, which is 180 feet above its level at East Ithaca.

In the Watkins Glen quadrangle the northerly dips of the Alpine anticline usually vary between 1° and 2°, rising rarely to 3°. The southward dips are much stronger and range between 3° and 10°. Northeast of Chambers southerly and southeasterly dips of 3° to 8° are seen. In the ravine one-half mile east of Alpine the dips range from 8° to 10° in a southeasterly direction. Just west of West Danby the southward dips vary from 3° to 6°. The average southward dip for this fold is probably 3½° to 4°.

The total uplift of the strata on passing southward from the synclinal axis bordering the anticline on the north is slight as compared with the southerly depression on the south side of the fold. The steeper southward dip on the southern limb of the fold, which continues for several miles, results in an appreciable lowering of the strata for the whole region. This effective southward dip explains the descent of the base of the Chemung along the hills on the southern flank of this fold.

The synclinal axis to the south of this fold enters the Watkins Glen quadrangle about a mile near the middle of its western boundary. Passing northeastward through Millport it crosses Cayuta Creek just south of Cayuta and leaves the quadrangle about 1 mile north of the Tioga-Tompkins County line.

Van Etten anticline.—The axis of the Van Etten fold crosses Cayuta Creek at Van Etten. Bearing a little to the north of west it crosses Catharine Creek about one-half mile south of Pine Valley. Thence trending a little south of west it passes just north of Catharine and probably leaves the Watkins Glen quadrangle west of Quackenbush Hill. East of Van Etten the axis of this anticline follows the valley of Catatonk Creek from Spencer to West Candor, bearing thence eastward to Candor; but beyond the latter point it has not been recognized. The north and south dips of this fold may be seen along nearly all of the streams which it crosses. The dips of the north limb are particularly well displayed in the outcrops along Dry Run, Langford Creek, and Cayuta Creek. The dips of the south limb may be seen along Dean, Cayuta, and Baker creeks, and a number of other small streams to the south of the axis, varying usually from 2° to 3°. They may be seen in nearly all the ravines joining Catatonk Creek between Spencer and Candor.

The synclinal axis south of the Van Etten fold apparently crosses Cayuta Creek about 2¾ miles north of Reniff. Its position has been recognized just east of Horseheads, but west of that point the complexity of the local dips renders the determination of its general course uncertain.

Elmira anticline.—The axis of the southernmost anticline of these quadrangles runs eastward from a point near the abrupt southerly bend of Chemung River east of Elmira, and passing south of North Chemung and north of Chemung Center crosses Cayuta Creek just north of Lockwood. At Lockwood the north limb of the anticline has flattened so that the dip can not be detected by the clinometer or hand level, but there is probably a very small northward dip for 2½ or 3 miles up the valley to the southward dips of the Van Etten fold. The northward dips are pronounced along Baldwin Creek northeast of North Chemung and in its tributaries to the west of North Chemung. The northward dip at the quarries east and north of Elmira, which averages about 2°, may be observed nearly to Horseheads. The southward dips of this fold along the east side of Chemung River range from 3° to 5°. Farther east the southward dips may be seen along the banks of nearly every southward-flowing stream to the eastern border of the Watkins Glen quadrangle. West of Elmira the course of the fold is not entirely clear. Strong southwest dips have been observed for 2 miles along the river west of the city, but the nature of the warping of this part of the quadrangle has not been determined with certainty. The Elmira anticline doubtless represents the eastern extension of either the Harrison or the Sabinsville anticline of Pennsylvania, probably the former.

In the vicinity of Tioga Center the outcrops show strong dips indicating an east-west fold having its axis about 1 mile north of that town. The outcrops permit its definite recognition across a belt of territory about 3 miles in length. The scarcity and small extent of the exposures in the southwestern part of the Catatonk quadrangle make it impossible to demonstrate the continuity of this fold with the Elmira fold of the Watkins Glen quadrangle, but that the two are parts of the same fold appears probable, because of their position approximately midway between two folds that have been traced continuously across the belt in which the continuity of the Elmira and Tioga Center folds has not been demonstrated. The Tioga fold is characterized by southerly dips ranging between 2° and 10°. Good examples of these dips may be seen in the river cliffs northeast of Tioga Center, and along the highway west of the town. The northerly dips do not exceed 2° and appear along the branches of Pipe Creek.

The syncline to the south of the Elmira anticline is well defined in the southeastern part of the Watkins Glen quadrangle. The axis crosses Cayuta Creek about 3 miles north of Waverly; passing westward between Shoemaker Mountain and Narrow Hill it crosses Chemung River north of Wellsburg. Southerly dips along South Creek, Christian Hollow, and Bird Creek indicate the near approach of this synclinal axis to the State boundary in the vicinity of Bird Creek, beyond which it has not been traced.

Sabinsville anticline.—The axis of the Sabinsville fold runs nearly parallel with and just south of the State boundary, passing through the southern part of Waverly. The north dips, which in general do not exceed 2°, appear in the cliffs at Narrow Hill, west of Waverly; in Ridgebury Glen, south of the State boundary; and in a branch of Roaring River. East of Waverly they may be seen in most of the large exposures south of the Susquehanna as far east as Wappasening. South of the State boundary the south dips, ranging from 3° to 5°, may be seen along Wappasening Creek near Windham and opposite the mouth of Cayuta Creek east of Sayre. Farther west they appear just south of Willawanna, near old Bentley Creek post-office, and just south of Gilletts. After crossing South Creek in Bradford County the fold trends southwestward across Tioga County.

Folds in Bradford and Tioga counties, Pa.—The next anticline to the south is the Wellsboro. Its axis enters Bradford County, Pa., in Columbia Township, and runs eastward, crossing the Susquehanna between Milan and Athens, thus approximately paralleling the folds of the Watkins Glen quadrangle and in Bradford County not differing notably from them in the magnitude of the dips which characterize it. To the southwest in Tioga County, however, this fold increases in strength, showing maximum dips of 15° to 20°, and is bordered on each side by synclinal mountain ridges.

The anticline next south of the Wellsboro is the Towanda, bearing slightly north of east and lying about 18 miles south of the State boundary. The dips of this fold increase in magnitude from east to west and southwest more rapidly than those of the Wellsboro fold. At Susquehanna River the southerly dips are less than 10° as a maximum, but at Leroy they exceed 45°. The influence of the strong dips and correspondingly greater arches is most clearly registered in the physiography of the region. In the western part of the county, where the folds are most abrupt, are great synclinal mountain ridges—South Mountain, bordering the Towanda fold on the south, and Armenia Mountain and Mount Pisgah, separating the Towanda from the Wellsboro fold. East of Susquehanna River the folds cease, almost if not entirely, to affect the topography, because of their less pronounced arches.

General southerly slope of the beds.—As a result of the series of anticlines and monoclines already described the strata of the quadrangle generally lie at a lower level at the south than at the north, the difference amounting to several hundred feet. This is not the result of an approximately uniform rate of dip to the south, as has been generally assumed. On the contrary, the rocks rise toward the south on the north limb of each anticlinal fold. The angle of the dip of the southern limb is, however, as stated above, usually greater than that of the northern limb. In the Alpine anticline the southward dip is very much greater than the northward dip.

Between the south end of Cayuga Lake and Newfield the north and south dips about balance each other, the beds of a given horizon being at nearly the same level at these two points. The same is true of the dips of the beds in the Seneca Lake valley, those at similar horizons lying about as high at the axis of the anticlinal fold 2 miles south of Montour Falls as at College Point, 8 miles farther north. After crossing the axis of the Alpine anticline, however, a southward dip ranging from 3° to 8° brings the beds very rapidly toward sea level.

The southerly depression of the strata resulting from the influence of individual anticlines is augmented by the general monoclinal tilt of the rocks of these quadrangles toward the south. The combined result of these two structural characteristics is to depress the beds of any given horizon to a level several hundred feet lower on the south than on the north side of the area.

Age.—The synchronism of the small folds of southern New York which have been described and the great mountain folds of the northern Alleghenies seems to be indicated by all the data relating directly to the subject. Where the latter approach their extinction, as in the region east of Susquehanna River in Bradford County, Pa., they are closely comparable in magnitude with the New York folds. The general trend of the New York folds is parallel with that of the nearest of the Pennsylvania folds.

The Sabinsville and Elmira anticlines, which represent the adjacent folds of the New York and Pennsylvania series, have a common synclinal axis between them. These facts indicate that the comparatively insignificant folds of the southern New York quadrangles were developed by the same forces and at the same time as the Pennsylvania folds. Some of the latter have arches which, if restored, would rise 2500 feet or more above their troughs. Correlation of the folds of these quadrangles with those of the northern Alleghenies places the date of their development in the time of the Appalachian revolution which followed the Carboniferous period.

Local flexures.—Small anticlines of very slight extent occur somewhat rarely in the quadrangle. They show much heavier dips than the broad folds just described. An example of local disturbances of this class occurs in a ravine $1\frac{1}{4}$ miles southwest of Glen Aubrey. The beds involved are sandstones and shales of the Chemung formation. The axis of the fold follows the course of the stream, which is about east and west; on either side in opposite directions the strata are inclined at 15° to 20°. The beds are broken at the crest of the fold, making a sharp V-shaped fold, which is probably not more than 100 feet in width. Another example of local flexures occurs in the small ravine 1 mile northwest of Beaverdams. The beds involved in this fold dip about 15° on each side. The strata in the ravine just west of Spencer Lake are disturbed by two or more local folds, which affect the strata over a width of only a few yards. These local crumplings of the strata have doubtless been developed at various periods. Erosion has probably made some of them possible by removing overlying beds, thus permitting local relief from compression to develop local arches. One very small fold of this class has been observed in the face of a quarry 2 miles north of Elmira, on the east side of Newtown Creek. This arch affects only the highest beds exposed in the quarry face, bowing them upward into the overlying glacial clay over a width of a few feet. The projection of the arched and comparatively easily eroded bed rock into the glacial clay indicates the postglacial age of this disturbance; for it is improbable that the strata of the fold could have escaped removal by glacial erosion had it existed previous to the glaciation of the region.

FAULTS.

No faults of large throw occur within the quadrangles. A few small ones are known. One of these is exposed in the bank of Catlin Mill Creek, about $1\frac{1}{4}$ miles below Odessa. Another disturbance of similar character occurs at the mill dam on Sixmile Creek. The amount of throw in these places is unknown, but it is probably only a few inches.

A few small normal faults have been observed. The largest of these occurs in Glen Creek about 2 miles above the New York Central Railroad bridge. It appears in the south side of the gorge where the stream bends sharply to the east. The downthrow is about 20 feet. About 200 or 300 yards below this fault a small fault, having only about 1 foot of displacement, can be seen in the south bank of the stream. (See fig. 22, illustration sheet I.) In the bed of a stream three-quarters of a mile northeast of Alpine the strata are inclined for a few feet at an angle of 55°. The exposure is not sufficient to make certain what the nature of the disturbance has been, but it is probable that the tilting is due to a fault. In "Glen Chaos," Havana Glen, the strata, which have been bent upward by a local disturbance in the bed of the stream, are inclined at an angle of 38°. A vertical displacement of about 14 inches is shown in the beds along a small stream entering Tioughnioga River at Marathon.

JOINTS.

In common with nearly all indurated rocks, the strata of the Chemung formation are characterized by joints. Few of the individual joints, however, extend for any considerable distance either vertically or laterally. Many joints are confined to a single stratum. In the underlying Portage formation the joints are remarkably well developed. (See figs. 15 and 16, illustration sheet I.) The cliffs along the east shore of Cayuga Lake afford excellent examples of well-developed joint structure which the illustrations of Hall and Dana have made classic.

In this region the joints are vertical or nearly vertical fissures, in general not wide enough for the insertion of a knife blade. The intervals between the joint planes are extremely variable, ranging from a few inches to many yards.

Systems.—The joints of this region belong to two systems cutting each other usually about at right angles and trending within 10° or 15° of north and south and east and west. The variations in direction from the cardinal points within these systems locally amount to more than this, but most of the joints in the two systems vary not more than 5° or 10° from these points. A small percentage of the joints do not fall within either of these systems. A numerical statement of the conditions at an average locality will give a fairly correct idea of the small proportion of these erratic joints. In one of the small gorges north of Ithaca the north-south joints have directions varying between N. 8° E. and N. 2° W. Within a space of 85 feet there are fifty-three joints falling within these limits in direction; in the same distance there are only four joints which do not fall within the limits of the east-west or north-south system. While the intersection of the joints of the two systems is generally within a few degrees of a right angle, there is also variation in this respect.

The joints of the north-south system are at many places more perfectly developed and more numerous than those of the east-west system. At some localities, however, as along the east shore of Cayuga Lake, the two systems appear to be about equally well developed. At any one locality the joints of the same system are nearly parallel, the variation in direction as a rule not exceeding 3° or 4°.

The vertical and lateral limits of the joints are highly variable. Many joints disappear after extending a few feet in the face of a cliff or quarry. Others have great vertical and lateral extent. In the Taghanic Gorge, a short distance north of the Watkins Glen quadrangle, many joints are seen to be continuous from the top to the bottom of the gorge, a distance of 250 feet. That some of the joints descend to profound depths is suggested by the presence in them locally of dikes of igneous rock.

Most joints of normal type cut the rocks at right angles to the bedding, but there are local exceptions to this rule. In one of the quarries south of Ithaca most of the north-south joints dip toward the east at angles of 5° to 18° from the vertical. One of these joints consists of two planes, joining along a horizontal line and forming a wide angle; the upper one is inclined toward the east at 5°, and the lower toward the west at 17° from the vertical. At Taghanic Falls, a few miles to the northwest of the Watkins Glen quadrangle, the joints are inclined at 50° to 65° from the vertical. The inclined joints at Taghanic assume a vertical course on passing upward from the Genesee into the Portage beds. In the gorge above East Virgil is exposed a joint of a very unusual type which has not been observed elsewhere. This joint makes a double reversed curve. The presence in the East Virgil section of a bed of concretions composed of hard siliceous material, harder than the inclosing rocks, affords an opportunity to observe the variable behavior of the joints on coming into contact with concretions. Some of the joints continue across the concretion, cutting it exactly in the same plane which they follow in the adjacent rocks; other joints cut squarely up to the concretion on all sides and stop without entering it. In places the concretion is cut by joints which parallel those in the adjacent rocks but do not extend beyond the sides of the concretion.

Age.—The presence of dikes in some of the north-south joints affords a clue to the relative age of the two sets of joints. More than twenty-five small dikes have been observed to occur in the joints about the head of Cayuga Lake. These are confined to the north-south joints, not one of them being known in an east-west joint. It appears from this either that the east-west joints were closed by pressure at the time of the development of the dikes, or that east-west joints were not in existence when the intrusion of the dikes into the north-south joints occurred. If the latter hypothesis is correct it follows that the dikes and the joints which they fill are older than the east-west joints. It is a significant fact that the east-west system of of joints is parallel in direction with the axis of the broad folds characterizing this region, suggesting the possibility of their development by the same pressures which developed the folds. The latter are correlated with Allegheny folds which are of post-Carboniferous age. In the present incomplete state of knowledge concerning the origin of joints, this correlation of the east-west joints with the low folds in age and origin can only be stated as possibly true. If the hypothesis is correct the development of the east-west joints occurred just after the close of the Carboniferous period. The north-south joints were developed at some earlier time between Middle Devonian and the end of the Carboniferous. They may be dynamically related to the tectonic forces which at different times in the latter part of the Paleozoic era elevated parts or all of the Cincinnati anticlinal region.

QUATERNARY SYSTEM.

By Ralph S. Tarr.

GLACIAL ACTION AND TILL DEPOSITS.

WISCONSIN ICE SHEET.

During the last or Wisconsin stage of glaciation the ice spread over this entire region, leaving records of its presence in the form of till, transported bowlders, and glacial scratches on even the highest hills. The glacier extended into Pennsylvania for a distance of 45 or 50 miles south of the state boundary, which lies along the extreme southern border of the quadrangles. After halting there for a time and building a terminal moraine, the ice front began to recede, rapidly disappearing from the southern half of the quadrangles, but remaining in the northern half long enough to build distinct recessional moraines and other marginal deposits at successive stands of lower and lower level. (See fig. 11.) This morainic belt, described by T. C. Chamberlin nearly twenty-five years ago,[a] presents some interesting Quaternary phenomena and distinctly records the behavior of the receding margin of the ice sheet.

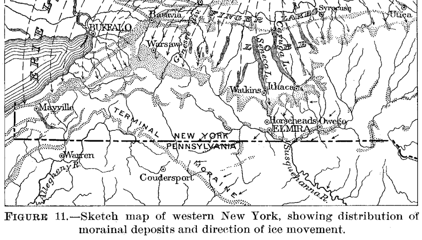

FIGURE 11.—Sketch map of western New York, showing distribution of morainal deposits and direction of ice movement.

From maps by Chamberlin, Leverett, Fairchild, and Tarr.

EARLIER ICE ADVANCES.

No direct evidence from glacial deposits has been discovered in this area to prove invasion of this region by ice sheets of a stage earlier than the Wisconsin. In numerous places discolored till is found beneath the surface layers, but invariably in such position as to lead to the belief that it is merely an oxidized belt along a zone of percolation. In none of these deposits are the accompanying pebbles more decayed than in the undoubted Wisconsin till. Till is frequently found resting on stratified deposits, but never on distinctly decayed deposits, nor in positions where the interpretation of an overriding of earlier Wisconsin deposits is impossible. Many of these occurrences are probably due to an overriding of marginal deposits accumulated during the advance of the ice.

In only one area have deposits been found whose origin during an earlier ice advance seems possible. These deposits occur (*a*) in the Cascadilla Creek valley near the South Avenue Bridge on the southeast corner of the Cornell University campus; (*b*) at Forest Home, in the Fall Creek valley; and (*c*) on the north side of this valley about a mile above Forest Home. All the occurrences are essentially alike and all are at points where sand for building purposes has been taken out. The sand, which is very compact, lies in steeply inclined layers, with some faulting and with an excellent development of vertical joint planes. The faults contain a deposit of carbonate of lime and the sand appears to be older than that in the deltas of the glacial lakes; but it is not noticeably decayed, nor are the pebbles more crumbly than is common in the sand banks of the deltas. At Forest Home the sand has an ice-eroded crest, above which is a layer of bowlders, mostly angular, with a sand matrix and some clay. (See fig. 33, illustration sheet II.)

As is shown in the section on "Physiographic record" (pp. 29–32), the through valleys and hanging valleys, as well as the marginal channels, furnish clear testimony of an earlier ice advance.

DIRECTION OF ICE MOVEMENT.

In most portions of the quadrangles the striæ are weak, short, and irregular, indicating weak ice movement and ice currents extending in various directions at different times. In many places a single outcrop shows movement in several directions without erasure of the older striæ. In the northern part of the quadrangles the striæ are longer, straighter, and deeper, being grooves rather than mere scratches. This is particularly true north of the recessional moraine, where the ice stood longer, moved more actively (being influenced by valleys), and was deeper than in the hilly country of the southern half of the region.

The direction of ice motion over the area as a whole was toward the west and southwest. In fact, in the southern half the ice movement was almost entirely in this direction and most of the striæ extend nearer west than southwest. This condition is interpreted as a result of the influence of pressure from the direction of the Catskill Mountains, modifying and deflecting the movement of the Adirondack-Canada ice sheet.

In the northwestern part of the area the striæ testify to a very different trend of ice motion, and in this respect they harmonize with the moraines. In the larger north-south valleys, notably those of Cayuga and Seneca lakes, the striæ show a close parallelism to the valley walls, proving that the valleys directed the ice movement when glacier tongues were projected up them. The evidence is clear that a great tongue swung into the Cayuga Valley from the northeast and moved southward along it, being locally deflected into the minor tributary valleys. Therefore, while at Ithaca the striæ point S. 25°–30° W., east of Ithaca, in the Fall Creek valley, they extend northeast, and southeast of Ithaca they point toward the southeast. On the nose of South Hill, in the southern outskirts of Ithaca, there are many striæ extending in various directions, showing the deflecting effect of this hill brow on the ice current, which split here, one lobe going southeastward into the Sixmile Creek valley, the other southward into the inlet valley. Both striæ and moraines prove great variation in direction of ice movement from place to place and, in the same situation, from time to time, as the ice edge thinned and the deflective influence of topographic features became more effective.

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[a] Third Ann. Rept U. S. Geol. Survey, 1883, pp. 353–363.

On the steepened slope of Cayuga Valley the striæ descend vertical rock faces. Just north of Ithaca, north of Fall Creek, for instance, a series of parallel striæ of definite character dip 13° S.; and a series of striæ on Quarry street dip 22° S.

GLACIAL EROSION.

Whatever was the result of possible earlier ice advances, the Wisconsin ice sheet failed to notably modify the topography in the greater part of this area. In all parts of the region, except in the northwest, the evidence on which this conclusion is founded is abundant and of several kinds.[a] First and most important is the presence of unremoved products of rock decay, not only on hilltops and lee slopes, but also on the stoss slopes of hills. In scores of places roadside cuts reveal disintegrated rock, most commonly in the form of residual clay beneath broken and weathered sandstone layers, bearing glacial scratches or polish on the upper surfaces. (See figs. 29 and 30, illustration sheet II.) The clay represents disintegrated shale beds between the sandstone layers, and that it has not been formed in postglacial time is proved by the distinctness of the striæ on the sandstone cap and the freshness of the till resting on it. The depth and extent of the disintegration point to the same conclusion. In many places the decay extends 3 or 4 feet into the rock, and not only is the shale reduced to a sticky clay, but the fossiliferous sandstone layers are honeycombed by decay along the weaker portions occupied by the fossils. The sandstone caps are so disintegrated that they are separated into small slabs by decay along the joint and bedding planes and can be easily removed by hand from over the residual clay layer. The plow often turns them up in regionsof thin soil; yet the glacier did not tear them off down to the fresh rock.

That the ice should not have removed this loose material is certainly remarkable in view of the evidence of profound ice erosion in the northwestern portion of the area, and can be accounted for only on the theory that the Wisconsin ice sheet in this part of the region was most inactive. As has been pointed out, this explanation is supported by the weakness and indefiniteness of the striæ. Apparently the ice was thin, of brief duration, and slowly moving in this region. The slow movement may have been due to the combined influence of the hilly topography and the situation of the region near the junction of Catskill and Adirondack ice. That the ice moved through some of the larger valleys with greater power and effectiveness is probable; but even there evidences of residual decay are occasionally found, and the topography of the southern half of the quadrangles does not suggest marked ice erosion.

Besides the presence of decayed rock in place in a few cuts, more widespread evidence of decay is furnished by the fragments of sandstone cap often turned up in the fields, and by the abundant weathered sandstone slabs that have been built into the stone walls. Angular cliffs, mantled with drift, are numerous on the hillsides and hilltops; not cliffs of plucking, but angular forms resulting from the denudation of the plateau before the Wisconsin ice advanced over it. These occur in all situations, at right angles to the ice movement and parallel to it. In harmony with this evidence of slight erosion is the fact that the mature upland divide areas have suffered notable modification only by deposition and not at all, so far as can be seen, by ice erosion.

In the northwestern portion of the Watkins Glen quadrangle, on the other hand, in the Cayuga and Seneca and numerous other valleys, the topography clearly indicates profound ice erosion. This topograpic evidence includes (*a*) a change in the valley slope, at about the 900-foot level, in the Cayuga and Seneca valleys, with a distinctly steepened slope below (see figs. 2–5); (*b*) the presence of hanging valleys at this level; and (*c*) the straight, smooth, almost undissected steepened valley slope below the 900-foot level.

From the very beginning of the study of glacial geology, the efficiency of ice in eroding the surface over which it passes has been a matter of discussion. The various workers have held widely different views, and the region of the Finger Lakes has been one of the American localities regarding which diametrically opposite views have been held. On the one hand, the hypothesis has been proposed that the smoothing of the hills north of the moraine, and the great depth and smooth sides of the Cayuga and Seneca valleys, with their associated hanging valleys, are due to profound glacial erosion resulting from the fact that these valleys were long occupied by active ice tongues.[b] On the other hand, it has been held that these features are due to stream and atmospheric work, with very little if any distinct modification from glacial erosion.

The discovery of a number of facts apparently opposing the glacial-erosion explanation of the topographic peculiarities of the Cayuga and Seneca valleys led the author to question it and to propose alternate hypotheses for consideration. A careful examination of these hypotheses, in the light of all the facts, has not only failed to verify them, but has brought forward overwhelming objections. The subject has been presented with some fullness elsewhere, and it does not seem well to repeat the discussion here.[a]

In summarizing the conclusions reached in these papers, it may be said that no other explanation than that of ice erosion seems possible for the topographic features observed. But it is clearly evident that this erosion was not wholly that of the Wisconsin stage. There was an earlier period of ice erosion during which both the Cayuga and the Seneca valleys were profoundly modified, both by broadening and deepening. Evidence of this action is afforded by the presence of hanging gorges, partly buried in Wisconsin deposits, their bottoms lying not far from the present level of the lake surface. These are evidently interglacial gorges cut in the bottoms of hanging valleys that were left hanging by overdeepening of the main troughs through ice scouring.

The major part of the valley modification seems to have been due to this earlier ice erosion. That the Wisconsin ice occupation modified the form and depth of the Cayuga and Seneca valleys very little, at least above the present lake levels, and that whatever notable glacial erosion there has been above the present lake levels must be associated with earlier ice advances, are indicated by the three following facts: (1) Just north of the Watkins Glen quadrangle, in the Portland quarry on the east side of Cayuga Lake, there is pronounced residual decay in the Tully limestone. This must antedate the Wisconsin ice advance, because the striæ produced during this ice advance are still left undecayed on the limestone blocks, between and under which the residual clay occurs. This occurrence, however, is at a point where vigorous ice erosion would hardly be expected, being only a short distance south of the junction of Salmon Creek with Cayuga Lake, on the outer bend of a pronounced elbow in the lake where there may well have been slack ice currents. (2) Below the steepened slope, in both the Cayuga and the Seneca valleys, there are numerous angular cliffs, with partial till or moraine cover, whose form is quite like cliffs resulting from subaerial denudation, but whose production by glacial erosion is in some cases inconceivable, even by the most remarkable form of plucking. That they could have been formed by subaerial agencies and have escaped destruction by vigorous ice erosion is impossible; yet the fact that they are covered by moraine and till proves them to have been formed before the deposit of these materials by the Wisconsin ice. (3) The older buried gorges, already described as cutting the lower steepened valley slopes, have not been erased by ice erosion. To illustrate by a single instance, the older gorge of Buttermilk (Tenmile) Creek, 2 miles south of Ithaca, is cut in the smooth, regular hillside on the steepened slope below the level of the hanging valley. In this respect, though larger, it resembles the postglacial gorge; but it is partly filled with Wisconsin drift, which proves it to antedate the advance of this ice sheet. Profound Wisconsin glacial erosion should have partly or completely erased this gorge; but, so far as can be seen, it has not been greatly modified by ice action.

For a while these facts seemed opposed to glacial erosion, but they are all readily explained by a double period of ice occupation. It may be confidently claimed, therefore, that all the facts favor glacial erosion, while no other explanation is free from fatal objection. This carries with it the necessity of believing in 1500 feet of vertical erosion in the Seneca Valley by the continued ice work of at least two periods of glacial occupation, separated by an interval of gorge cutting several times as long as the postglacial interval. Not only are the two main valleys ice eroded, but many of the smaller ones, such as the Sixmile Creek valley, Pony Hollow, and Texas Hollow, present convincing evidence of pronounced glacial erosion. This subject is treated further in the section on the physiographic record.

TILL SHEET.

Spread over most of the quadrangles is a veneer of till, or ground moraine, composed of a mixture of clay and larger rock fragments, even including some bowlders, whence the name "bowlder clay" often applied to it. Till is the common drift deposit of the region, being absent only from the steeper rock slopes and where covered by later deposits, as in parts of the morainic areas and in the larger valleys. It represents the drift that was dragged under and in the bottom layers of the ice and that was carried in the glacier and deposited when the ice melted. Where fresh and unweathered the till is blue in color, rusting to a yellow in the surface layers. Much of it is very hard and so compact that digging into it is difficult. Such till is locally called hardpan.

Although the till sheet is uniform in its general characteristics and origin, it varies considerably in depth and composition in the different parts of the quadrangles. In general the till cover is only a few feet thick, probably averaging less than 10 feet. It is deeper in the valleys than on the hills, where it is in many places only a few inches or a foot or two in depth. Wells from 10 to 20 feet deep usually pass through the till sheet to the rock almost everywhere in the district above the valley bottoms. On the uplands the thickness of the till sheet averages less than 3 feet, and over large areas rock outcrops almost continuously in the roadside gutters; and even in the fields the plow often reaches the bed rock. The till veneer is so thin and so smoothly laid that the bed-rock topography is rarely masked or noticeably modified.

There is much difference in the percentage of foreign fragments present in the till. Everywhere there is a large proportion of local fragments, but this proportion decreases toward the northwest, where both the number and the size of the foreign rocks increased. Some of these foreign rocks north of the outermost recessional moraine are good-sized bowlders, weighing several tons; and their noticeable difference from the local rocks is recognized by the farmers, who call them "hardheads." They include both fragments of sedimentary rocks from each of the Paleozoic horizons northward to Lake Ontario, and crystalline rocks, probably from the Archean of Canada, or possibly of the Adirondacks.

In the uplands south of the recessional moraines foreign fragments are much more rare, and in some parts of the uplands a careful search is required to find even a small pebble of crystalline rock, while bowlders are practically absent. On these uplands the soil is made of a mixture of till brought from a distance and of local fragments of sandstone, together with residual clay derived from the decayed shale. This association gives rise to a very peculiar soil, quite different from ordinary till, having in fact some of the characteristics of till and some of a soil of residual decay. Even in the region where this peculiar local soil is found, the larger valleys have more normal till, with a larger proportion of foreign fragments, indicating freer ice movement in these valleys.

VALLEY FILLING.

The valleys almost uniformly show a thickening of the drift sheet. In the northwestern quarter of the Watkins Glen quadrangle the valley filling is largely morainic; and in the rest of the area the larger valleys contain deposits that are in the main capable of definite classification as moraine, kame, esker, or outwash gravel. In the smaller valleys, however, there are deposits which it has not been found possible to classify definitely and which have been mapped as valley filling; such deposits occur also in many of the minor valleys where their extent is too small for mapping.

As a rule the valley filling is till, at least at the surface, though in places it is sandy and gravelly; and many cuts reveal a variation in character from top to bottom. Its chief characteristic is its greater thickness than the till sheet of the hills, as if it had been dragged under the ice into the valleys, locally completely obscuring the topography of the valley bottom and burying the gorges. In addition to its greater thickness and more variable structure, as revealed by stream cuts, much of the valley filling possesses a surface undulation of a semimorainic form, quite unlike the normal smooth surface of the till sheet. Outside of the belts of moraine, however, it is rarely possible to find morainic topography sufficiently strong in development to warrant definite classification of the material as moraine, though in many places there is a suggestion of morainic topography, but without any continuation out of the valleys.

Such irregularity is to be expected, and the remarkable feature is not that it is present, but that it is so imperfectly represented. When the ice melted from the upland, stagnant blocks must have lingered in the valleys, and surface wash upon them and against their margins must have combined with the drift in the ice to roughen the deposits in the valleys. The fact that these deposits did not more often assume the form of definite moraines and moraine terraces, kame deposits, eskers, and deltas, affords testimony that the ice of the uplands contained little drift and that its melting was very rapid. Pointing to the same conclusion is the fact that morainic topography and thickening of the drift are shown on few of the hills south of the belt of recessional moraines. Here and there are small scattered patches of drift, notably on the cols and in the upland valleys, locally with swamps behind them; but these patches are neither extensive nor continuous, and few of them are well defined.

DRUMLOIDS.

In several of the smaller valleys there are peculiar and puzzling forms of valley filling which, for reasons stated below, are interpreted as drumloids. They do not occur in all the valleys, but are abundant in some, especially in the southern half of the Catatonk quadrangle in the north-south valleys of medium size. In the Pipe Creek valley, north of Tioga Center, for example, there are fifteen, and also several in tributary valleys; and there are nine in the Big Choconut valley south of Vestal, besides a cluster of four at the mouth of the valley. They do not occur in the morainic area of the northwest, and no law of distribution has been discovered.

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[a] Tarr, R. S., Jour. Geology, vol. 13, 1905, pp. 160–173.

[b] For this view see Tarr, R. S., Bull. Geol. Soc. America, vol. 5, 1895, pp. 339–356; with full reference to earlier papers.

[a] For further consideration of this subject reference may be made to the following articles: Tarr, R. S., Bull. Geol. Soc. America, vol. 16, 1905, pp. 229–242; Am. Geologist, vol. 33, 1904, pp. 271–291; Jour. Geology, vol. 14, 1906, pp. 18–21; Pop. Sci. Monthly, vol. 68, 1906, pp. 387–397.

These drumlin-like hills occur in fairly broad valleys with mature slope, and project as spurs out into the valleys, though their longer axes are parallel to that of the valley. Many of them almost clog the valley, pushing the stream over to one side, where it is forced to cut a gorge in the rock. The result is the anomaly of a broad, mature valley abruptly narrowing and then broadening to its normal width below the obstruction. In places the stream is not forced over into the rock, but even there the valley abruptly narrows and broadens again; and in the narrows the stream is forced to cut against the drumloid, revealing a great depth of drift on the side of the drumloid, even though rock is bared on the opposite side of the narrows.

The drumloids vary in length from a few hundred yards up to half a mile, and where undissected by erosion have usually a fairly regular profile, similar to that of the normal drumlin, with the longer axis parallel to the valley walls, and a back slope toward the nearest valley wall, so that there is a distinct trough between the drumloid crest and the rock wall of the valley. In many places, though not in all, the contours represent this valley peculiarity. A few of the drumloids have a morainic topography over a part of their surface, especially at the south ends.

Careful inquiry at the farm houses situated on these drumloids disclosed no evidence of a rock core, though many of the wells are from 15 to 30 feet deep. Nor do the streams cut into rock in any of the drumloids which they trench. On the northernmost drumloids in the Nanticoke Valley, $2\frac{1}{4}$ miles north of Nanticoke, is a well 80 feet deep which passed through "hardpan" most of the way and did not strike rock. This well goes down below the base of the hill and the level of the stream. Here, at least, the drumloid is a drift deposit, and all evidence leads to the conclusion that others are of the same character. The well records and stream cuts prove a variable composition, much of the material being evidently till, but with some gravel and sand. Nowhere was evidence of older drift found.

These facts indicate the development of peculiar drumloid forms in some of the valleys, but do not make plain the reason for these drift deposits. The fact that they occur in valleys having an unusually deep drift filling, and the further fact that on the valley sides there are, in some places, faint undulations resembling a partly erased moraine, have led to the theory that the drumloids in these valleys are overriden moraines formed during the advance of the Wisconsin ice sheet and partly erased by its further advance. Otherwise they must have been built up under the ice in a region where the general drift sheet is very thin.

As has been stated, one of these drumloids is proved to be made up entirely of drift by a well reaching down to its very base; most of the others are so anomalous as to require the explanation of a drift obstruction in the valley. Still others, some mapped, some unmapped, are doubtful; and of this class are the forms mapped as drumloids east of Union in the Susquehanna Valley. On the uplands, in the mature divide areas, there are drumlin-like hills which may be either small drumlins or rock hills veneered with drift. They have not been mapped as drumloids because they occur in a region of thin drift and no well records have been obtained to prove whether they are drift or rock; but the form of many of them is that of a perfect small drumlin.

MORAINES, INCLUDING MORAINE TERRACES AND KAME AREAS.

MORAINES.

GENERAL CHARACTERISTICS.

The complex of moraines in the northern part of the Watkins Glen quadrangle and the northwestern part of the Catatonk quadrangle, contrasted with the general absence of moraines in the southern half of the area, forms one of the most striking features of the Quaternary geology. The maze of moraine deposits is the result of two facts—(1) that, as the ice was withdrawing from this area, it halted at several levels, and (2) that, owing to the pronounced irregularity of the topography, the ice front was exceedingly irregular in outline at each halt. The general absence of moraine material in the south and east is due to the fact that the ice melted from that area with no prolonged halts. Owing to these widely different conditions in the two parts of the region, it will be clearer to consider them separately. The boundary between the morainic and nearly moraine-free areas lies south of Seneca Lake and farther north in the valley south of Cayuga Lake. It also loops southward in the Sixmile Creek valley and southeastward in the Dryden Valley.

MORAINES OF THE UPLAND.

On the upland, south of the area of the recessional moraines, little moraine material is found and no definite system has been worked out. Indeed, it seems improbable that any system can be worked out, for, although moraine deposits are present in many of the larger valleys, nowhere except near Elmira and Horseheads have they been found leading out of these valleys toward the hilltops. The upland moraines consist of isolated patches, usually of small extent and slight relief. Doubtless they were formed in part along the ice front, during halts of very brief duration, but mainly in connection with stagnant ice during the period of general melting. The smoothness of the hills and general absence of morainic forms are certainly remarkable and testify to rapid and uniform melting over the entire area.

Much of the rock topography closely simulates morainic terraces and even sag and swell moraine, so that in places it is difficult to determine whether the topography is that of a moraine or that of the bed rock. In one locality, for instance, just east of Nichols, what seemed to be a good moraine was found to contain decayed rock a foot below the surface.

MORAINES OF THE SUSQUEHANNA VALLEY.

Outwash gravels constitute the principal glacial deposit in the Susquehanna Valley, but there are also eskers, kames, and moraines. The valley sides, where not too steep, have thickened drift on the lower slopes, and this material locally assumes the form of distinct moraine terraces. More commonly, however, its surface is roughened and shows a distinct sag and swell topography. There are also morainic areas in the valley bottom, but here the moraine simulates a kame and at times is a perfect kame. No morainic loops across the Susquehanna, no lateral moraines leading out of the valley, and no evidence of living ice tongues like those present in the northwestern part of the district have been found. All the phenomena, both of the moraine and of the stratified deposits, harmonize with the theory of stagnant ice blocks rather than active ice tongues. The interpretation that is placed on the drift phenomena of this large valley is, therefore, that during the recession of the glacier the ice was left stagnant over this region, and that after the hills were bared large blocks still remained in the valleys. Naturally the ice blocks remained longest in the largest valleys, and here marginal wash from the hills and from the ice accumulated drift which assumed the moraine form in a more or less definite way. The hanging fans, described later, apparently belong to this stage.

MORAINES OF POSSIBLE ICE FANS.

Between Wellsburg and Waverly there is much moraine material, which is especially well developed near the incoming streams from the north. It varies in topography from a regularly undulating surface to a typical kame moraine, with portions of which a series of esker ridges is associated. The morainic development opposite the stream mouths assumes the form of a bulb-shaped series of ridges, as if ice tongues, descending through these southward-sloping valleys, had spread out in fan shape on reaching the level Chemung bottom. This condition is best illustrated near the city of Waverly, which is situated between moraines apparently of this origin. On the western outskirts of Waverly there is a moraine with an apparent eastward-facing ice contact; and just east of the city there is a series of excellent westward-facing ice contacts rising with hummocky, kamelike fronts to the level of outwash gravel terrace tops. That there was an ice mass at this point, with its front facing eastward, can not be doubted; and yet it is hardly conceivable that an actively moving ice tongue pushed this far down the valley from the west, because the motion of the main ice sheet, as indicated by the striæ, was from the northeast. The only other explanation of the phenomenon is that, suggested above, of a nice fan from a tongue spilling down through the Cayuta Valley into the Chemung Valley, when the main ice sheet covered the hills to the north. The position of similar moraines opposite other streams farther west—Dry Brook, Wyncoop Creek, and an unnamed creek northeast of Wellsburg—lends support to this explanation; but it can not be considered demonstrated until further studies have been made opposite the mouths of other streams in the region to the east of the Catatonk quadrangle.

MORAINES OF THE ELMIRA-BIG FLATS REGION.

Leaving for the present the moraines north of Horseheads, which belong distinctly to the northern system, we may say that, from the western edge of the Watkins Glen quadrangle to its junction with the Susquehanna, wherever the slopes are not too steep for deposits to stand, the Chemung Valley is almost continuously bordered on either side by morainic accumulations. This valley-border moraine most commonly partakes of the character of a terrace of varying breadth and lying at different elevations, though generally at about 1000 to 1100 feet. It usually slopes from the hillside toward the valley, here evenly and there with distinct morainic surface. Where not cut away by subsequent erosion, its edge slopes smoothly, though it locally has a hummocky margin with distinct kettles, as if formed along an ice contact. In one or two places marginal drainage channels were found, as on the heights just west of the southern part of Elmira.

Very commonly the terrace broadens perceptibly where streams come down from the hillside, as at the mouth of Hoffman Brook in the outskirts of Elmira. In such places the surface has much the appearance of alluvial fan; indeed, at Hoffman Brook it is not easy to see where the modern alluvial fan ends and the fanlike moraine terrace begins. Cuts in these marginal terraces show great variety in composition, but stratified drift predominates, though it is rarely as well waterworn and stratified as in the outwash gravels and kames.

Both north of Elmira and west of Horseheads these marginal terraces are associated with a series of low morainic ridges, evidently terminal to ice lobes which extended into these valleys. These ridges are partly submerged beneath outwash gravels and have been in part worn away by the streams that brought the gravels. The mass between Horseheads and Big Flats interposes an effective barrier to the passage of the Chemung northeastward along that broad valley. These terminal-moraine deposits consist of broad, low ridges, some of gravel, some of till, and some of clay, many of them with distinct ice contacts toward the north or northeast. They are interpreted as proofs that at one stage an ice tongue from the Seneca Valley divided into two branches, one reaching Big Flats, the other Elmira, and that during their recession these tongues built other moraines in the middle of the valley, while at the same time moraine terraces were being constructed along the valley margins. The terminal moraine which enters the city of Elmira has a distinct ice-contact front toward the north for a part of its length; but toward both the west and the south it grades into an evenly sloping terrace top which apparently blends into an alluvial fan.

LATTY BROOK MORAINE LOOP.

Associated with these valley tongues was a smaller branch extending a short distance into the Latty Brook valley southeast of Horseheads. Here a remarkably perfect morainic loop, or terminal moraine, rising to a height of 80 feet, was built completely across the valley at a recessional stage, probably contemporaneous with the Elmira moraine. The brook, deflected from its course by this terminal-moraine loop, has cut a small postglacial gorge in the shale of its north bank; and just above this gorge, where the stream swings against the east base of the moraine, sand has slipped over the moraine clay in a series of landslides, giving rise to typical landslide topography.

OTHER MORAINES OF THE CHEMUNG VALLEY.

The morainic deposits elsewhere in the Chemung Valley are much more puzzling than those treated above, for the evidence is conflicting. In places the moraine terrace has the appearance of having been built at the margin of a stagnant ice block; but elsewhere the descending of moraine terraces and morainic belts from the hillsides suggests that they are merely parts of lateral moraines of active ice lobes which halted for a short period. The hill slope east and southeast of Elmira has such descending moraines, but they could not be traced far out of the valley. It is, of course, possible that there are moraines of both kinds, stagnant-block moraine terraces succeeding those formed by active tongues.

An ice halt of some duration in the Seely Creek valley is indicated at and near Webb Mills by a very typical kame area, one of the best developed in the region. The kames occur on both sides of the valley, but are most prominent on the east side, where they rise more than 200 feet above the valley floor, their upper portions, however, being built on the rock slope of the hill. Possibly to be correlated with the ice stand during which this kame area was made is the kame area east of Wellsburg. Here there is a succession of ice fronts facing westward; and on the south side of the valley, just east of Wellsburg, there is a series of high-level moraine terraces sloping down toward them. There seems little doubt that an active ice tongue, later becoming stagnant, extended eastward this far into the Chemung Valley, though the position of its margin across the uplands has not been traced. Its correlation with the kame area of Webb Mills is a matter of conjecture.

CAYUTA VALLEY MORAINE TERRACES.

Eastward-moving ice pushed from the Seneca lobe into the Cayuta Valley to a point some distance below Cayuta; and from the Cayuga lobe a westward-moving tongue reached a point 1 or 2 miles northwest of Van Etten. The proof of this is found in moraine terraces sloping in the direction of ice motion, and in partial loops across the valley where these terraces change to terminal moraines. Between these two points, and south of Van Etten nearly to Waverly, no evidence of active ice motion was discovered; but along the valley sides, wherever the slope is not too great, there are marginal terraces composed of a mixture of stratified and unstratified drift, as a rule decidedly modified through erosion both by the main stream and by its tributaries. These terraces are interpreted as morainic accumulations built along the margins of a stagnant ice block. In places they are undulating, but much more commonly they are smoothly sloping terraces trimmed by the erosion of Cayuta Creek.

In the north-south section of this valley, between Van Etten and Waverly, the terraces broaden opposite the mouths of most of the streams and are represented by what are interpreted as high-level or hanging alluvial fans. Cuts in these portions reveal distinctly stratified materials, and the surface form is smooth and regularly sloping like a truncated alluvial fan, with the top from 20 to 30 feet above the modern stream. The tributary streams that are believed to have built these fans, probably against an ice base, have cut trenches through them into which the heads of modern alluvial fans are now extending. The hanging fans grade into the irregular, thickened drift of the moraine terrace, in which the percentage of washed drift diminishes both away from the fans and from the valley margin toward the hill slope.

MORAINES NEAR HARFORD.

In the northeastern quarter of the Catatonk quadrangle there is a great deal of moraine material, especially in the valleys. Some of it, that near Harford and Franks Corners, is a part of the recessional moraine described in the next section, and some of it was evidently deposited in association with stagnant ice blocks. This seems true of the marginal deposits in the valley of the East Branch of Owego Creek between Harford Mills and Berkshire, and in the Tiougnioga Valley north of Killawog. These deposits vary greatly in character, but many of them are in the form of terrace-like deposits of gravel, as in the Tioughnioga Valley, where the rock terrace at the level of the hanging valleys usually bears a veneer of gravel with some morainic topography. The rock terrace of this valley gives the deposits the appearance of a pronounced moraine terrace, which is somewhat deceptive.

West of the Tioughnioga Valley, from Lisle to Hunts Corners and thence on to East Virgil, there is an area which contains considerable moraine material, but efforts to trace it as a continuous band failed. In places the moraine is strongly developed, as at Hunts Corners, where there are excellent morainic loops with eastward-facing fronts and level, gravelly tops back or west of the fronts. Similar though less perfect moraine deposits occur near Lapeer, in the valley next north of this, but no continuous moraine was found connecting these two areas. West of the Lapeer and Hunts Corners moraine area, in the valley leading toward Harford, there is some moraine material, which appears to be due to stagnant block conditions; and the same is true of the valley leading from Center Lisle westward to Richford.

It is evident that the key to the explanation of the moraines of this part of the area will be found to the east and north, and therefore that at the present time a definite explanation can not be offered. But, in view of (*a*) the direction of the striæ in the southeastern part of the Catatonk quadrangle, as contrasted with those in the northeast and northwest, (*b*) the eastward-facing loops, (*c*) the morainic front of the Lisle delta plain, and (*d*) the relative abundance of moraines in this northeastern section, the following hypothesis is tentatively proposed: This region is the area in which the Adirondack and Catskill ice bodies began to separate, when the receding glacier front had reached the stage of halting marked by the recessional moraines of the Cayuga and Seneca valleys. This hypothesis would explain the facts so far discovered, and as yet no other has appeared which seems to do so. It certainly is true that there are eastward-facing moraine fronts at Hunts Corners and Lapeer; and that at Franks Corners, 5 or 6 miles distant, there are northwestward-facing morainic loops; and there appears to be no local topographic influence sufficient to deflect a general ice sheet in this manner. If it can be demonstrated that Catskill ice influence extended this far, it will be an important point in the interpretation of the behavior of the American continental glacier during its waning stages.

SOUTHERN MINOR VALLEY MORAINES.

Most of the smaller valleys of the southern half of the quadrangles are free from distinctly morainic accumulations; but in some there are marginal morainic deposits and terminal loops that indicate the presence of active tongues of brief duration. The valley of Baldwin Creek illustrates this condition best of all. Across this valley there are several moraine loops, some well defined and kamelike, but all apparently formed during brief ice halts, as there are no definite and continuous lateral moraines rising out of the valleys. Leading from the moraine just south of North Chemung, however, is a distinct terrace, which rises to a height of about 200 feet, but whose lateral extension could not be traced.

Doubtless stream erosion has removed the evidence of some of the moraines of the minor valleys; but even with a very large allowance for this removal the general absence of moraines in the valleys of the southern half of the area is a striking fact, and markedly in contrast to the condition in the northwestern quarter. There certainly were not prolonged halts, and so far as the evidence shows there were not even brief halts in the recession of the ice. Every evidence points to stagnant ice melting rapidly and with little contained débris and consequently little deposit.

LATERAL MORAINES OF SENECA AND CAYUGA VALLEYS.

The Seneca and Cayuga valleys were for a long time occupied by ice tongues, which as they melted away, stood for a time at successively lower levels, leaving distinct moraines. The clearest and best-defined records of these ice stands are found on the west side of the Seneca Valley, where there are at least five lateral moraines, one above another, the three lower ones running straight along the smooth hill slope. The upper ones are more irregular because of the complexity of the topography. Topographic complication on the east side of the Seneca Valley and the west side of the Cayuga Valley prevents the simple, almost diagrammatic, parallel development of moraines found on the west side of the Seneca Valley. The two lower moraines, one at and near the 1000-foot level, the other about 100 feet higher, are not distinctly and continuously traceable on the east side of the Seneca Valley, and on the west side of the Cayuga Valley they seem to be merged into a single broad moraine. They vary greatly in material, from till to stratified drift, and in strength of development, from gently undulating sag and swell moraines to hummocky kame moraines opposite the lateral streams, which evidently supplied some of the materials that are built into them. Where they cross the larger streams, like Glen (Watkins) Creek, the moraines flatten out into broad terrace tops back of an undulating, kame-like front. Between the two bands of lateral moraines the surface is gently undulating, with scattered morainic hummocks and ridges, indicating that the ice did not drop from one level to the next absolutely without halting.

These two lower lateral moraines follow almost along the contour of the valley side, the lower moraine scarcely descending at all in the 9 miles north of Watkins Glen, while in the same distance the next higher moraine descends less than 200 feet. This difference in rate of descent of two neighboring, nearly parallel moraines is doubtless due to the fact that the higher moraine was built when the ice was less distinctly under the influence of the inclosing valley. In both moraines the rate of descent is remarkably slight, and strikingly in contrast with the rate at which the ice margins descended into other, smaller valleys. The broad, deep Seneca trough, into which the ice crowded, with movement parallel to the valley walls, seems to have been favorable to the presence of a tongue whose marginal slope was exceedingly slight. At this lower stand the ice may possibly have been floating at its lower end in the ice-dammed lake waters.

The higher lateral moraines are far less regular and simple, but they, too, indicate a very moderate slope for the Seneca tongue. Their lack of simplicity is due to the fact that hills rose across the path of the ice, forming nunataks at some of the stands, while the broader valleys of the upland caused a deflection of the ice margin up lateral valleys and, in some places, like Johnson Hollow, across divides and down the valleys. These conditions, combined with the fact that in crossing such valleys two neighboring moraines may swing together, account for the complex of moraines developed southwest of Watkins and Ithaca.

On both sides of the valley, from Watkins to the northern boundary of the quadrangle, there is absolutely no development of morainic deposit below the 1000-foot moraine, and the same thing is true in the Cayuga Valley.

FRAYED MORAINES.

Where moraines descend to cross a lateral valley, they usually slope steeply, in many places descending as much as 100 or 200 feet in less than half a mile. Though a continuous band on the hillside, the moraine does not descend as a single ridge, but as a series of diagonally descending ridges radiating, fan-shaped, from the hillside moraine. Thus a moraine which on a hill slope occupies continuously a space of less than one-fourth of a mile, with a vertical distance of say 100 feet, may fray out into a dozen or more moraine strands spread over a space of 1 or 2 miles. Where best developed these frayed moraines somewhat resemble a rope, the strands of which are untwisted and spread apart. The surficial geology maps show many illustrations of these frayed moraines. Examples are on the hillside north of Bennettsburg and where the moraine crosses the valley at Mecklenburg.

The separate strands represent halts in the retreating tongue which extended into the lateral valley. The ridges of which the main-valley moraine bands are composed are undoubtedly the correlative of the strands; but these ridges are usually so close together and so interwoven that they can not be separated and correlated with their respective strands in the lateral valleys. How many times a foot of vertical oscillation in the main valley tongue is multiplied in the horizontal oscillation of the lateral valley tongue, as indicated by the moraine strands, is uncertain; but it is evident that the amount varies with the width of the deflecting valley, the slope of its sides, its bottom slope, and the angle and direction of ice approach. The morainic loops of the larger valleys, described in later sections, are closely related in origin to the conditions which give rise to these frayed moraines.

As in other portions of the moraine, the materials of these morainic strands vary greatly, from till on the one hand to stratified drift on the other. They vary also in height and breadth, as well as in details of form. Usually they are distinct ridges with undulating crests not over 20 or 30 feet high. Many of them show distinct evidence of stream erosion, doubtless caused by streams marginal to the ice tongues. In some places the strands have the appearance of erosional forms, as if a sheet of morainic drift had been carved diagonally by streams descending the hill slope along the terminus of the ice lobe; but more commonly they are evidently in the main constructional forms.

MORAINES OF LATERAL ICE TONGUES.

The larger tributary valleys served to deflect the ice lobes so much farther that in them the distinctively frayed appearance of morainic strands is lost. The best and most typical instance of this influence is in the Odessa Valley southeast of Montour Falls; but the Moreland Valley southwest of Montour Falls also illustrates it, though here its effect is somewhat masked by the north-south continuation of the through valley into the southward-sloping Johnson Hollow, which led the lateral lobe in the direction of movement of the main valley tongue.

Into these larger valleys the ice swung by rather steeply descending slopes, indicated by moraines and in many places by by distinct morainic terraces, which, where crossing the valleys, are represented by crescentic morainic loops, with hummocky and kame fronts, against which the ice rested. In the Odessa Valley there is a succession of these terminal loops, connected with the ice stands of various levels, from a point just west of Odessa, where the lowest moraine crosses the valley, to a point about midway between Alpine and Cayuta, where the highest moraine crosses. The lowest moraine is here at about the 1000-foot level, and the highest at about 1800 feet on the hills. As this distance is about 6 miles, it is evident that a vertical oscillation of about 800 feet is represented in a valley of this kind and position by a horizontal oscillation of the ice tongue of about 6 miles.

MARGINAL LAKES.

Each of the halts of these successive ice levels interfered with the preexisting drainage, which was without doubt westward in the Odessa Valley before the advent of ice. With the natural direction of outflow blocked by active ice, the ice front was necessarily faced by standing water, into which was poured débris from the glacier, as well as that brought by marginal drainage and by land streams, filling some of the lakes completely and others partly. Where the lakes were completely filled the terminal moraines rise to a level terrace top, as in the region east of Odessa; and some of these terrace tops, usually made of outwash gravel, have been raised still higher by alluvial-fan deposits brought by the marginal and land streams. Where the marginal lakes were not completely obliterated, as in the valley south of Wedgewood, the deposits of gravel and clay have leveled the valley floor somewhat, and the site of the lake outlet is marked by a distinct overflow channel.

In some places the lake filling is further represented by the presence of distinct deltas, a stage between the two just described. One of the best instances of this is that of a lake, just north of Odessa, which was held up in the lower end of Texas Hollow for so long a time that a subglacial stream flowing from the west built a very perfect delta with an area of half a square mile. Similar to this is the development of delta plains in and around Breesport, built when a side tongue of ice entered the Newtown Creek valley from the west, holding up a lake whose outflow was southward into Baldwin Creek behind a morainic ridge on the divide. This delta plain has a morainic ice-contact front toward the west, correlated with the ridge just mentioned, and a delta front toward the east. As the ice tongue was lowered, another more extensive plain of outwash gravel was built behind it and at a lower level, with an outflow across the Baldwin Creek divide, which was not yet entirely freed of ice. For a mile or more this remarkably level gravel plain fills the valley from side to side, except where cut by the present stream.

In the Watkins Glen quadrangle there is every gradation from complete lake filling to the partial filling of a very temporary lake stage; and from a study of the deposits it is evident that marginal lakes were a prominent feature of the ice stands across these lateral valleys. In one place only is this lake filling demonstrated, by the presence of an esker, to be connected with subglacial drainage, though doubtless such a connection existed at many places, the feeding esker having been buried beneath later moraines and associated lake filling. The esker-fed delta just mentioned is about 1 mile east of Burdette, where a small but very perfect esker ends in a gravel plain whose western face is that of an ice contact, while the northeastern face is that of a delta. This condition did not last long enough to fill the lake completely, nor quite to connect the delta with the moraine front of the next higher stand.

TERMINAL-MORAINE LOOPS.

One of the most striking features of the morainic topography of the area is the development of pronounced terminal-moraine loops across the valleys wherever the ice stood long enough.

About halfway between Bennettsburg and Reynoldsville there is one of these loops, concave toward the north and therefore formed by a tongue from the north. It stands as a barrier part way across the valley, and near its center rises to a height of about 100 feet above the valley floor. It is a single ridge, undulating and kettle-like on the top and composed largely, if not entirely, of stratified drift. Toward the east this terminal-moraine loop ends abruptly where cut by the stream, and it is not represented by a well-defined moraine on the east side of the valley; but toward the west it broadens and ends in a very pronounced moraine terrace which rises into a distinct moraine area on the western hill slope. Both north and south of this exceptionally fine loop are others less well pronounced, extending down the hillside, finger-like, as frayed morainic strands from the massive hillside moraine.

North of Reynoldsville, in the same valley, are two other terminal loops representing later ice stands. These are not single ridges but a complex of kame hills, and the northern one was fed by an esker, which may account for the fact that its form is so different from that of the loop just described.

A very perfect morainic loop crosses the Taghanic Valley at the village of Mecklenburg. Both east and west of this valley a morainic band is easily traceable for a considerable distance. This band descends into the valley very steeply from the west and rises again toward the east, and it is followed for about a mile by the Mecklenburg-Ithaca highway. Where it descends into the valley, however, this single moraine breaks up into several strands, each bending at a slightly different angle up the valley, so that the moraine on each side of the valley has somewhat the appearance of an arm with outspread fingers on the end. It is a notable fact that the strands do not extend far up the valley, this proving that the valley deflected the ice very little.

Northeast of the Mecklenburg loop and east of Perry, at the northern border of the Watkins Glen quadrangle, a very pronounced morainic loop, fully 60 feet high, extends across a small valley. This is a smooth, regular till ridge, almost esker-like in its form, along the crest of which a road runs. Similar to this ridge is a very perfect single moraine ridge which forms a loop across Buttermilk (Tenmile) Creek about 5 miles south of Ithaca. It both broadens and weakens in development on the hill slope, like the other loops. Indeed, the Buttermilk loop, strongly developed and perfect though it is, extends into a moraine which is lost among the hills farther southwest.

There are in the area many other terminal-moraine loops with characteristics similar to those just described. Most of these are, however, less well developed, and some of them, as already stated, are backed by plains where marginal and subglacial drainage have succeeded in filling the lake held up by the ice. Why there should not be similar flats behind other loops described in this section is not clear, for at some of them, for example, the Buttermilk loop, there was unquestionably a lake dammed back in the valley across which the loop was built. Either the supply of sediment must have been meager or the length of time occupied in building the loop brief.

UNEQUAL DEVELOPMENT OF MORAINES OF VALLEY LOBES.

The moraine formed at any one halt of a valley lobe is, as a rule, much better developed on one side of the valley than on the other. For example, northeast of Odessa there is a remarkably perfect kame moraine, whereas the moraines of the same ice stand south of Odessa are either weakly developed moraines of the sag and swell type or else are morainic terraces of no great width. There is probably from twenty to thirty times more material in the moraine of the north side than in that of the south side. In the valley east of Burdett the same condition exists; but here traces of moraines have not been detected on the south side, though numerous well-defined morainic strands descend the hillside on the north valley wall. Near the northern border of the Watkins Glen quadrangle just south of Logan, six good moraines descend the eastern hillside, but none could be traced out along the western side.

This condition is essentially universal and is undoubtedly the result of the operation of a law governing morainic accumulation along the margin of valley tongues. This law seems to be that the least morainic development is on the side which has the least supply from the ice and from the marginal drainage. (See fig. 12.) On applying this principle to the Odessa Valley, it is evident that the lobes entering that valley offered a much longer course for marginal streams on the north side of the tongue than on the south side. The streams on the south side headed on a divide from which water flowed southward along the margin into the main valley, and by a short course into the Odessa Valley. This short journey along the margin of the lateral lobe was not sufficient for the streams to gather much drift for transportation. Moreover, the ice movement itself was unequal, that on the north side being a continuation of the southward movement of the drift-laden margin of the main valley lobe, that on the south side being supplied from ice that was freer from drift. The influence of supply from the land streams may in some localities modify the unequal development of moraines, which is one of the most striking morainic features in these quadrangles.

Unequal effects of marginal drainage and ice supply, similar to those just described, account for the fact that morainic bands lose distinctness and are even not traceable across some of the divides, or, where traceable, repeatedly change from kame areas of stratified drift to low ridges and hillocks of sag and swell type, composed mainly of till. In such moraines the influence of marginal drainage is reduced to a minimum, and the dominant and often the sole cause for morainic accumulation is the melting out of rock fragments from the ice front.

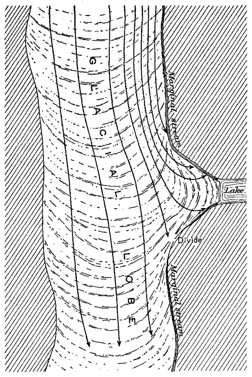

FIGURE 12.—Diagram illustrating unequal supply of morainic material from ice and marginal drainage on two sides of a minor ice tongue.

MORAINIC COMPLEX BETWEEN CAYUGA AND SENECA VALLEYS.

Because of the effect of the irregular topography on the several ice stands, the moraine between the Cayuga and Seneca valleys seems to have little system. Some of the morainic bands have been traced for several miles; others have been lost in crossing the valleys, into which they descend as a series of morainic strands that have distinctive character on one side but are either very faintly developed or entirely absent on the other. Into each of the valleys the ice of each stand sent tongues, each moraine dividing into a series of strands or loops. The distance to which the ice extended into the valleys varied here, as elsewhere, according to the direction, slope, and width of the valley and the direction of approach of the ice.

Into many of the valleys ice tongues extended from both directions. In the Reynoldsville-Bennettsburg valley, for example, ice descended as an active tongue from the north, building terminal moraines to a point within $1\frac{1}{2}$ miles of Bennettsburg, while a side tongue from the Seneca Valley extended up to a point above Bennettsburg. In the same way an ice tongue from the north reached far down the Texas Hollow valley, while a tongue from the Odessa valley extended northward some distance into it. The Enfield Valley also had an ice tongue from two directions, the north and the east. Well-defined terminal moraines prove these conditions, though it has not been found possible to correlate the moraines of any one period in opposite ends of the valleys.

High-level terraces and other moraines prove that the ice moved freely through some of these valleys at an earlier stage; and thickened hillside deposits, many of which are of a morainic character, suggest the presence of stagnant ice blocks between the period of active movement through the valleys and the period of halting tongues entering from both ends into them. This complex history explains why the moraines of this area are so complicated and undifferentiated.

COALESCING OF ICE TONGUES.

A morainic loop in the Enfield Valley, about $1\frac{1}{2}$ miles south of Enfield, is peculiar in the fact that it is doubly crescentic, with concave faces toward both the north and the south. Moraines on the valley sides lead toward it from both directions, so that the loop has the distinct appearance of having been built by two almost coalescing ice lobes.

About 2 miles southwest of Newfield the coming together of two tongues is suggested by the morainic deposits. At an earlier stage a lobe extended down to the head of the Pony Hollow stream, building a distinct hummocky terminal moraine and outpouring the gravels which have made the outwash plain in that valley. When the ice melted back to the fork between the valleys of West Branch and Butternut Creek, it seems to have stood for a while, the two tongues in those valleys almost coalescing, and in the angle between the tongues a delta-terrace mass of stratified drift, in places a true kame, was accumulated. Later the two tongues separated and built distinct terminal moraines farther north in each of the valleys. Such partial or complete coalescing of ice tongues must have occurred frequently in a region of irregular topography like this, though in most places it is difficult to demonstrate its occurrence.

MORAINIC FANS.

On the eastern slope of the Enfield Valley, about 2 miles north of Enfield and just north of Applegate, there is a very peculiar accumulation of morainic drift. Near the divide it is mainly till, deeply dissected by valleys, in some of which there is at present very little water. The amount of dissection and the number of valleys, are out of harmony with the present water supply. Farther down the slope the drift is more morainic in topography and contains a much larger proportion of stratified material, and near the base it is largely stratified. A fairly well defined morainic band extends up to this divide from both the north and the south. A similar accumulation, in the same topographic situation, occurs about 4 miles northeast of Cayuta Lake, and less well defined morainic masses of similar character are present in a number of other places on the slopes below broadly open divides.

These accumulations are interpreted as the deposits from hanging glacier tongues, which extended across the divides when the edge of the main valley lobes rested at a level just above the divides, and from which débris-laden waters escaped, both depositing and eroding. The name *morainic fan* for these deposits was suggested by M. L. Fuller, who crossed the Enfield locality with the writer.

NUNATAK MORAINES.

During the several ice halts it frequently happened that isolated hills or groups of hills projected through the ice as nunataks, and on them, during these stages, numerous moraines were accumulated. These deposits range from till ridges to hummocky kame moraines, and they vary greatly in position. Many of the moraines cap the hilltops, making nunatak moraine caps, formed apparently when the hilltops barely rose above the ice. Some of these caps are single ridges, some sag and swell moraines, some merely thickened drift in which, as in one locality west of Reading Center, wells 30 feet in depth fail to reach the rock.

Other hills rose so far above the ice that morainic collars were built around them. These nunatak moraine collars are not developed uniformly, but as a rule thicken toward the lee side of the hill, where they form great masses, in some places of irregular till and clay, and in other places of gravel with kame topography. These lee-slope accumulations are not always connected with a traceable collar. Three miles northeast of Sullivanville, for example, there is an extensive kame area, which is interpreted as a deposit in the lee of a nunatak, to which no moraine has been traced. Where collars have been traced around the hills their slope is always downward toward the lee side deposits.

On the north end of the hill which separates Texas Hollow from Smith Valley there is a morainic accumulation which is either a nunatak deposit or else the moraine formed between two lobes, one extending into Texas Hollow, the other into Smith Valley, but, owing to the steepness of the slopes, leaving no moraine record on the hillside. This high-level moraine on the north end of the hill, possibly a nunatak deposit, is prow-shaped at the north with a perfect marginal channel extending toward the southeast and a marginal collar back of it. The ice evidently split against this hill, but whether it united farther down on the hilltop or extended in lobes into the neighboring valleys has not been determined.

MORAINIC COMPLEX IN THE UPPER CAYUGA AND SENECA VALLEYS.

All the moraines of the northern part of the Watkins Glen quadrangle are records of ice stands of two lobes, one extending up the valley of Cayuga Inlet, the other up the valley of Catharine Creek, the inlet to Seneca Lake. Between the principal ice stands, indicated by the lateral moraines and by the loops across the lateral valleys, there were series of lesser halts too brief to make definite and continuous records. There were probably also oscillations of the ice front. In the main valleys, where the ice movement was freest and its erosive work consequently greatest, this complex history made possible the deposit of a very extensive and complicated series of moraines; and the fact that these northward-sloping valleys were occupied by ice-dammed lakes, in which the ice fronts stood, renders the morainic accumulations still more complicated. It is these extensive and striking masses of morainic deposits (see fig. 27) which have been most often seen and correlated with the moraines farther east and west. They represent the concentrations, in two long, narrow valleys, of terminal deposits of several closely associated recessional moraines which are attenuated and spread apart on the inclosing valley slopes.

The hillside or lateral moraines, previously described, develop into moderately sloping moraine terraces near their ends, and locally into a series of well-defined ridges, rapidly descending into the main valley. Examples of this condition are found at Nina, south of Ithaca (see fig. 28, illustration sheet II), and south of Havana Glen, in the Seneca Valley. Where the slopes of the main valley sides are very steep, descending lateral moraines are absent; but on the more moderate slopes they are usually represented by well-defined moraine terraces, generally composed of gravel, and near the tributary valleys broadening into fanlike plains. These descending moraines and moraine terraces are found nearly as far south as Horseheads in the Seneca Valley and Spencer Summit in the Cayuga Valley; and from these points northward, nearly to the northern limit of the valley moraine, all the moraines in the valley bottom are confidently correlated with the several lateral moraines already described.

No traceable lateral moraines lead from the extreme northern portions of these areas of valley moraines, and these portions are therefore believed to have been formed by ice stands so brief that, while terminal records were possible, definite lateral moraines were not made. Beyond the southern margin of these massive valley moraines, near Spencer Lake and Horseheads, there are distinct morainic areas, already described as rising above the outwash gravel plains. These are correlated with the highest moraines of the series, thus representing the earliest stand of the ice and the most southerly prolongation of the lobes of which traceable records have been left on the hills.

That the morainic complex in the valleys is very deep, though the exact depth is not known, is proved by the following well records. A well 1 mile east of Pine Valley found no rock at a depth of 104 feet; one at Millport found no rock at a depth of 187 feet; and one on a morainic hummock at Cook Academy, Montour Falls, found no rock at a depth of 436 feet. The moraine topography is exceedingly irregular, some of the hummocks and ridges reaching a height of 200 feet above the valley bottom; and there are many deep kettles, some of which contain small ponds and swamps. Stream erosion has in places deeply dissected the unconsolidated morainic deposits, adding greatly to the topographic irregularity.

All kinds of glacial drift are to be seen in these moraines, though stratified clay, sand, and gravel predominate, but till is revealed in many of the cuts. These materials are confusedly placed together, and a single small cut may reveal two or three types of drift. Much evidence of movement subsequent to deposition is also found, both in the occurrence of small but abundant faults and in crumpling of the layers. The brick clays at Newfield, for example, are highly inclined and crumpled and contain slickensided surfaces along which the clays have slid in faulting. These movements are doubtless due in part to settling after deposition, as by the melting out of stranded ice blocks, and in part to ice shove, either by the main ice lobes or by floating bergs. There has also been much modern slipping where undermining through stream erosion has established unstable conditions, allowing sand masses to slide down over underlying clay, or parts of clay beds to slip along sandy planes of stratification. This often gives rise to remarkably perfect landslip topography.

The morainic complex of these two valleys exhibits three very different characteristics from south to north. In the south the lateral-moraine terraces extend into perfect terminal-moraine loops, as in the vicinity of Pine Valley, in the Seneca Valley, and just north of Spencer Summit, in the Cayuga Valley. The latter is the most perfect and typical, being a well-defined crescentic ridge, concave northward, and with outwash gravel terraces extending southward from each end. The distinct ridge form disappears near the middle, being replaced by a maze of kames with many gravel hillocks and deep kettles. There are one or two less perfect terminal-moraine loops just north of this one.

Moraines of a second type, occurring immediately north of these loops, consist of a series of broad, rather flattened ridges, roughly crescentic, with concave faces toward the north and with crests reaching a nearly uniform level. These are interpreted as the result of ice stands in a lake of sufficient duration to build the moraine to the level of the lake surface but not to fill the lake completely and make a plain. This belt of moraines is not very broad.

North of this belt, and constituting the bulk of the valley moraine, is a veritable morainic jumble, in which almost no system can be seen up to the level of the lateral-moraine terraces, which were built above the level of the glacial lake. The hummocks rise to various levels, and, while there are numerous ridges extending out into the valley, there are no distinct terminal loops. An approach to terminal-moraine loops is, however, to be found at several places, as between Nina and Stratton, between Stratton and West Danby, and at West Danby, where the moraine hodgepodge is more massive and better defined than elsewhere. But excellent moraines occupy the entire area between these places of greater morainic development.

The irregular, indefinite form of the hummocks and ridges, the exceptionally large proportion of stratified clay, and the position of the deposit in a northward-sloping valley whose divide is higher than the crests of the morainic hummocks prove that the moraines of this third type are sublacustrine in origin. Their marked irregularity of structure and form and the absence of definite terminal loops indicate that varied and, in part, unusual conditions were involved in their formation. Among these conditions were standing water, rapidly moving currents and eddies near the ice margin, direct dump of débris from the ice, inwash of sand and gravel from marginal and subglacial streams, ice shoving, the shove of grounding icebergs, and the melting out of buried ice blocks. Such a complex of conditions suffices to account for the jumble of moraines in this section. The great length of the morainic area is readily understood when one considers the fact that this valley moraine represents the effect of the horizontal oscillation of an ice lobe during vertical shrinking of several hundred feet, as registered by the hillside lateral moraines.

RECESSIONAL MORAINES OF EASTERN TRIBUTARIES TO CAYUGA VALLEY.

The great maze of moraines in the eastern tributaries to Cayuga Valley seems very complex. So it is, in fact, though there is, nevertheless, a distinct system in it. Briefly, this system is the result of a series of halts in a region of irregular topography, in which each valley deflected the ice front more or less at each halt in the recession. Owing to the fact that ice motion was interfered with by the topographic features in some places and accelerated in others, and to the fact that deposition along the ice margin was greater at some points than at others, the morainic records are not everywhere of uniform clearness. In some places no recognizable record is left in one part of an ice stand which in other parts has left a record that is remarkably clear. The principal causes for these irregularities of record have already been stated topically; for this particular area the recessional moraines will be treated in order, beginning with the earliest.

When the ice front first began to halt across this area, it consisted of a series of prominent tongues and several minor ones, connected by ice which swung up across the hills. It reached farthest south in the Cayuga Valley, coming down nearly to Spencer. A minor tongue extended into the Michigan Creek valley, and another down the Danby Creek valley to the Tompkins-Tioga county line. In the Willseyville Creek valley the tongue reached halfway down the valley between White Church and Willseyville. There was a tongue extending eastward in the Sixmile Creek valley beyond Slaterville Springs; another southeastward to Harford, in the Dryden-Harford valley; and another in the Virgil Creek valley to the neighborhood of Franks Corners. In several of these valleys outwash gravels were poured forth and carried downstream by the ice-born floods, and in all of them outflow streams found their way across divides to southward-flowing drainage. These phenomena of outflow streams and outwash gravel plains are described under other headings.

The stand east of Slaterville Springs was in a westward-sloping valley, but the glacial deposits graded this up, forming a broad outwash gravel area, the Caroline flats, faced on the west side by a steeply rising morainic front, against which the ice rested and from which distinct moraines may be traced, especially toward the north. Doubtless at first the site of the Caroline flats was a lake; but in the last stages it was a graded plain down which the glacial streams flowed, and which now is the divide between Sixmile and Owego creeks. Under the gravel deposits are probably buried moraines, for lateral moraines lead down to the flat.

In the Harford Valley there are broad lateral-moraine terraces, nearly level, but in places with undulating crests, indicating here a condition of nearly stagnant ice with the deposition of moraine terraces along its margin.

These outermost morainic deposits are clear and well defined in the valleys, indicating, on the whole, distinct movement of the tongues and abundant supply of drift from the ice, ice-born streams, and marginal drainage. The form of the terminal deposits varies greatly from place to place; moraine terraces, well-defined loops, areas of kame moraine, and level terraces with morainic front may all be seen. With this variation, however, there is one uniform feature—the presence of ice-contact fronts to the moraine, which crosses the valleys in crescents, concave toward the north or west, the direction from which the ice moved.

Back of the outermost moraines are others that are roughly parallel, indicating brief halts in the receding tongues; and between these successive terminal loops is a continuous development of moraine material with greater or less perfection of form, proving that the ice receded with sufficient slowness to leave a continuous record, but halted a little longer here and there. This intermediate moraine, best developed in the largest valleys, like the Cayuga, Sixmile Creek, and Dryden valleys, is in many places hummocky and kettle-like, and locally even consists of true kames, a condition due doubtless to the deposition of drift in marginal lakes, or on parts of the ice which were cut off from the main tongue and which on melting gave to the drift its irregular topography. It is believed that Dryden Lake occupies a large kettle on the site of such an ice block.

That the ice recession from these valleys, although slow enough to leave a continuous deposit with records of halts, was nevertheless fairly rapid, is proved by the fact that the valleys are not completely graded up with deposits. Had the ice stood long enough across these valleys, whose slope was toward the ice, they would inevitably have been filled and graded, as was the area east of Slaterville Springs. An approach to this condition was reached in the Dryden Valley, where there are broad terraces on either side of the valley, especially opposite the side streams. These terraces become morainic or kamelike toward the middle of the valley, where stagnant ice would be deepest and linger longest.

That the moraines of the outermost stands of the ice have not been traced from valley to valley across the hills, although carefully searched for, is apparently due to several facts. First, even well-defined valley moraines lose distinctness in crossing the hills, as is pointed out below in the description of a moraine that was traced from valley to valley. In the second place, the topography is very rugged, some valley slopes being too steep to hold drift, and there is much wooded area in this region, in which faint hill moraines would be almost impossible to detect. The irregular topography must have split the ice into various currents, retarding it in many places on the uplands, thus diminishing the possibility of its leaving definite records; and from the evidence in the valleys it is known that the ice was receding with some rapidity, so that the ice margin among the irregular hills must have been variable as well as impotent. Altogether, the absence of moraine bands across the hills, though disappointing, is easily understood.

The highest moraines of these recessional stages pass northeastward from the Catatonk quadrangle just east of Franks Corners, where there is a very perfect moraine at an elevation of about 1900 feet, which, however, could not be traced to the exact border of the quadrangle. Associated with this moraine is a marginal channel. West of it, just east of Dryden, a moraine has been developed around an 1800-foot hill, which apparently rose as a nunatak while the ice swung down into the Virgil Creek valley, forming a great mass of terrace-like moraine with westward-facing fronts. This stand was evidently later than that represented by the 1900-foot moraine just described.

With the recession of the ice front there were several halts at lower levels, giving rise to complex morainic topography in places, notably north of Slaterville Springs, where ice moving from the west through Sixmile and Cascadilla Creek valleys succeeded a halt with the ice front extending across the hills from the Dryden Valley to the Slaterville Springs terminal moraine. The details of the successive ice fronts here are not clear, but it is evident that the ice margin was irregular, that there was later a condition of stagnant ice blocks, and that as a result of ice dams across the streams moraine-terrace deposits were laid down on some of the earlier moraines. Apparently also, as will be shown later, this stage of moraine was complicated by ice tongues pushing southward over the divide between Fall and Cascadilla creeks.

Continued recession finally separated the Cascadilla and Sixmile Creek lobes, which had hitherto been connected through the gap between Slaterville Springs and Ellis. A relatively prolonged halt was made at Besemer and Brookton, and, as the moraine of this halt has been traced continuously for 10 miles or more, it will be described in some detail. Starting near the edge of the steepened slope of Cayuga Valley, the moraine forms a very prominent crescentic ridge across the valley of Buttermilk (Tenmile) Creek, already described. It extends up the eastern valley side, rising about 300 feet in 2 miles. It is an exceedingly well developed moraine, consisting of short ridges and hillocks, with many kettles and some kames, its whole breadth being from an eighth to a quarter of a mile, with a vertical range on the hill slope of 50 to 75 feet. For the next 2 miles the moraine contours the hill almost at one level. This is the area between lobes which may be considered to be frontal to the main ice sheet as distinguished from the lobes of the valleys, which accounts for its horizontality. In this area the moraine loses strength and in places is difficult to trace. Instead of hummocky moraine of striking form, it develops into a pair of low till ridges, not over 10 to 15 feet high, but with a back or uphill slope. The moraine then begins to descend abruptly into the Sixmile Creek valley, in a mile descending more than 200 feet, and then branching where the nose of the ice tongue oscillated in the valley bottom.

On the north side of the Sixmile Creek valley, from Besemer southward, there are three westward-facing loops with terrace-top conditions behind (eastward), and from these the moraine swings up the hillside past Besemer, rising about 400 feet in a distance of 2½ miles as a broad, well-defined moraine belt. It then descends 200 feet in a mile to the Cascadilla Valley, forming a very pronounced loop across the valley at Ellis; but its extension out of this valley has not been definitely traced, though it apparently extends through the Ringwood Valley to the pronounced morainic loop about 2 miles west of Dryden.

Later and lower stands have been traced for considerable distances, as is indicated on the surficial geology map. Associated with these later stands is an excellent moraine terrace 3 miles southeast of Ithaca and a number of good morainic loops, the two best of which lie east of Ithaca in the Cascadilla and Fall Creek valleys. The former descends the slope of Turkey Hill at a steep angle, in the form of a high, esker-like ridge, broadening and flattening toward the valley bottom, where it forms a terrace-like flat with a steep upstream slope and a westward-facing morainic face. The Fall Creek loop rises directly east of Varna and represents a lower and later stand than the loop just described. Its west face is crescentic and continuous with a broad terrace extending southward from Varna, but not definitely traceable northward. The front rises 120 feet and is a perfect ice-contact front, but the top is fairly level and on the south side is veneered with gravel. Both the form and composition prohibit its interpretation as a delta. The stream cuts completely through it, revealing a great complex of gravel, sand, clay, and till, the clay being extensively contorted. Westward from this loop Fall Creek flows past Varna between drift walls, broadly separated and with morainic form, evidently due to ice-block molding of marginal terrace deposits.

North of Fall Creek, on the low, moderately level slope, the moraine is in the main not well developed, the ice here evidently having varied greatly in position and having little constructive power. One fairly definite moraine belt extends continuously northwestward from Etna, consisting of parallel, overlapping ridges, usually short and low, but here and there developing a hummocky topography and even the characteristics of kames.

During some of the ice stands lacustrine conditions developed along this part of the ice margin. Some of these were temporary terminal lakes; some marginal. When the lake conditions lasted long enough, broad flats were built, for example north of Dryden Lake, east of Slaterville Springs, and north of Brookton. A similar condition developed in the hanging valley east of Ithaca, where a great flat extends between Cascadilla and Fall creeks. Its surface is lake clay, but moraine material projects above it in several places. A well 140 feet deep at the Bool farm, on this flat, did not reach rock. A series of six wells farther east, in the Cascadilla Valley, passed through 45 to 65 feet of clay before reaching the till. This flat evidently represents the accumulation of drift, marginal to the brief ice stands, in a temporary lake into which sediment-laden waters were poured, both from the ice and from the two streams that now cut across the flat.

A peculiar condition exists east and northeast of Etna. The valley floor is covered with stratified deposits of lake clay and sand apparently of considerable depth, on which rest some low kames and a low esker. Manifestly the clays and sands were not deposited after the esker; otherwise it would be buried. This flat lies just south of an outwash plain north of the Catatonk quadrangle and east of a moraine formed by the protrusion of a tongue from the west into Fall Creek valley. Although the glacial deposits to the north have not been mapped in detail, the outwash gravel plain and morainic deposits known to exist in that region indicate the presence of a southward-moving tongue just north of this quadrangle. If this was the case, the area about Etna was inclosed between a southward-moving and an eastward-moving lobe of the ice, and consequently a lacustrine area must have existed in which extensive deposits might be made. This, however, does not account for the unburied esker which seems to rest on the flat. The hypothesis of a slight readvance of the ice would explain the esker, and also a peculiar undulating surface of the valley-bottom deposits which is quite out of harmony with lake-bottom topography. This hypothesis is therefore advanced to account for the peculiarities of the Etna flat.

Though lacustrine conditions were at times destroyed by filling, as a rule the deposits did not suffice to bring about this result. This is particularly well illustrated in the Sixmile Creek valley, below Besemer, where the ice tongue must have ended in a lake with an outflow past White Church. Here both the morainic topography and the composition of the moraine are very irregular. Cuts reveal till, lake clay, sand, and gravel, confusedly thrown together and locally faulted, folded, and even crumpled. The irregular topography is due to a combination of irregular deposition and later slumping by the melting out of ice blocks and stranded bergs. A later veneer of deltas in the Sixmile Creek arm of the ice-dammed Cayuga Lake has locally leveled the valley moraine, but stream dissection has cut the deposits both of moraine and delta into an exceedingly rough topography.

With the expansion of the ice-dammed lake of Cayuga Valley the ice front ended in the lake waters and the moraine deposit was weak. This no doubt in part accounts for the absence of moraines below the 1000-foot level, where lake clay forms the soil over most of the area. Normally moraines below this level would be expected, for at the very northern border of the Watkins Glen quadrangle, north of Ithaca, there is an excellent moraine at about the 1000-foot level; but it loses intensity southward and finally is lost, though near the uppermost deltas of Fall and Cascadilla creeks morainic topography appears at the proper level for correlation with this moraine. This indicates that the lacustrine conditions prevented the making of a continuous record of this stand of the ice.

Where traced continuously these morainic deposits prove both a rapid grade of the ice into the lateral valleys and a shortness of the lateral tongues. The ice evidently did not extend as long, narrow lobes far into the side valleys, but as short lobate protrusions from the main ice mass. Thus, while moraines rise out of the steep-sided Cascadilla Valley at the rate of about 200 feet in a mile, the moraine on the gently sloping north wall of Fall Creek ascends but 40 feet in 3 miles.

A peculiar condition exists on the south side of the range of hills which extends eastward from Turkey Hill on the south of Fall Creek. Against this range the main ice sheet crowded in its descent from the north, swinging across the west end of the range to form a lobe in the Cascadilla Valley, and probably in earlier and higher stands swinging across the hills farther east. There are several north-south gaps across this range of hills through which the ice seems to have protruded short tongues. One of these was across the gap between Turkey Hill and Mount Pleasant, another across the gap north of Ringwood. In the latter the evidence of an overflow of the ice through the gap is clear. On the south side of the divide there is much moraine material, in several places with crescentic loops that are concave northward, the most massive of which is just north of Ringwood. Associated with the deposits of this tongue across the divide is an excellent esker, probably developed in the course of the melting out of the ice of this tongue after it became disconnected from the main ice mass. Similar deposits, with an esker, occur south of the gap east of Turkey Hill; but the next valley to the east, lacking a gap at its head, also lacks these deposits.

The striking development of moraines on the north side of Cascadilla Valley is interpreted as in part a result of this peculiar condition, for when the ice spilled over the divide through the gaps, a lobe also swung up into Cascadilla Valley from the west and added its supply to the normal marginal drift.

KAME AREAS.

Throughout the morainic area there is an abundant development of kames, every gradation from undoubted moraine to perfect gravelly, kettle-like kame being shown. Almost all the kame areas are so definitely associated with morainic bands and terminal deposits that they have been interpreted as a part of the morainic evidence of former ice-front positions. The kames of these quadrangles appear to occur wherever rapidly moving water currents brought quantities of sand and gravel to rest upon ice which later melted away, or in marginal lakes which were not completely filled. It is probable that in the latter case stagnant ice was also to some extent involved. As the following description indicates, several causes for kames are believed to be illustrated in this area.

At several points where side streams from the land ended against the ice, kame areas form a part of the distinct lateral moraines; and in such positions the lateral moraine is not only more gravelly and kamelike, with the typical elongated ridges modified to dome and kettle topography, but also broader than usual and extends farther down the hill slope. The evidence indicates that in such places the land streams melted the ice and formed marginal lakes into which débris was poured, both by the land streams and by those flowing along the ice margin. This débris completely filled some of the lakes, and in other places was dumped upon unmelted portions of the ice sheet, which, on later melting, gave rise to topography of the kame type.

Many morainic loops consist in part or entirely of kames; for example, the center of the Spencer Summit terminal-moraine loop described above. Here also there may well have been buried ice, and the fact that in the kame portion the terminal moraine is both lower and broader than on the ends lends support to this view.

Another class of kames comprises those that are closely associated with eskers, locally forming a part of them, and evidently due to subglacial deposition. This class will be described in the section on eskers. No other kames were found which seemed to demand explanation as subglacial deposits.

MARGINAL AND OUTLET CHANNELS.

MARGINAL CHANNELS.

Closely associated with the moraines are channels that were evidently occupied by streams marginal to the ice lobes. Besides being too large for the streams now occupying them, and being at many places in positions where drainage could not exist without the presence of some barrier that is now gone, these channels are peculiar in a variety of ways. Some of them are in drift, some in rock, but all are of moderate depth and width. They range from fairly definite valleys with rock walls to mere notches in moraines, where streams descended along the nose of an ice lobe. In places there is only one bank, the other having been the ice; elsewhere they both begin and end abruptly, the continuations of the channels having been on the ice, and hence now melted away; and in still other places they terminate in gravel deposits built of débris which they brought. Some of the plainest of these marginal channels are indicated on the surficial geology maps, but there are many others of smaller size and less perfect development; and there are also many places where postglacial drainage has evidently destroyed the record of them. Descriptions of several of the more perfect marginal channels will suffice to illustrate their characteristics.

Two miles northwest of Harford the broad morainic terrace is cut by a series of deep, broad valleys, in some of which no water now flows. From this it is believed that after the morainic terrace was formed marginal to the ice, streams flowing along the ice margin found escape into the valley where ice had formerly stood and, with the local base-level thus reduced, cut deeply into the terrace.

Two miles northwest of Watkins station there is a marginal channel of a second type. It is a level, flat-bottomed channel behind the lateral moraine, with the moraine for one wall and the gently rising hill slope for the other. Here, as is very common elsewhere, the broad, flat channel is swampy, and at present there is no stream in it. The stream which formed this channel trimmed the rear side of the moraine into a regular erosional slope, a feature noticed at many places in the moraine belts, even where well-defined marginal channels are not present.

A marginal valley of a third type occurs on the hillside about 2 miles east of Dryden, where a moraine collar swings around a high hill and thence down into the Virgil Valley. Here, back of the moraine, is a flat-bottomed valley, roughly following the contour of the hill, but sloping southward. It is a notch in the hill slope. Of this kind there are numerous illustrations; for example, a channel 2 miles east of Franks Corners, and a group of channels east of Slaterville Springs, where the ice swung against the hillside and forced the lateral drainage and that of upper Sixmile Creek valley against the hill nose. One of these channels is of particular interest because it starts as a broad, flat-bottomed valley on the northwest hillside, cut through the drift and a short distance in the rock, then abruptly changes to a rock gorge fully 50 feet deep with a fall at its head. On the two sides of the gorge the hillside has the normal rock slope, interrupted by the contouring gorge with a descent eastward. Aside from the impossibility of the normal development of a gorge in such a situation, the fact that there is now no water in the upper half of the gorge proves that it was due to some abnormal condition. That it was caused by marginal drainage is evident from its form and situation; and that the drainage followed this line for a long time and with considerable cutting power is proved by the length and depth of the gorge with a step fall at its head.

On the northeast end of a hill 1 mile north of Townsend, about on the 1400-foot contour, there is a winding marginal drainage channel fully 50 feet wide and about a quarter of a mile long, with a moderate slope toward the south. This channel notches the hill slope, approximately along a contour, in a position where no stream could possibly have existed if there had not been some barrier, like ice, on the downward side where there is now a fairly regular slope.

A fourth kind of marginal drainage channel is illustrated by the valley half a mile south of Brookton. This channel was formed by the escape of water along the base of a steep hill in the angle between two ice lobes, one in the Slaterville Springs valley, the other in the White Church valley. The water flowed against the base of the hill, undercutting it and adding to its steepness. How much of the hill it cut away is not certain, but the fact that for a part of the distance the channel has a rock wall even on its west side indicates a great amount of cutting. This action of marginal drainage, observed in other places, has produced at least some of the steep valley slopes and rock cliffs in the region; and when it is remembered that the same action was possible when the ice sheet was advancing, and also in earlier ice advances, it is evident that the sum total of this form of erosion may have been considerable.

A fifth kind of marginal drainage channel is found where the marginal stream discovered a lateral passage across a divide. This type finds its best illustration in this area in a crosscut north of Spencer, near the Tompkins-Tioga county boundary. When the ice rested against this hill slope a marginal stream crossed a divide, lowering it greatly and cutting a deep gorge with a flat floor in it, now swampy and without running water. A road follows this old waterway as a route eastward out of the Michigan Creek valley. Although occupied by an outflow during the recession of the Wisconsin ice sheet, this channel has had a complex earlier history. It was a divide valley of fairly mature form, like the one a little over a mile to the south, and there was drainage both ways, as indicated by a flaring of the valley walls toward both the northwest and the southeast. Marginal drainage at a lower level (described below) steepened the western valley wall and truncated the westward-sloping valley; and there has evidently been more than one period of marginal drainage occupation.

About 2 miles northeast of Odessa there are three marginal channels, the two lowest being very short and ending on the hillside, while the highest is traceable for fully 2 miles. The lowest one, which is approximately 200 yards long, is about 15 feet deep, and in a part of its course is rock walled on both sides, proving that the marginal drainage cut a gorge in the rock. Its bottom is flat and swampy, with a gentle southward slope. The lower half of the long uppermost channel is occupied by a small brook, which for a considerable distance meanders as if lost over the flat bottom between steep, straight erosional slopes that rise fully 50 feet above. At one point the channel, which is in the main over 50 feet wide, narrows decidedly where it has cut a gorge in a rock spur. At the lower end of this channel there is a broad, delta-like accumulation into which the modern stream has sunk a deep valley. This delta mass was apparently built of materials brought by the marginal stream and deposited in a lake held up by the moraine and ice tongue which stretched across the lower end of the Cayuta Lake valley.

There are numerous other channels in this region, two or three cutting across the nose of the hill between Texas Hollow and Cayuta Lake valley, others formed by drainage out of the lake valley into the main Cayuta Creek valley. One of these is now occupied by the outflow of Cayuta Lake.

OUTLET CHANNELS.

Closely related to those channels which are distinctly marginal in character are channels through which the glacial waters escaped across divides. Some of these outlet channels are direct continuations of distinct marginal channels; others represent the outlets of marginal lakes. South of Wedgwood there is an interesting marginal channel through which water escaped southward into Johnson Hollow (see fig. 31), and thence into the Seneca Valley; and at a lower level, crossing the moraine near the middle of the valley, is a distinct channel of later date, in which there is now no stream. This was evidently the outlet of a marginal lake held up here by a lower ice stand. There is a similar channel crossing the morainic loop 2 miles west of Newfield, and another farther south, at the head of the Pony Hollow stream.

From the outermost positions of each of the valley lobes ice-born streams emerged, building deposits of outwash gravels where the slope was away from the ice or where, by deposition in marginal lakes, the valley floor was so built up as to slope away from the ice. The courses of these glacial streams are still recognizable on some of the outwash plains, not as single deep valleys but as branching shallow channels such as occur on an aggraded valley floor. In some situations the outflowing stream cut a channel in the rock instead of aggrading it with gravel deposit. Such is the case in the channel about 3 miles south of Slaterville Springs; but here the valley deepening is complicated by an earlier period of cutting, probably associated with an earlier ice advance.

With recession of the valley lobes, some of these channels were occupied for a considerable period and under widely different conditions. For example, the outflow along Danby Creek, at first building a narrow strip of outwash gravels, became later a stream cut into both the moraine and the outwash gravels, and, in its latest stages, was the outflow of an ice-dammed lake in the Buttermilk (Tenmile) Creek valley near Danby. At the head of Michigan Creek there was first an outflow depositing gravels in the valley, and later an outflow which cut into both the valley-head morainic loops and the outwash gravels.

The largest and best of the outlet channels are those through which the high-level lakes of the Cayuga and Seneca valleys overflowed southward. The course of the outflowing stream for the Seneca Valley glacier is distinctly traceable from the mouth of Johnson Hollow southward beyond Horseheads. At its highest stage this outflow must have been a large stream, carrying as it did the overflow of the large glacial Lake Newberry. The width of the overflow channel is in places nearly a quarter of a mile, and the depth, at the north, fully 40 feet. Near the north end it is bounded on one side by an eroded rock slope, but elsewhere the walls are of drift trimmed into straight, regular slopes by erosion of the outflow stream. The bottom is flat and so gently sloping that it is not at present well drained, and therefore for a long distance is swampy. This slack drainage is still further increased by the building of alluvial-fan deposits where streams now enter, as at Pine Valley and Horseheads, where the overflow channel is obliterated for a short distance.

This ancient channel, followed by the electric line from Horseheads to Pine Valley, crosses the present divide just north of Horseheads and has therefore been named the Horseheads outlet. Catharine Creek follows it northward to Pine Valley, then leaves it, crossing the moraine mass farther east. That modern drainage has not continued to occupy this channel, which was presumably at the lowest point in the moraine, is noteworthy; and it is also rather anomalous that Catharine Creek should flow northward in a direction opposite to the slope which the bottom of the overflow channel must have had when it was formed, and which must have been still further increased by postglacial uplift. The only possible explanation of this anomaly is that ice, buried beneath the moraine, held the morainic level near the center of the valley above that of the west side, and that, after the lake stage, the melting out of this ice allowed a settling, making the central part of the valley lowest. Rich, working especially on marginal and overflow channels in this region, has found interesting confirmation of this explanation in the discovery of a kettle depression in the overflow channel itself. The point of beginning of the outlet, at the mouth of Johnson Hollow, 5 miles north of the present divide, proves that the effect of depression of land in the north placed the end of Lake Newberry here, whereas at the present level of the land the lake would have extended nearly to Horseheads.

During the recession of the glacier from these quadrangles there was an ice-dammed lake of considerable size in the Sixmile Creek valley, and another in the Cayuga Inlet valley. To the former lake Fairchild has given the name Ithaca Lake, to the latter West Danby Lake. Ithaca Lake overflowed across the divide at White Church at an elevation of approximately 980 feet. This overflow, lasting for a long time at Ithaca Lake expanded northward by the melting back of the ice dam, and fed by a large volume of water, cut a broad, flat-bottomed channel, entirely in drift, across the moraine and through the previously deposited outwash gravels. Modern stream cutting and gravel deposits have modified this channel in its lower course, and alluvial fans have been deposited in it near the divide at White Church; but it is still a clearly defined channel up to and across the divide, in its upper part being swampy and occupied by a small stream. Two railroads, the Delaware, Lackawanna and Western and the Elmira and Cortland branch of the Lehigh Valley, make use of its grade to cross the divide and the irregular morainic area below the divide of this through valley.

West Danby Lake overflowed north of Spencer at an elevation about 100 feet higher than Ithaca Lake. For a short distance the channel is rather poorly defined in drift, but it then enters a very pronounced, flat-bottomed rock gorge, in which Michigan Creek now flows. (See fig. 34, illustration sheet II.) This rock channel is bordered on the east by the steepened hillside, on the west by a narrow rock ridge. The position and form of this peculiar channel indicate that it was cut on the base of the hill slope because of a barrier to the west; in other words, it was evidently begun as a marginal channel when ice crowded against this slope and before the West Danby Lake came into existence. Its cutting against the east side of the valley has greatly steepened the slope of the rock wall. The West Danby Lake overflow occupied this channel, already formed for it, because it was lower than the region to the east, where a pronounced terminal-moraine loop extends clear to the western valley wall. The outlet joined the marginal drainage channel by a great curve or meander. To the north are two or three small marginal channels which were apparently of the same age and origin as the channel described.

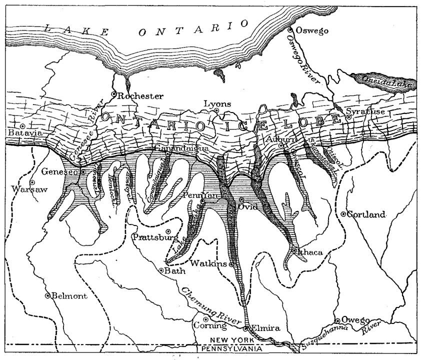

FIGURE 13.—Sketch map of glacial Lake Newberry in west-central New York.

Ruled area is glacial lake, outletting at Horseheads and flowing past Elmira to Susquehanna River. Heavy black line, southern edge of ice dam. Dashed line, natural watershed. After H. L. Fairchild.

As the ice front receded the two lakes (West Danby and Ithaca) coalesced and the waters of West Danby Lake fell abruptly to the level of the White Church outlet, which was afterward occupied until the further expansion of Ithaca Lake uncovered a lower pass westward into the Seneca Lake valley. Then the Ithaca Lake level dropped and a new lake (see fig. 13), called Lake Newberry by Fairchild, came into existence, with an overflow through the Horseheads channel south of the Seneca Valley, already described. The drop from the level of West Danby Lake to that of the White Church outlet is clearly recorded on South Hill, about 2 miles south of Ithaca. Here, on the west side of the hill nose, at an elevation of about 1040 feet, there is a well-defined marginal channel, about 100 yards wide, with rock walls on both sides and a flat, swampy bottom. This leads northward for a quarter of a mile, vanishing on both ends; but toward the northeast it develops abruptly into a terrace, with a rock cliff 30 to 40 feet high and fully half a mile long, swinging eastward around the hill nose. This forms so sharp a break in the normal slope of South Hill as to be noticeable several miles away. At the base of the cliff is a level bench, evidently of rock, with a gentle eastward slope. This is interpreted as a marginal channel which had one wall of ice. Toward the east the cliff diminishes in strength, but the terrace continues, developing into a moraine terrace with morainic northern face, first coalescing with the hill, then separating from it, and finally developing into a series of morainic ridges. Evidently at this stage the ice swung into both the Sixmile and the Inlet valleys and pressed against the nose of South Hill. That the phenomenon is not due to the action of lake waves is proved by the eastward slope, the elevation (being above the White Church outflow), the double-walled channel leading up to the terrace, the morainic development of the terrace toward the east, and the absence of similar deposits at the southwest end of the cliff. Below the terrace, however, there is a cliff which is interpreted as a shore line of the Ithaca Lake.

Outside of the area of recessional moraines in the northern part of the Watkins Glen quadrangle and the northwestern part of the Catatonk quadrangle there is a general absence of outlet as well as of marginal channels. The principal exception to this is the outlet southeastward from East Richford, where there is a well-defined channel which carried across the divide the waters that were dammed back in the Center Lisle valley by an ice blockade across its east end.

EROSION ALONG MARGINAL AND OUTLET CHANNELS.

It is a mooted question to what extent marginal and overflow glacial streams carved valleys. To the question whether such valleys as that followed by the Chemung west of Elmira or peculiar valleys like Texas Hollow were caused by the erosion of glacial streams, it is difficult to obtain a satisfactory answer, but the writer has been led to believe in slight rather than great erosive power during the closing stages of the Wisconsin ice sheet. A fuller discussion of this subject will be undertaken in a later section (p. 30); but here it may be pointed out that, wherever distinct outlet or marginal channels have been traced, the work of erosion has been exceedingly slight, as a rule barely more than the notching of drift deposits. The closing work of the ice sheet was evidently in the main one of construction rather than of destruction, and if the closing stage alone were involved the answer to the question raised above would be clear, so far as this area is concerned. There are, however, the further questions: What was the action of ice-born streams as the glacier was advancing? And what was it during possible earlier ice advances? To these questions direct answers have not been obtained.

Undoubtedly the best evidence for decided erosion by ice-born streams is that of the "gulf" through which the waters of Cayuta Lake flow southeastward. This "gulf" is a deep, narrow gorge, with no rock in place on the bottom and with the drift filling not yet cleared out. Whatever its origin, it is not postglacial. That there were originally two small valleys here, one draining northwestward, the other southeastward, is indicated by the flaring of the "gulf" valley in these two directions. Morainic masses lying across the lower end of the broad Cayuta Lake valley prove that the normal outlet for the waters of the lake valley was blocked for a time during the closing stands of the ice in this region; and the moraines in the valleys north of the lake prove that much water was poured into it from this direction. While the ice was standing in these positions, water unquestionably escaped through the "gulf," for it is flat bottomed, and a broad channel extending out past Alpine was formed by a current far larger than that supplied by the present drainage. Near by there are two similar gorges, one north, the other northeast of Alpine. Not only has the postglacial drainage been unable to remove the drift from these valleys, but there are tributaries to them which enter in drift-filled gorges far wider than neighboring postglacial gorges. Some of them are trenched in the bottom of hanging valleys of mature form. This proves conclusively that there was a period of gorge cutting after the base-levels of the "gulf" and of the other channels were lowered to at least their present depth, and before the advance of the Wisconsin ice sheet. No other conclusion seems possible than that these peculiar valleys were formed by marginal-drainage work during an earlier ice stage.

ESKERS AND ESKER DELTAS.

ESKERS.

CENTER LISLE ESKER.

Westward from Lisle in the Catatonk quadrangle, there is a broad, mature east-west valley which extends across the divide at East Richford, forming a through valley. The drainage on the west side of the divide passes southward through a well-defined overflow channel, but the through valley extends westward to the valley of the East Branch of Owego Creek, above which it hangs. West of Richford there is a continuation of this east-west depression through to the valley of the West Branch of Owego Creek and thence on to Slaterville Springs. This system of through valleys, possibly once a single valley dissected by north-south glacial drainage, is such a natural gap across the plateau that it once served as the site of an important highway, known as the Catskill turnpike. In it are some interesting drift phenomena, including the largest and best-defined esker in the quadrangle.

On the very west end of the Center Lisle trough, northeast of Richford, there is a prominent esker ridge extending out to the steepened walls of the Richford Valley and associated with kame deposits. It can be traced eastward almost continuously for a mile, then ends in a mass of kame hills. Half a mile farther east there is an esker ridge about 50 feet high, extending along the valley wall for half a mile and flattening out to the east where it ends on the hill slope. Beyond is a gap of three-quarters of a mile, and just west of the church at East Richford there is a low gravel mound, from the east side of which extends a low gravel ridge a few feet high, but gradually increasing in size toward the east, reaching an elevation of 30 feet at a distance of 1½ miles from the church. In the course of 3 miles it attains an elevation in places of at least 100 feet. In its total length of about 5 miles, from East Richford to Center Lisle, there are but two places in the esker where streams from the north cross it. It deflects drainage and interferes with it, causing swamps in places, and forms a prominent topographic feature in the valley bottom which attracts the attention of all observant travelers and which finds expression on the topographic map. For much of its length the Catskill turnpike follows its crest. (See fig. 32, illustration sheet II.) There are many kames associated with the ridge, and here and there the esker branches, and assumes a kame like habit. The kames are mainly on the north side, and the esker keeps Dudley Creek on its south side. In one place what appears to be a small feeding esker comes from the northwest. There are three short esker sections east of Center Lisle; and on the east side of the Tioughnioga Valley, opposite Lisle, is another esker.

The increase in size of the Center Lisle esker toward the east is believed to demonstrate that it was formed by an eastward-moving stream; but there is no reason to believe that the long esker is continuous with the shorter eskers to the east and west. That the esker was formed in connection with the melting out of a stagnant ice block is considered probable because of the perfection of form of this long, winding ridge, which even slight ice motion would destroy. Its relation to the delta plain between Center Lisle and Lisle is considered in a later section.

JACKSON CREEK ESKER.

The second largest and one of the most interesting eskers in the Watkins Glen quadrangle, in McCorn and Jackson Creek valleys north of Swartwood, has a total length of 4½ miles. It commences in a kame-moraine area on the east side of McCorn Creek valley, then descends to the middle of the valley, where it develops into a perfect, winding, wavy-crested ridge, rising fully 50 feet above the valley bottom. Associated with it are kame expansions, and, in one or two places, secondary esker ridges, which, however, join again. After crossing the creek the esker is continued on the western valley slope, where it changes in places to kame hillocks, elsewhere to terrace forms with a kettle-like slope toward the valley, resembling a lateral moraine deposit; and in one short section, except for the presence of gravel on the hillside, it disappears entirely. Beyond this indefinite portion the distinct esker reappears, first as a low ridge clinging to the hill slope, then developing rapidly into a perfect esker ridge. Within a mile of the junction of McCorn and Jackson creeks the esker has assumed the form of a high ridge with associated kames. It then rapidly descends the hill slope to the bottom of the Jackson Creek valley, where a cut reveals a confused mass of sand and cobbles, some of the well-rounded blocks weighing fully 200 pounds. The esker is cut by Jackson Creek, but rises on the opposite side, continuing to the mouth of the valley as a ridge, with irregular crest, from 100 to 150 feet high. Here it branches and is associated with a mass of very high, irregular kamelike deposits.

Although possibly this esker was for a short distance a marginal deposit, in the main it was evidently built in a subglacial tunnel. Otherwise its perfect form would not have been possible, nor could it have descended into and ascended out of the Jackson Creek valley without losing its form and leaving associated areas of kames. So long, perfect, and high a ridge, built both in the valley bottom and on the hillside, could not have been formed by marginal accumulation; nor does it seem possible that it could have been lowered to the ground from a surface or englacial channel without losing its perfection of form.

That the esker was built under a stagnant ice mass and not in one that was actively moving is indicated by the fact that the serpentine windings are not disturbed, as they must have been by even a slight forward ice movement. That it was made by a southward-flowing stream is proved by its increase in size toward the south; and the abrupt termination of the high esker in a massive kame area near the mouth of Jackson Creek proves that the ice block ended there. The height of the terminal portion of the esker and the associated kame, together with the absence of any extension of the deposit, proves the presence of some obstacle to the distribution of the gravels. Only two such obstacles appear possible—standing water and ice. That it was not a large body of standing water is proved by the absence of the delta form and by the narrowness of the area occupied by the kame. It seems evident, therefore, that the esker terminated against a large ice block in the Cayuta Creek valley, which permitted the gravels to come to rest either directly on the ice or else in a small marginal lake at the mouth of Jackson Creek.

ETNA ESKERS.

Northwest of Etna a distinct esker enters the Catatonk quadrangle from the north and in about a mile becomes mixed with a kame and morainic area through which it is only indistinctly traceable. Turning eastward in a sharp bend, as a very low (10 to 15 feet) but distinct ridge, it extends to the bank of Fall Creek with only one gap, where a brook cuts through it. It is gravelly throughout, with some large pebbles but no bowlders on its sides. Its top is fairly level and its course is strikingly serpentine. On the east side of Fall Creek there is a similar ridge extending northward and believed to be a continuation of the esker just described. Where cut through, in an orchard half a mile north of Etna, this section of the esker a few years ago revealed a perfect concentric stratification.

East of and parallel to the esker section northeast of Etna is another small esker, with a low kame area at either end. Neither of these eskers rises very high. They are in a few places more than 20 feet high, but are commonly only from 5 to 15 feet, and the breadth at the base does not as a rule exceed 50 to 75 feet. No evidence was discovered to prove the direction of flow of the water; but the perfection of the esker form and the preservation of the serpentine curves prove a stagnation of the ice.

ESKER EAST OF WATKINS.

On the hill slope east of Watkins is an esker which runs around the hill approximately parallel to the lateral moraines. It is a distinct gravel ridge with undulating crest, somewhat serpentine in course, in places broadening out into kame areas. The position of this esker has led to the suspicion that it was a deposit marginal to the ice at one of its halts, and in consequence really a lateral moraine. Elsewhere lateral-moraine ridges simulate eskers in both form and material, though nowhere quite so perfectly as here. It is by no means impossible that, in favorable situations, rapidly moving, heavily laden marginal streams may have flowed in valleys or tunnels cut in the ice, making deposits which, on the melting of the ice, took the esker form.

CHEMUNG VALLEY ESKERS.

In the Chemung Valley, between Elmira and Waverly, there are a number of eskers. The northernmost of these rises above the outwash plain along the road between Elmira and Southport. The fact that this esker rises above the outwash plain shows that the plain is not very deep at that point.

A distinct esker ridge, in close association with a moraine area, descends the hill slope about 4 miles southeast of Elmira. Where it crosses the highway, it splits into a series of ridges which inclose deep kettles, and merges into a broad kame area which has been partly cut away by Chemung River.

Eastward from a point near Lowman there are several high and very perfect esker sections, two of which are over a mile long, with extensive kame deposits, evidently part of a single system. Both kames and esker have been cut away in places by the Chemung and its tributaries, so that the esker is in sections, though it is not certain that all these sections were originally continuous. The esker sections have a relief of more than 100 feet in the east, where they are highest. This fact shows the direction of flow of the esker-building stream and is in harmony with the evidence from westward-facing ice fronts in the kame areas, that the ice tongue in this valley extended toward the east. The facts indicate the presence of an almost motionless if not completely stagnant ice tongue, against which, at various points, gravel was accumulated as it poured out from the esker tunnels. That the esker ridges preserve their serpentine form, and that they were not buried beneath later gravel deposits, testify that the ice moved feebly, if at all.

ESKERS IN THE SUSQUEHANNA VALLEY.

The Susquehanna Valley contains a number of short eskers which vary greatly in height and perfection. They are all associated with kame areas or with kame moraines, and in places are bordered by kames and end in kames. Some of them seem to end in the outwash gravels, and, as described below, one near Apalachin certainly does. Although these eskers have been diminished in length by erosion of Susquehanna River, and possibly also by earlier ice-born streams, and although their axes are parallel to the valley, it does not seem probable that they are disconnected parts of a single esker. The principal objection to the theory of a single esker is the fact that the different sections vary in elevation and perfection, not in a regular manner from one end to the other, but from individual to individual. It is believed that the eskers were developed during the melting out of stagnant ice in the valley, and that for the most part the several eskers are distinct masses, formed at the successive stages of ice melting. This point will be discussed again in connection with the consideration of esker deltas and outwash plains.

No eskers were found south of the Susquehanna nor in the valleys north of it in the southern part of the Catatonk quadrangle. This is interpreted as further evidence that the ice in the southern half of the quadrangle contained little débris above the bottom layers. Otherwise it seems probable that eskers would have developed in the course of the melting out of the stagnant blocks that must have occupied the valleys tributary to the Susquehanna.

OTHER ESKERS.

A few short esker sections, associated with kames and in places reaching great height and perfection of development, occur on the north side of the valley east of Slaterville Springs. The presence of the esker sections and kames on the north side of the valley here and in the Center Lisle valley may have some significance; but if so it is not at present clear.

In the valley north of Ringwood is a very prominent esker over a mile long and reaching a height from base to crest of 40 to 100 feet, interfering with drainage so that much swamp area is associated with it. It has a very irregular crest line; its course is somewhat winding; and in places it branches and assumes a kamelike habit. It ends on the north in a strongly developed kame area and on the south in a kame moraine associated with the morainic loop across the Ringwood Valley. It is interpreted as an esker formed during the melting out of an ice tongue which passed across the divide from the north. Of similar character and apparent origin is a rather straight esker in a valley about 3 miles west of this one. This esker is approximately one-half mile long, 50 feet high on the east side, and 10 to 30 feet high on the west. Neither of these eskers, which are in the woods, is indicated on the topographic map.

There is a perfect esker southeast of Dryden Lake ending on the northwest in an area of striking kames and on the southeast near the outwash gravel plain which extends down the Harford Valley. It is very serpentine, from 20 to 40 feet high, and is interrupted in one or two places by stream cuts, elsewhere by causes which are not now apparent.

There are three small eskers near Lapeer, probably a part of a single esker cut apart by the stream. The northernmost of these winds about in a series of curves resembling the meander of a meadow brook, being perfectly serpentine. These eskers are low, but are very perfect, and they are interpreted as the products of subglacial drainage in the final or stagnant stage of the ice lobe which built the Lapeer morainic loops from the east.

ESKER DELTAS.

Deltas built by feeding eskers and commonly called sand plains are here called esker deltas. Definite examples were found in only a few places in these quadrangles, one of these, near Burdett, having already been described. Others are described below.

SUSQUEHANNA VALLEY ESKER DELTAS.

Both north and south of Apalachin there are two short eskers terminating in gravel plains which have evidently been built of gravel deposited by the esker-forming streams. The southern of these is most typical. Here a short, low, serpentine esker built from the east branches into two arms toward the west and then rapidly fades out into a gravel terrace which extends back to the hill base. The terrace has been trimmed by stream erosion and therefore does not have a perfect delta form; but its association with the esker and its partial delta form lead to the interpretation of an esker-fed delta in a temporary ice-blocked lake. Other sections of the outwash gravels of the Susquehanna are believed to be of the same origin, but in most of them subsequent dissection has so obscured the evidence that this explanation is offered with far less confidence for these than for the one described. An esker in the extreme southwest corner of the Catatonk quadrangle terminates beyond the quadrangle boundary in a delta-like plain which is apparently an esker-fed delta.

LISLE ESKER DELTAS.

Between Lisle and Center Lisle there is a remarkable deposit of gravel, completely filling the valley from side to side except where cut across by Dudley Creek and its tributaries. This gravel does not form a continuous single plain, but is apparently in three parts, the easternmost, near Center Lisle, being both the smallest and the lowest, with a surface elevation of 1160 to 1200 feet. North and west of this section gravel mantles the lower hill slope, but does not form a definite plain, evidently having been cut away by the stream. South of Manningville is the second plain, rising to a level of 1260 to 1300 feet and forming a more perfect and larger plain than the contours on the map indicate. The third plain lies north of Manningville and reaches a level of 1200 to 1260 feet, being therefore intermediate between the other two. It is much the largest and most perfect and extends up to the hill base with a level line of contact. Streams on the south side of the valley reach rock beneath the plain, showing that it is built on the hill slope.

As has been stated above, a long esker leads up to the western plain and ends at Center Lisle; there are three short esker sections associated with the plains; and a prominent esker exists outside of the Catatonk quadrangle, on the east side of the Tioughnioga Valley. It has already been stated that the long Center Lisle esker was built from the west; that there was a glacial stream overflow from this valley southwestward; and that at Lisle the gravel plain presents evidence of an ice contact on the east face of the plain. This evidence of ice contact is in the form of a very irregular, kamelike front toward the east, with terraces at different levels, each with an eastward-facing front of ice-contact type. Farther west, about a mile northwest of Lisle, is another kame moraine which rises above the level of the plain, in which it is partly buried.

The field evidence clearly points to an ice blockade across the valley mouth at Lisle, and a blockade at successively lower levels, first at the point where the kame rises above the plain northwest of Lisle, and later at lower levels. This ice is believed to have come from the east and to represent the last stages in the shrinking of westward-moving ice from the Center Lisle valley. The two larger or easternmost plains are believed to have been built at this stage in temporary lakes dammed back in the Center Lisle valley, and with different levels, the gravel being esker fed from the east. The Center Lisle esker was approximately contemporaneous with this stage, and the westernmost and lowest of the delta plains was built during the melting out of the stagnant ice block that was left in this east-west valley when the westward moving ice was no longer able to keep it actively moving.

The reasons for not correlating these plains with the Center Lisle esker are several, as follows: (1) The larger plains have an eastward-facing ice-contact front, and a large esker leads up toward them from the east; (2) there are evidences of recessional ice fronts, as already stated; (3) there is a pronounced overflow to the southwest; (4) there must in any event have been an ice dam at Lisle in order to permit the building of the plains; (5) the vast amount of gravel in these plains seems too great for supply from an ice block left stranded in a valley, and there is no evidence to suggest that there was an ice tongue from the west, and every evidence against such a theory. With so extensive a deposit of gravel there must have been much clay, and the fact that it does not occur in the valley above Center Lisle and does not even mantle the esker leads to the belief that this part of the valley was still occupied by a stagnant ice block while the delta plain was being built. The outlets determining the levels of the three plains have not been determined, though the level of the outlet at East Richford, approximately 1300 feet, corresponds fairly well with the level of the highest plain.

Southeast of Lisle, in the quadrangle east of the Catatonk, there are some interesting gravel plains, not yet carefully studied, which may throw light on the peculiar and interesting deposits of the Center Lisle valley.

OUTWASH GRAVEL PLAINS.

MODE OF FORMATION.

Closely associated with the moraines and outflowing streams are extensive plains built by the deposit of sand and gravel outwashed by the streams from the glacier. Where these glacier-fed streams emerged into valleys sloping toward the ice, their deposits came to rest in lakes which were at times completely filled, forming broad plains like those in and near Odessa, already described. Where the supply of gravel continued after the lake was filled and a grade away from the ice was established, some of these plains were transformed into outwash gravel plains.

Where, on the other hand, the streams outflowed down a surface sloping away from the ice, they deposited their surplus load on the valley bottom, gradually raising its level, as streams flowing out from the Alpine glaciers are to-day building up their valleys. By dropping the excessive load of sand and gravel in its channel, the stream quickly built its bed above the level of the surrounding region, and was, in consequence, soon forced to shift its position to the lower places. The course of such an overburdened stream was therefore divided into a braided network of channels, so that all parts of the valley bottom were reached and built up, making a smooth plain resembling a flood plain. In fact, such an outwash plain was really the flood plain of an extinct stream which brought sand and gravel in excess of its ability to move it onward.

POST CREEK OUTWASH GRAVEL PLAIN.

There are several distinct outwash plains in this region. The westermost of these is in the Post Creek valley near the west side of the Watkins Glen quadrangle. Just north of Beaverdams, approximately on the divide, is the terminal-moraine loop of an ice tongue formed at one of the highest stages of the Seneca Valley lobe. During this halt the glacier waters poured southward through the Post Creek valley, leveling the bottom of the valley to a perfect outwash gravel plain; but as the valley narrows toward the south, the later meandering of Post Creek and the incoming of rock waste from the side valleys have been sufficient to cover and obscure the outwash gravels in that section. Near the head of this plain it is difficult to tell where the moraine ends and the plain begins; for the moraine becomes very gravelly and kamelike near its terminus, and the outwash plain near its head is distinctly terraced and contains numerous kettles. Lower stands of the ice front in this region were in a valley sloping toward the ice, and consequently during them no outwash plain was built.

PONY HOLLOW OUTWASH GRAVEL PLAIN.

Under conditions very similar to those just described an outwash gravel deposit was built in the Pony Hollow valley below the terminal moraine of an ice tongue from the north; but it is possible that some of the gravel near Cayuta was supplied by the tongue which extended into this valley from the Seneca ice lobe and which at lower stages made the broad moraine terraces in the westward-sloping valley near Odessa. As in the Post Creek valley, this gravel plain is lost in the narrow part of the Cayuta Valley, where the work of recent streams has covered it with other surficial deposits. Whether this outwash gravel deposit extended through the Cayuta Valley to Waverly is not positively determined; but the graded condition of this valley, the fact that the Pony Hollow waters must have escaped this way, and the presence of outwash gravels both at Van Etten and in the broad lower part of the valley north of Waverly make this almost a necessary conclusion.

OUTWASH GRAVEL PLAINS IN OTHER THROUGH VALLEYS.

Where broad enough, all the other north-south through valleys show a general condition of gravel filling; and even where they are narrow it is evident that the gravel is present, but is hidden by modern stream wash. These trains of gravel all have their beginning in the outermost moraines of the recessional stages of the ice lobes. There the moraines are kamelike, with many kettles, changing rapidly downstream to kettly terraces, through a gradation which it is difficult to classify as either kame or outwash plain, and finally to a gravel plain, which evidently once extended completely across the valley, but has since been dissected into terraces of greater or less perfection of development. The gravel is all well rounded and assorted and is coarsest near the moraine. It is evident that these gravels were brought by streams issuing from the ice, and were contemporaneous with the building of the moraine.

Such plains are found on the east branch of Owego Creek, heading in the moraine northwest of Harford; on the West Branch of Owego Creek, heading in the moraine near Slaterville Springs; and in the Willseyville Valley, heading in the moraine north of Willseyville. These three valleys unite and the outwash plain extends into the Susquehanna Valley, at Owego. A narrow outwash plain, heading in the moraine of Danby Valley, northwest of Willseyville, unites with that of the Willseyville Valley. North of Spencer is a broad outwash plain, which heads in the moraine of Cayuga Inlet; it receives an accession through the narrow Michigan Creek valley, where the gravels head in the moraine of a small ice lobe. In the cross valley from Spencer to Candor outwash gravels were spread continuously, connecting the outwash gravel plains of the Spencer and Willseyville valleys. There are smaller outwash gravel areas connected with minor moraines west of Slaterville Springs, east of Ringwood, at Franks Corners, northwest of Killawog, and in the Nanticoke Valley near Union Center. These smaller areas are associated either with minor ice stands or else with the melting out of stagnant ice blocks.

It is evident that these gravels fill many valleys deeply; that they have graded them up and determined the grade of the present streams; and that in some places, as east of Slaterville Springs, the gravels have so filled the valley as to reverse the original slope. Numerous wells from 50 to 100 feet deep in these valleys fail to reach rock. Some of them passed mainly through gravel, others through a mixture of gravel, sand, and clay, indicating variable conditions of deposit. For the most part the valleys are so narrow and the gravel deposit so dissected that the channels of the outwash streams are not clearly traceable; but very commonly there is a channel close by one valley wall in which long, narrow swamps occur.

In general the plains are level, though there are numerous kettles, especially near the moraine; but in many places there is a puzzling condition of terraces with trimmed faces, showing dissection subsequent to deposition and evidently not by the present streams. This condition is typically shown in the Willseyville Valley in several places, for example just below the mouth of the Prospect Valley stream. Here there is a high terrace, fully 60 feet high, beginning abruptly and sloping rapidly southward, being destroyed at the south end by the erosion of Willseyville Creek. That this terrace, with trimmed face, was not cut from a more extensive deposit by postglacial erosion is proved by its abrupt termination on the north and by the fact that a lower outwash gravel plain skirts its base. Such terraces are interpreted as fans built at the ice front in brief earlier halts, and later dissected by the glacial streams which built the lower terraces after dissecting the upper one.

SPENCER OUTWASH GRAVEL PLAIN.

From the terminal moraine loop at Spencer Summit southward to Spencer there is an extensive outwash plain. Near Spencer Lake, this plain was built up around an earlier moraine area, partly submerging it. There are numerous kettles in the outwash plain, especially near the middle of the valley, where there is a line of kettles, in one of which Spencer Lake is situated, and in another, at the very north end, an extensive marsh. This North Spencer marsh kettle is roughly heart shaped with the broad upper part at the base of the terminal moraine, and the two sides bordered by outwash gravel terraces, while the apex points southward, along a line of kettles toward the Spencer Lake kettle. The marginal terraces, which nearly unite at the south end of the marsh, are level topped, moderately steep faced, and in places morainic in form. Even if excessive amounts of gravel were supplied from both the east and the west ends of the terminal moraine, as was apparently the case, such terraces could not be built by any normal process of subaerial accumulation. There must have been something present on the site of the marsh to prevent accumulation there. That this was not water is indicated by the entire lack of delta form in the enwrapping gravel terraces. The only other obstacle that can be suggested is a stagnant ice block which occupied the ground and against which the gravel was accumulated. That such a block actually existed is indicated by the irregular bottom of the marsh, in which there are gravel knolls; the finger-like projections of the terminal moraine into the marsh area at levels below the terrace tops; the absence of any dam for holding up a water body to the terrace level; the morainic irregularity and absence of delta form of the terrace front; and the low, hummocky, kame condition of the moraine north of the marsh, suggesting that this too was formed on a buried ice mass.

CHEMUNG VALLEY OUTWASH GRAVEL PLAIN.

The largest of the outwash plains of this area is that in the Chemung Valley. Although doubtless fed in part from tributary valleys, such as those of Post and Cayuta creeks, the main source of materials was the ice lobe which extended southward from the Seneca Valley. At each of the ice stands south of the divide, sand and gravel were poured into the Chemung Valley; but no distinct stages in the history of these outwash gravels were traced. They are all connected with a receding ice front, each successive stage tending to cover and obliterate those of earlier date and, in general, succeeding. Near the moraine of the later ice stands there are outwash gravel terraces and kame areas which grade abruptly into a level plain crossed by one or more stream channels, in which, at present, there is rarely running water. The partly buried moraines of earlier stands show the same condition, with the addition of partial burial and trimming where the outwash streams of later date have partly cut them away. In general the highest gravels are the youngest; though near the older moraines the earlier gravels may rise to a considerable elevation above the gravels of later date.

Near the source of the outwash gravels there is at many points a terraced condition indicating a marked activity and variability in the streams near the ice front. Terraces also occur in the outwash plain itself, some formed during the building of the plain, some by the work of existing streams.

Kettles abound near the moraine, and here and there are some of large size at a distance from the moraines. These kettles, many of which have swamps in their bottoms, evidently mark the sites of buried ice blocks which, on melting, allowed the surface of the plain to settle. There are also good-sized areas of abundant kettles in the midst of the outwash plain. One of these is at Eldridge Park, in Elmira, where there are also associated kame hummocks. Whether this area represents the projecting top of a kame-moraine area or a very irregular part of the outwash plain has not been determined. There is a similar kettly area just southeast of South Elmira, where the general level is above that of the surrounding plain. In this area a morainic origin seems the most probable.

North of the divide, in both the Cayuga and the Seneca valleys, the correlative of these plains is the hummocky morainic complex already described. There the standing-water conditions already induced the deposition not merely of sand and gravel, but also of clay. The great preponderance of sand and gravel in the outwash plains proves that a vast amount of clay found its way seaward. It is probable that more rock waste passed off in this way than was deposited in the gravel plains.

How much material is actually contained in these outwash plains is not certain, for well records are not numerous, and those obtained are not exact enough to be of much value. It seems probable, however, that the outwash gravels are not of great depth, being rather in the nature of a leveling agent on previously deposited valley drift. Both the variable nature of the materials passed through by wells and the fact that moraines and eskers project well above the outwash gravels are indications of the comparative shallowness of the gravels themselves. The records suggest the presence of both morainic and lacustrine deposits beneath the outwash gravels; and, whatever the proportional importance of the gravels, it is certain that they are merely the last of a series of deposits which have raised the valley bottoms decidedly.

Being deposited by running water, the outwash gravels are graded, and the direction of their surface slope has had much to do with the direction of modern drainage. It is due to them, together with the moraines southwest of Horseheads, that Chemung River has found a lower grade through the narrow valley west of Elmira, instead of along its former course past Horseheads. The gravels streamed out westward toward Big Flats as a broad, low alluvial fan against whose slope the Chemung could not flow. This outpouring of gravel westward must have tended to pond back Chemung River west of Big Flats; and the fact that the outwash material west of Big Flats is distinctly more sandy than elsewhere is an indication that there actually was a ponding of the stream in this region.

The Chemung Valley outwash plain extends eastward to the Susquehanna Valley, locally having been partly removed and veneered with stream-bottom deposits on one side, and even on both sides of the river. Some of the gravel of this eastern section may have come from the Elmira-Horseheads supply, but doubtless much of it was derived from other ice lobes. To unravel the full history of this outwash plain would involve the careful study of several other quadrangles.

SUSQUEHANNA OUTWASH GRAVEL PLAINS.

In the Susquehanna Valley there is a development of outwash gravels from the eastern edge of the Catatonk quadrangle to the point where the river is joined by the Chemung; but they are much more extensive, continuous, and better developed west of Owego than farther east, apparently as a result of the supply furnished by Owego Creek. In places this outwash plain is perfect in development and composition, but much of it is irregular both in composition and form. Near Owego and to the east parts of the plain are made up of sand and even of a fine loam. There are, however, large areas of perfect outwash gravel east of Owego.

Throughout the valley there is evidence that the outwash gravels had a very complex origin and that they were not built by a continuous flood of gravel-bearing waters from the valleys to the north. It has already been shown that some sections are apparently esker deltas. The presence of distinct ice-contact fronts, of abundant kettles, and of trimmed terraces at different levels, well illustrated in the gravel area between Lounsberry and Goodrich Settlement, demonstrates the association of ice near at hand during the gravel building. Later outwash streams dissected these gravels, forming a broad channel through the area, now represented by a lower terrace of outwash gravel, in which the modern Susquehanna flows with a border of characteristic flood-plain deposits. The presence of ice during the deposition of the gravels is further indicated in the area by the presence of a distinct back (north) slope, forming a broad, irregular valley along which the Lehigh Valley and Erie railroads pass. This valley is evidently the result of failure to deposit and not of subsequent erosion.

At other points in the valley the same appearance of local deposit is present. For example, 2 miles north of Osborn, on the north side of the river, there are distinct terraces with a pronounced westward grade ending on the west in a delta-like front. An extensive gravel cut here shows the layers dipping sharply westward, as in a delta, and quite unlike the layers of an outwash gravel plain. Moreover, some of the gravel cuts show sand below and gravel above; and many wells find clay beneath the gravels.

The total depth of the Susquehanna deposits is not known, but wells from 50 to 100 feet deep are numerous and fail to reach rock; and there are some deeper wells that do not pass entirely through the drift. The deepest well noted is on the south side of the Susquehanna, opposite Endicott, where rock was not reached in a well 150 feet deep. This well passed through 32 feet of gravel, 70 feet of blue clay, and 48 feet of coarse sand and gravel. At Goodrich Settlement a well 80 feet deep in sand and gravel failed to reach rock; but a report of somewhat indefinite character places the rock bottom here at 200 feet. In the center of Owego a well 101 feet deep passed through gravel, then sand, and did not reach the rock.

From the facts outlined above, it is inferred that the conditions in the Susquehanna Valley are the result first of the irregular melting out of the ice, either in the form of stagnant blocks or else during brief halts, building patches of outwash gravel in the form of esker deltas when the ice terminated in temporary lakes and of esker fans when the drainage away from the ice was free from obstructions. Later a large volume of sediment-laden water flowed down the valley, dissecting the earlier deposits, filling the depressions with sand, loam, and clay, and with gravels where the process lasted long enough, notably west of the mouth of Owego Creek. The Susquehanna, at first swollen by the glacial waters of some of the ice-dammed lakes, has since still further dissected the gravels and has built a flood plain of finer material which veneers a portion of them. That the river in its present condition did not trim the higher terraces into the forms they now have is proved by the gravelly character of the lower terrace, and by the presence in it of kettles (1½ miles north of Lounsberry, for example), which would surely have been filled if covered by the present stream.

ICE-DAMMED LAKE DEPOSITS.

HANGING DELTAS.

GENERAL FEATURES.

At several points high-level deltas are found in situations indicating the presence of small marginal lakes. Their positions are shown on the surficial geology map and they call for no special description.

In both the Seneca and the Cayuga valleys, however, there is an extensive series of perfect deltas hanging upon the hillsides at various levels along the larger tributaries, and less perfect deltas and gravel areas bordering the smaller streams. Along some of the streams from seven to nine distinct delta levels are found, producing a distinctly terraced appearance on both sides of the tributary streams.

The tops of these deltas are flat, with a moderate slope toward the steeply descending frontal end, and on their surfaces many well-defined channels leading to depressions in the delta margin are present. The margin is lobate or crenulated, with a very steep slope toward the main valley. The materials of which the deltas are made are water-washed gravel and sand, which numerous cuts show to be distinctly cross-bedded. Above the typical delta series there are morainic terraces near some of the streams, and these in places closely simulate deltas in form; in fact, some of them were evidently formed in marginal lakes while the ice lobes were actively moving up the lake valleys.

Many of the uppermost deltas, standing approximately at the 960-foot level, are hummocky and kamelike on the upper or back side, though having a perfect delta form in front. The site of these kame areas is commonly depressed below the delta level, and this fact, together with the kame topography, makes it difficult in many places to determine the exact boundary between delta and moraine. It is believed that these kame areas represent the beginning of delta building against and on the ice as it was receding from the level of the lowest lateral moraine, and that the delta material, finding its way upon stagnant ice, later settled into the jumble of kame topography. With the further melting of the ice, the enlargement of the marginal lakes, and the outward growth of the deltas the form of the deposit became that of a more perfect delta, resting on the land, not on buried ice.

These deltas were built in higher but rapidly shifting levels of Cayuga and Seneca lakes, when the glacier was melting out of these valleys and uncovering successively lower outlets. One long stage, represented by a series of perfect deltas, has been named the stage of glacial Lake Newberry, whose outflow past Horseheads has been described above. This lake was preceded by earlier stages in which local southerly outlets were occupied in each of the valleys; but as the ice melted away, and the local lakes coalesced, the lowest of the several outlets, that past Horseheads, became the outlet for the large Lake Newberry, made by the union of the lakes in the several valleys. When a lower outlet was uncovered farther north, the Horseheads overflow ceased, and the high-level lakes eventually drained eastward between the ice and the land through the Mohawk Valley. The lower deltas probably represent brief stands at the levels of several such outflows uncovered by the continued melting back of the glacier.

The general history of these lakes has been stated by both Fairchild and Watson,[a] but much yet remains to be done before the full details of this history are clear. For example, the lower deltas have not yet been correlated with any overflows, nor has it been shown that they rise to any such uniformity of level as would indicate general water levels. This and a number of other interesting questions arise concerning these deltas and their significance. Since answers to these questions demand detailed studying of a much wider area than that described in this folio, they will not be further considered here. When the entire region of the Finger Lakes has been mapped, the correlation of facts discovered by that study will doubtless settle most of the problems.

Notwithstanding the size of the deltas and the perfect form of most of them, it seems certain that the duration of the lakes of various stages was very brief. This is indicated by the general absence of well-defined shore lines, either constructional or destructional, between the deltas. The size and perfection of the deltas are due largely to the fact that the streams had an abundant supply of loose drift and rather high grades, so that the material could be readily and quickly removed to the successive lake levels. During the building of the upper deltas the streams had a series of moraines to trench, and these were at first bare of vegetation. For building the lower deltas there was added to this supply that of the deltas of higher levels, many of which have been cut in two by the streams that built them at the earlier lake stands.

HANGING DELTAS NEAR ITHACA.

It has already been stated that the receding ice dam across Sixmile Creek valley held up a marginal lake with an outflow across the divide at White Church; that it later received the waters of West Danby Lake through the marginal channel on South Hill; and that, with the uncovering of a lower outlet westward into the Seneca Valley, the lake level fell, forming a larger lake in both Cayuga and Seneca valleys, called Lake Newberry. With continued recession the lake dropped to successively lower levels. The evidence of this lake history is of four kinds—(1) overflow channels, (2) hanging deltas, (3) shore lines, and (4) lake clays. The overflow channels have already been described and the general features of the deltas have been stated. A few of the more notable deltas near Ithaca will now be described and interpreted.

The only delta in the Catatonk quadrangle which can be definitely associated with the Ithaca Lake, overflowing at White Church, is the very large delta at Brookton, which has an area of over a square mile and a perfect delta form both on its top and front. A deep cut made by Sixmile Creek at Brookton completely dissects it, revealing clay beneath; and an extensive gravel cut at the Lehigh Valley Railroad station clearly exhibits its delta structure, with foreset and topset beds. The construction of this delta was preceded by a deposit back of the Besemer moraine, northeast of Brookton, evidently supplied by marginal drainage. An overflow from Cascadilla Valley combined with the Sixmile Creek drainage from the Slaterville Springs region to make an extensive deposit back of the morainic loop, with an outlet along the base of the hill half a mile south of Brookton through the marginal channel already described. This stage lasted long enough to fill the depression back of the moraine and to build up a fanlike deposit. The main Brookton delta, which was built in the lake that was formed when the ice receded from the Besemer stand, continued to grow as the lake expanded, and ceased growing only when the White Church outlet was abandoned. It therefore had a long history, starting in a very small lake and ending its growth in a large lake. Its surface is at an elevation of about 1020 feet, which is more than 20 feet above the level of the outflow channel.

That neither Fall Creek nor Cascadilla Creek contains a delta of this stage is somewhat remarkable. It may be due to the presence of ice-block remnants in these valleys, which prevented the growth of good deltas at this stage. The nearest approach to a delta at this level is just east of Varna; but, as has been shown, this is really a morainic loop with a delta veneer on the south side. There is a considerable lake deposit east of Cornell University, between Fall and Cascadilla creeks, which may represent the White Church stage of deposition; but it is lower than the outlet, and is not a gravel deposit; nor has it a delta form. Some condition, while permitting the deposit of lake clays, prevented the formation of deltas at the Ithaca Lake level in Fall and Cascadilla Creek valleys.

South of Besemer a delta was built at a later stage in the Sixmile Creek valley, almost coalescing with the Brookton delta, but at a lower level. Its surface is at an elevation of 940 feet, and it is deeply dissected by Sixmile Creek and its tributaries. Belonging to this lower lake stage are well-defined deltas formed by both Cascadilla and Fall creeks. The Cascadilla delta lies just east of the East Ithaca station of the Lehigh Valley Railroad, and rises at the crest to 940 feet. The Fall Creek delta forms a gravel plateau, with perfect delta form and lobate western front, about a mile north of the creek and north of Cornell University campus. Its surface is between 920 and 940 feet in elevation. No attempt has been made to determine the heights of these delta tops by levels. They are believed to be deltas in Lake Newberry.

The situation of the large, perfect Fall Creek delta at a distance from the present stream is peculiar. Leading up to it, as indicated on the surficial geology map, is a well-defined channel, partly in rock. This channel emerges from the Fall Creek valley as a distinct valley in the drift at about the 960-foot level, about 100 feet above the present stream bed. It is broad and well defined, with a flat, swampy bottom, and is occupied in its lower course by the very small Pleasant Grove Brook, which wanders aimlessly about over the swampy floor. The channel is perfect across the divide between this brook and the drainage into Fall Creek. That this was the course of Fall Creek during the building of the hanging delta admits of no question; but why the stream flowed here and later changed

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[a] Fairchild, H. L., Glacial lakes of western New York: Bull. Geol. Soc. America, vol. 6, 1895, pp. 353–374; Glacial notes in the Finger Lake region of New York: Idem, vol. 10, 1899, pp. 27–68. Watson, T. L., Some higher levels in the postglacial development of the Finger Lakes of New York: Fifty-first Ann. Rept. New York State Mus., 1899, Appendix B, pp. R65–R17.

its course to its present channel past Cornell University is not so easily answered. There is a morainic barrier across the valley at Forest Home, but it is not nearly high enough to have caused the deflection. Moreover, the stream now crosses this barrier in a drift cut, reaching rock in its bottom, and if there had been two outflows it would seem probable that the ease of cutting in drift at Forest Home would have permitted this branch early to have robbed the northern branch, which cut its channel partly in rock. It seems necessary, therefore, to assume that there was an actual barrier which for a time prevented Fall Creek from following its present course, and that after the delta was built this barrier disappeared. No other barrier of this kind appears possible except a buried ice block, which, on melting out, permitted the creek to abandon its northern course and take its present one. Harmonizing with this view is the breadth of the Fall Creek valley at the point of former divergence of the stream, and the presence on its walls of an irregularity which is evidently constructional and of such form as is commonly present where ice blocks have rested. The same type of valley wall occurs in places between this point and Varna. This explanation of deflection of the stream by a buried ice block is therefore offered with some confidence to account for the peculiar facts discovered. If this explanation is correct, it is further evidence of the briefness of the stand of this lake, and consequently of the rapidity of recession of the ice. It would also make more probable the explanation suggested above, that the presence of ice blocks in Fall and Cascadilla creeks prevented the development of deltas during the higher stand of water in the Ithaca Lake stage.

Both Fall and Cascadilla creeks have a succession of lower deltas forming a practically continuous gravel deposit, in delta steps, down the steepened slope of the main valley on both sides of each creek. These have not been compared by careful levels, and the lake outlets to which they correspond are unknown. Similar deltas occur in the Sixmile Creek valley, but as that valley is lower and its slope less steep, they are farther apart and less continuous. Moreover, they are deeply dissected by Sixmile Creek and its tributaries, so that they are very imperfect in form, being represented mainly by small areas of gravel plateau on the valley-bottom clay and moraines.

Each of the other creeks in the upper Cayuga Valley, notably Buttermilk (Tenmile), Lick Brook, Coy Glen, Butternut (Enfield), and Newfield, has a succession of deltas similar to those described; and the streams entering Seneca Lake are similarly fringed by hanging delta steps.

SHORE LINES.

Shore-line phenomena associated with these several lake levels are so faint as to have escaped detection in all but a few places. For example, about 2 miles east of Ithaca, on the western base of Eagle Hill, at and just below the 1000-foot level, is a pronounced shale cliff with a narrow, bowlder-strewn area at its base. The cliff is complex, consisting of one well-defined cliff and two minor ones at slightly higher levels. The bowlder-covered area is not level bottomed, but slopes westward somewhat like a bowlder pavement. It extends about half a mile southwestward with diminishing importance. Toward the northeast there is a low gravel ridge, at the same level, which appears to represent a beach. Up to this level the lake clay extends. The phenomena are not sufficiently developed to warrant definite interpretation as of shore-line origin, but they suggest this origin rather than that of marginal drainage, though the two higher cliffs may be due to the latter.

On the nose of South Hill, 2 miles south of Ithaca, there is a low shale cliff below the level of the marginal channel described in a preceding section. Being below the level of the outlet, and at the proper elevation for the glacial Ithaca Lake, this cliff is interpreted with some confidence as a wave-cut cliff on the shores of that lake. A gravel deposit, apparently a beach, occurs at the same level a little farther southwest.

About 2 miles north of Forest Home, near the 1000-foot level, there is a band of abundant bowlders, possibly also of shore-line origin. Other bowlder lines occur at various points at proper levels for association with some of the higher lake stages; and there are also shale cliffs apparently of wave origin. No attempt has been made to map and correlate these indistinct and discontinuous shore lines, though it can undoubtedly be done.

LAKE CLAYS.

The deposition of so much sand and gravel as is found in the deltas of various levels represents the assortment of a much larger quantity of drift from which the streams removed the clay. The supply of delta material came partly from till, in which there is much clay; and the attrition of rock fragments in the stream bed supplied still more clay. The sand and gravel residuum was accumulated to form the deltas near the point of entrance of the streams into the high-level lakes; but the clay was carried off in the lake waters, settling to the bottom away the shore. Such lake clay is revealed here and there in cuts at the base of the deltas, which were built out over it; and its presence in this situation is even more commonly indicated by the occurrence of springs at the delta base.

As indicated on the surficial geology map, there is, in addition to this occurrence of lake clay, a widespread distribution of it on the steepened valley slopes, which were the high-level lake bottoms. This clay is characterized by very fine grain, distinct lamination when revealed in fresh cuts, a chocolate-brown color, and a cracked and crumbly appearance, producing small cubical forms when exposed to the weather. (See fig. 37, illustration sheet II.) Near small streams the clay may grade into sand or sandy clay.

There are very few stones in the lake clay, and a dozen borings with the soil auger to a depth of 3 or 4 feet may not encounter a single one. The surface, however, is in places covered with stones, having the appearance of a till area, but that the material is not till is easily disproved by boring into it and finding pure clay beneath the surface veneer of stones. These stones are too abundant to represent residual material from the washing away of the clay, and their exact origin is not clear. They may represent the action of shore ice drifting coarse fragments into the lake, or the washing down of such fragments from the upper hillside. Some of the more strongly developed stony areas occur near streams, which may have supplied the stones, possibly frozen in ice. These fragments are in places so abundant that stone fences are occasionally built on lake-clay land where borings with the soil auger encounter no pebbles; but generally the stone fences extend from the till areas to the clay, and there end.

The lake-clay sheet nowhere rises above the level of the upper deltas, but is replaced there either by till or moraine. On the lower steepened slopes it is either absent or so thin that it can not be detected, doubtless having been washed away by the waves of the receding lake, or by later rain wash. Between the upper delta level and these steeper slopes the clay is distributed somewhat unequally, and in places is absent, especially in areas remote from large streams. Its presence is indicated by muddy and rutted roads; where it is thick a pronounced ridging of the hillside, by closely set erosional channels extending straight down the slope, calls attention to it. Some of these ridges are from 10 to 20 feet high, and the erosion has in places reached down to the underlying till. This marked erosion of the lake clay, well illustrated on the Cornell campus, below the library, gives rise to a distinct type of topography and shows that at some stage, probably before it was covered by vegetation, this fine-grained deposit was readily worn away. When thoroughly wet the clay is almost liquid and runs easily, and this doubtless accounts for the fact that it is more distinctly eroded than ordinary till.

In thickness the clay varies greatly, being in some places fully 20 feet thick, but in others less than a foot. In much of it the soil auger reaches underlying till at a depth of 1 or 2 feet, and in many places till is found in gullies 5 to 10 feet deep. Doubtless all the hill slope was at one time covered by a layer of lake clay of variable thickness, which has been removed from the steeper slopes, and, where thin, worked in with the underlying till by the overturning of trees and by plowing. There are places where the concentration of the clay in belts suggests deposition in lakes marginal to the main valley lobes, as, for example, south of Ithaca, on the hill slope between Buttermilk (Tenmile) Creek and Lick Brook, where it is developed with especial strength between the 800 and 900 foot levels. In this locality the clay ends abruptly on the lower side and has a depth in the middle of fully 20 feet in places. Elsewhere the lower limit of the clay is at different levels; and on the whole the facts indicate that, though in some places it may have been accumulated in marginal lakes, its deposition was continued into the stage of general lakes.

OTHER LAKE DEPOSITS.

In preceding sections some of the lacustrine conditions have been described; for instance, in the Lisle Valley, in the Susquehanna Valley, and back of the moraine loops in many of the tributary valleys, as at Caroline, Burdett, Odessa, and southwest of Montour Falls. Minor lakes must also have been formed in many of the smaller valleys, and in some places the evidence of this is clear. For example, the Cascadilla Valley must have held a marginal lake during the recession of the ice; but although there is much gravel and clay, definite marginal lacustrine deposits have not been detected here. This may be due to the fact that the deposits were laid down on buried ice and later, by the melting out of the ice, given an irregular topography. The outlet of this lake is clearly defined south of Ellis. Similarly a lake must have been formed in Buttermilk (Tenmile) Creek back of the pronounced morainic loop. The outlet of this lake is also clear at Danby, and the flat at and near Danby is doubtless the result of lacustrine deposit; but later stream wash has somewhat obscured the evidence.

In many of the valleys, but nowhere better than in the Sixmile Creek valley below Brookton, there are extensive but very confused deposits of lake clay and gravel, locally faulted and greatly crumpled. (See fig. 35.) Some of this material may represent deposits made during the ice advance, but much of it is undoubtedly associated with the lacustrine condition during the ice recession. The outflowing of glacial waters supplied both gravel and clay, and their present confused position is clearly the result partly of ice thrust in temporary advances, and partly of slumping from the melting out of buried ice on which the deposits were in part laid down.

As already stated, large quantities of lake clay occur in the morainic areas south of Ithaca and Watkins. Similar clays are found in several other morainic areas that were built where the ice front stood, in lakes caused by ice dams across side valleys. Deep wells also indicate the presence of a great thickness of lake clay under the Ithaca and Watkins deltas, and beneath the outwash gravels in the neighborhood of Horseheads.

Some of the clays mentioned in the last paragraph may have been accumulated in lakes formed during the advance of the ice, but none of them are sufficiently weathered to warrant classification with an advance earlier than the Wisconsin. The mere fact of finding such clays under outwash gravels, or even under till, does not signify that they were formed earlier than the closing stages of the Wisconsin ice sheet. At one point, however, on the north bank of Watkins Glen, just above the railroad bridge, there is a deposit of stratified blue clay and sand resting on a bed of compact, partly cemented sand and gravel, and overlain by fully 100 feet of morainic material. These beds are accumulated in the old, buried interglacial gorge of the Watkins Glen stream. In the layers immediately above the gravel, a perfect leaf of an arctic willow, identified by Dr. Knowlton as *Salix reticulatus*, was found, indicating the prevalence of a cold climate during their deposition. The great thickness of overlying moraine and the depth in the old gorge at which the fossil was found make it impossible to interpret the leaf-bearing bed as contemporaneous with the close of the Wisconsin ice occupation; and the slightness of the weathering of the matrix is opposed to an age earlier than the Wisconsin. It is probable, therefore, that this deposit was made during the advance of the Wisconsin ice, when an ice-dammed lake occupied the older Watkins Glen gorge. The position of this plant-bearing bed in a deep, steep-walled gorge would protect it from removal by later ice erosion. As the glacier advanced, damming the northward-flowing streams, there must have been much clay deposited, and doubtless this in in part incorporated in the moraines of these quadrangles, where it would be very difficult to prove its age.

RECENT DEPOSITS.

FLOOD-PLAIN DEPOSITS.

The modern streams have cut valleys, both in drift and rock, which through meandering of the streams have been made wider than the streams themselves; those in drift are several times as wide as the ordinary stages of the streams. Over these broad, flat bottoms the streams have strewn débris, and many of the streams, especially the larger ones of moderate grade, rise over these débris accumulations in times of flood. In many places, too, there are higher, stream-cut terraces on the tops of which lie deposits made when the streams were flowing at those levels. Many of these terraces are defended by rock, compact clay, or till, and remain undestroyed.

These flood-plain deposits are of two opposite kinds, with every intermediate stage of gradation. At the one extreme, the steeply descending streams from the uplands have deposited exceedingly coarse gravel and cobbles, among which are both fragments brought from upstream and residual fragments from the drift that the streams are removing. In the latter category are to be included the large bowlders, weighing tons, which the streams have been unable to move and have left in many of the valley bottoms. Some of such flood plains are occupied by farms, though not usually the most productive; but more commonly they are too narrow and stony and too subject to torrential inundation to be of use for farming.

At the other extreme are the broad, level flood plains of the larger streams, notably Chemung and Susquehanna rivers, on which clay, sand, or fine gravel are deposited, in many places making excellent farm land, though subject to inundation. The streams of moderate size and grade have flood plains intermediate between these two extremes, and are the seats of many good farms.

Where the streams flow through areas of glacial gravel, the pebbles of the flood plains are well rounded and locally difficult to distinguish from the outwash gravels; but the larger streams, not being able to transport the coarser fragments, flow through these gravel areas in flood plains of a fine loamy character, veneering the gravels. This kind of flood plain is best illustrated along Susquehanna River.

ALLUVIAL FANS.

One of the most prominent kinds of postglacial deposits in these quadrangles, especially in their southern half, is the alluvial fan, built where streams of steep grade emerge from their hillside valleys upon the level bottoms of the major valleys. These fans are made of coarse gravel, not very well rounded and usually not well assorted. This gravel represents the concentration of the coarser fragments removed from the hill valley. As this material is usually either shale removed from the bed rock or angular fragments obtained from the till, the materials comprising the fans are in general only partly rounded, and thus fairly easy to distinguish from outwash gravels; but where the hill stream is cutting away deposits of the more rounded glacial gravels it is more difficult to delimit the boundaries of the alluvial fans.

At ordinary times the streams are not adding material to the fans, but the water sinks into them near their heads, many of which are in gorges cut in the hillsides. In times of flood, on the other hand, especially during the melting of the snows and during heavy summer thunder storms, the current becomes torrential, and great quantities of gravel are brought down and deposited on the gentler slope of the fans. So much material is deposited at such times that the stream bed is filled, and the water, with its sediment load, is turned out of its channel over part of the fan. It is by such frequent shiftings of the channel, in the coarse of time reaching all parts of the alluvial fan, that the deposit is built up symmetrically into its typical fan shape, with a slope radially outward in all directions from the point where the stream emerges from its hillside valley. As the fan is built upward, the lower course of the stream in the hill valley is also aggraded, and consequently the gorge bottom is often covered in its lower portion by a deposit of stream gravels obscuring the bed rock over which the stream once flowed.

The frequent shiftings of the fan-building streams cause much trouble and expense, for roads and bridges are washed away and portions of the fans are inundated with a flood of coarse stream pebbles. As the roads commonly ascend the hills along the stream valleys, starting at the heads of the alluvial fans, much destruction is done to them during these floods; and there is no more common type of road mending than that in which man is repairing the damage done by the alluvial fan-building streams. It is a contest in which the stream has the advantage, and in many instances man has given up the struggle, either abandoning the roads entirely or else remaking them at a distance from the streams. Tillage and removal of the forests, by giving greater loads for the streams during floods, have evidently caused an increase in rate of growth of the fans.

Many of the smaller villages are built on alluvial fans, partly because these deposits furnish level, well-drained building sites, but largely because they lie at the intersection of natural routes, where roads descend along the streams from the uplands and intersect roads along the larger valleys, Messengerville, Marathon, Killawog, Lisle, Harford Mills, Richford, Berkshire, Tioga Center, Nichols, and other places illustrate this.

Though the form of these deposits is typically that of a regular fan, the shape of many of them is distorted by the narrowness of some of the smaller valleys; by the deflection of the fan-building stream down some of the valleys; and, in some cases, by the emergence of two fan-building streams at essentially the same point, as at Berkshire, on the East Branch of Owego Creek. There is much difference in the slope of the alluvial fans, some, like that on which Watkins is built, being gently sloping, and others, built by small streams descending precipitous valley sides, being almost as steep as gravel will stand. The latter are sometimes called débris cones. The alluvial fans differ also in height, the steeper ones forming steeply sloping hills, and some of those of moderate size having such grades that in ascending them a horse is commonly allowed to walk. As a type of the large, gently sloping fans, mention may be made of the one about a mile north of Big Flats, where, in a distance of about three-quarters of a mile, there is an ascent of 80 feet from the lower to the upper end of the fan.

There is a marked difference in the extent of the alluvial fans, which is not always directly dependent on the size of the fan-building stream. Among the other factors which determine the size of the fans are the abruptness of the change in stream slope, the levelness of the valley bottom on which the fan is being built, and the abundance of detritus available to the fan-building stream. Where there is a level surface in the valley bottom and a great mass of glacial deposit open to rapid removal by the fan-building stream, the resulting fan may be very large, like the one north of Dryden. The striking development of alluvial fans in this area is due in part to the fact that the main valleys are so filled with glacial débris as to bring about a degree of levelness which could not be produced in a normal river valley in the same stage of development, thus introducing the abrupt change in slope which is so important a factor in alluvial-fan formation.

The alluvial fans are locally built in such positions as to retard the drainage of the valleys into which they extend, forming swamps and even lakes. It has already been pointed out that the Horseheads outlet owes its swampy condition in part to the obstruction of drainage caused by the small alluvial fans of streams entering it. A swamp near the head of Baldwin Creek, 1½ miles south of Breesport, is caused by alluvial-fan obstruction; and a small pond and swamp in the Lake Newberry outlet, about a mile north of Pine Valley, are caused by an alluvial-fan dam. Where the alluvial fans compete with larger streams they often succeed in deflecting the main stream. This is nowhere better illustrated in this area than in the Cayuta Creek valley between Van Etten and Lockwood, where practically all the major bends in the creek are determined by the deflective effect of the fans that the tributary streams have built. Cayuta Creek is so mastered by these fans that it is turned alternately from one side of the valley to the other, and in places has even been forced to cut against the inclosing rock wall. The same condition is well illustrated in the Tioughnioga Valley at Messengerville and Killawog, and on the East Branch of Owego Creek at Harford Mills and Berkshire, where the main stream is pushed over against the opposite valley wall by the growth of an alluvial fan.

The influence of the alluvial fans of the hanging-valley streams that emerge upon the deltas at Watkins and Ithaca is very marked and important. At Watkins the larger stream comes from the west and the highest and driest part of the delta is on the west side, while the east side, to which the inlet has been pushed, is swampy. Exactly the opposite condition exists at Ithaca; and in both places the locations of the towns are determined by the presence of these fans.

Mention has been made of the fact that the alluvial fans are better developed, both in area and height, in the southern than in the northern half of this area. This greater development has occurred in spite of the fact that there is a thinner till cover in the south than in the north; but this difference in the amount of till is not so effective as might at first appear, as there is much drift, not yet all removed, in the buried-gorge valleys of the southern region. Three factors enter into the explanation of this condition—(1) the greater general steepness of the valley sides in the south; (2) the greater extent of flat-bottomed valleys in the southern region, where the main valleys have been leveled by outwash gravels; and (3) the greater length of time that this region has been exposed to postglacial erosion. No facts are known to the writer which will permit a statement of the proper relative importance of these factors; but as it is not evident that the fan-building streams have performed notably greater erosion in the south than in the north, it seems necessary to assign to the third factor the least importance. The general truth of this conclusion is further indicated by the fact that destruction by fan deposit, and changes in the course of fan-building streams are more commonly seen in the southern than in the northern part of the region.

HANGING ALLUVIAL FANS.

In some of the larger valleys, but notably in the Susquehanna Valley, there are distinct alluvial fans, now dissected by the fan-building stream and with a new fan growing at the periphery of the older fan and in the cut through it. Some of these older fans have a steep front, locally irregular and somewhat morainic. They were undoubtedly developed with a higher base-level, and apparently against the ice blocks which were left stranded in the major valleys. The positions of the more notable of these fans are indicated on the surficial geology map. In the Susquehanna Valley some of them merge into outwash gravels.

MODERN LAKE DEPOSITS.

Along the shores of Cayuga and Seneca lakes the streams that descend the steepened slopes through the gorges have built deltas of triangular form. Like the alluvial fans, they are made up of coarse fragments, largely shale, derived from the gorges; and they resemble the fans in the fact that they have a decided slope from the mouth of the gorge to their edge. They differ from alluvial fans in the possession of a steep outer slope beneath the lake water, and in the fact that the apex of the triangle is not at the head of the delta, but usually on the end toward the lake. The latter fact is due to the influence of the lake waves and currents, which distribute the delta materials along the shore. Most of the streams on the east side of the lakes are on the north side of the deltas, because the prevailing effective waves and wind-formed currents are from the north, so that the materials brought by the streams are driven southward.

Between the deltas there is a narrow beach, backed at many points by a wave-cut cliff, in some places of decided prominence. The high shore resulting from the cutting back of these cliffs and the narrow beach strip are unfavorable to the location of summer homes; but many of the deltas are occupied, especially those on the west side of the south end of Cayuga Lake.

In both Cayuga and Seneca lakes the inlet streams have built large and very level deltas, each about 3 miles in length. These deltas are still in process of construction, both at their margin beneath lake water and on their surface, which in the lower parts is frequently flooded. By these floods, and by the growth of swamp vegetation, the delta level is being slowly raised. As has been already stated, the deltas are highest at those points where side streams are building alluvial fans upon them. At Ithaca the depth of drift deposits at one point in the delta is 435 feet, and at Watkins 1080 feet; but only the upper portion of this material is delta deposit—at Ithaca the upper 100 feet or thereabouts.[a]

By the grinding of the shale fragments on the beaches, and by the assortment of stream-borne materials, clay is supplied for deposition on the lake bottoms away from shore, whither it is drifted by the wind-formed currents. When the waves are high the water is discolored with clay for a considerable distance from the beaches; and after heavy rains or the melting of the winter snows the lake water is discolored for a long distance beyond the mouth of each of the streams. These modern lake-clay deposits doubtless already form a thick bed over the bottoms of the lakes; and by their accumulation, together with the outward growth of the deltas, the lakes are being slowly but surely filled. The greatest effect of lake filling has been accomplished at the lake heads, where a large amount of sediment is supplied by the inlet streams and their tributaries.

SWAMP DEPOSITS.

There remains but one class of Quaternary deposits to be considered—the bogs caused by the accumulation of partly decayed vegetation where, by some obstruction to drainage, there is either standing water or a condition of dampness sufficient to encourage the growth of swamp-loving plants, and partly to protect them from decay. These swamps, which are scattered over the two quadrangles, are for the most part too small to map; but there are a few of fairly large size.

There are several causes for the swamps, but undoubtedly the most common is the occurrence of springs, many of them on the hill slopes, around which sphagnum moss and other water-loving plants grow, forming a bog. These springs are always of small size, and in the hottest part of summer may dry up.

A second cause, also very common, is the accumulation of water in the bottoms of kettles in the moraines, the hanging deltas, and the outwash gravel plains. The largest swamp of this class is in the kettle at the head of the outwash plain at North Spencer, already described; and others of good size occur in the moraine north of this. Such kettles have swamps, rather than lakes, because the materials inclosing them are loose, open sand and gravel through which the water seeps rather readily. But the decay of the gravel, the inwash of fine rock fragments, and the growth and decay of vegetation form a sufficiently impervious cover to the bottoms of many of the kettles to prevent the complete escape of water by percolation.

There are numerous swamps, usually of small size, behind drift obstructions near divides. These occur in such situations, not because drift obstructions are more common there than elsewhere, but largely because the small headwater streams have not had sufficient cutting power to trench the barriers and drain the swamps. The influence on topography of the horizontal strata, which often render the divides nearly flat-topped, is an additional reason for a greater abundance of fairly large swamp areas on the divides than lower down the valleys. Of this origin is the swamp on South Hill, 3 miles south of Ithaca. When the ice first melted away from the upland similar swamps were doubtless common farther down the valleys.

As has been stated above, some swamps are formed behind alluvial fans. The level bottoms of the overflow and marginal channels are also favorable places for the slack drainage which develops swampy conditions. The long, swampy tract in the bottom of a part of the Horseheads outflow, already described, is but one of a number.

There are many swampy areas on the flood plains, especially along the larger streams, both where the level land is unfavorable to drainage, and in places where abandoned channels are still marked by depressions, though partly filled with sediment. A final cause for swamps is where level modern deltas are being built into lakes, as in Cayuta, Cayuga, and Seneca lakes. These delta surfaces have not been sufficiently graded to permit free drainage and consequently are so level, so low, and so frequently inundated that water stands upon them most of the time. The three areas mentioned are the largest swampy tracts in this region.

Some of these swamps contain peat which may be of use as fuel or fertilizer; and doubtless in some there is bog iron ore, and possibly infusorial earth or marl. The latter substances are of so little value, however, and their possible extent so slight, that they can scarcely be considered to be resources of importance. At present most of the swamp areas are waste land and a menace to health, especially those near the towns, as at Ithaca and Watkins. Their drainage is therefore to be desired, and where it has been undertaken, excellent farm land has been made; but much yet remains to be done.

MASTODON REMAINS.

Remains of mastodons have been found in two places in the Catatonk quadrangle. One of these was a few hundred yards north of Center Lisle, in a boggy place where a spring emerges from the base of a gravel terrace. The other was a swamp in

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[a] Tarr, R. S., Artesian well sections at Ithaca, N. Y.: Jour. Geology, vol. 12, 1904, pp. 69-82.

the valley bottom at Brookton. In both places the remains occurred in such a situation as to warrant the inference that the animals may have mired there after the valleys were cut down to their present levels. It is equally possible to infer that they were washed out of the gravels and, by chance, concentrated in these swampy areas. With the present information it is not possible to decide between these possibilities.

HISTORICAL GEOLOGY.

SEDIMENTARY RECORD.

By Edward M. Kindle.

GENERAL OUTLINE.

The geologic history recorded by the strata exposed in the Watkins Glen and Catatonk quadrangles is similar in its general features to that of the region extending for 50 miles to the north, 200 miles to the east, and 1000 miles to the southwest of central New York. The geologic time represented is the Devonian period, and the particular stages are the Hamilton, Tully, Genesee, Portage, Chemung, and Catskill. The rocks comprising the Hamilton and Tully formations do not appear at the surface in these quadrangles. They are included here, however, because the sediments of the Hamilton continued to accumulate and the fauna characterizing them lived on in the eastern part of New York throughout the Tully and Genesee epochs.

The sediments making up these formations were probably derived from land surfaces situated to the north, northeast, and east of the quadrangles, with shores not many hundred miles distant at any time and probably nearer than 100 miles during the deposition of the Chemung. From study of the geographic distribution of the materials of the formations it is inferred that there was connection by channels with the general oceanic basin. At the same time the area was shut off from the sea on the northeast, east, and south. Over nearly the whole of the gulf thus formed the argillaceous sediments comprising the Hamilton shale were spread until new conditions initiated calcareous deposition over the central part of the gulf, resulting in the Tully limestone. During the deposition of this limestone in the more central parts of the basin the argillaceous and arenaceous Hamilton sediments continued to be deposited over the area nearer the coast of Appalachia. After the close of Tully sedimentation the deposition of Hamilton sediments and the much finer Genesee sediments continued over about the same relative portions of the sea bottom as were occupied by the Tully and Hamilton. Thus the Tully and Genesee cycle of sedimentation was contemporary with the later part of the much longer Hamilton cycle.

The fineness of the sediment in the Genesee shale and its even and regular deposition in thinly laminated beds indicate quiet seas and distance from land; the coarser sandstones and shales of the Chemung indicate more disturbed sea bottoms; toward the top conglomerates, holding small-sized pebbles, point to rapidly moving waters not likely to occur except near the shore of the basin. The hypothetical land area lying to the east and south of New York in the Devonian age has been called Appalachia, and that to the north, including the present crystalline rocks of eastern Canada and the Adirondacks, has been termed Laurentia. The history may be expressed in four deposition stages recorded by the sedimentary formations.

GENESEE DEPOSITION.

During the Genesee epoch of sedimentation thinly laminated, fine-grained black shale was accumulating. This shale represents the finest products of land erosion; the minuteness of its particles rendered possible its dispersion over the sea bottom far beyond the mouths of the streams which furnished them. Finely macerated plant material was deposited with the inorganic materials to produce the characteristic carbonaceous black mud of this epoch. It is not improbable that much of this material came from low lands to the southwest which were subject to less vigorous erosion than the highlands of Laurentia and Appalachia and furnished correspondingly finer sediments. The absence of coarse clastic material from the Genesee shale and the extreme fineness of the sediment composing it indicate its deposition on a portion of the sea bottom somewhat remote from the shore line. The Genesee sediments extend eastward in New York only within 75 or 100 miles of the probable eastern shore of the Appalachian gulf of that time; their place in the sections nearer the old shore line is taken by the coarser rocks characteristic of the Hamilton and Portage formations. The absence of wave marks from the beds of the Genesee points to their deposition in quiet waters on a sea bottom not subject to wave action, and probably much deeper than that of the succeeding Portage interval. Beds of seaweed may have covered the surface, as in the sargasso seas of the present day, supplying by their decomposition and maceration the carbonaceous material of the shale. The marine conditions which prevailed during Genesee sedimentation were highly unfavorable to molluscan life, but just what these conditions were it is difficult to determine. The greater part of the Genesee shale beds are almost completely barren of animal remains, although *Lingula*, *Orbiculoidea*, and a few other types occur in the upper part. The appearance near the top of the Genesee sediments of thin lenses of calcareous sandstone in the midst of the black shale indicates a change either in the source of the sediments or in the conditions prevailing in the region whence they were derived.

PORTAGE DEPOSITION.

The initiation of the Portage sedimentation is reflected in a change in the color of the sediments from black to gray. The disappearance of the excess of carbonaceous matter from the sea was accompanied by the appearance of coarser sediments which produced the characteristic sandy shale and flagstone of the Sherburne member. In the eastern part of the Watkins Glen quadrangle the change in conditions was more abrupt than in the western part. In the Seneca Lake basin shale of lighter color was interbedded with the black carbonaceous shale of Genesee type before the Portage conditions entirely prevailed. After the final withdrawal of Genesee conditions there was deposited a great series of sediments composed of dark-gray thin-bedded sandstone, flagstone, and shale about 1200 feet thick. That these beds were deposited in a comparatively shallow sea is shown by the wave marks which generally characterize the thinner-bedded flagstone. There is no indication that any part of this area was above sea level at any time previous to the close of the Chemung, but a few local submarine unconformities were developed during the Portage epoch. An example is to be found at Watkins Glen in Cathedral Hall (see fig. 19, illustration sheet I), where the horizontal sandstone strata have been cut away to a depth of 3 feet or more across a space of about 40 or 50 feet. On the steeply sloping sides of this shallow trough lie the inclined strata which have been deposited after its excavation. Strongly developed wave marks characterize the stratum lying on the beveled edges of the eroded beds. This excavation, which appears to have been produced without the interruption of sedimentation elsewhere, may have resulted from the action of strong tidal currents.

Other examples of what may have been local erosion may be seen in the dark argillaceous shale at Ithaca, which contains sandstone lenses that have been called "channel fillings." These lenses, with a thickness of usually 9 to 12 inches, have a width of 5 to 8 feet and a length many times greater than the width. They lie in shallow depressions in the dark shale and are confined to a thickness of about 20 feet of the upper part of the Sherburne member. Whether these sandstone-filled channels are of tidal or other origin, they appear to indicate the action of some submarine erosive force soon after the deposition of the beds in which they occur.

With the opening of Portage time a new marine fauna appeared in this region and became dominant, continuing through the Portage and characterizing the rocks of the formation throughout its extent. Various names have been applied to this Portage fauna, according as one or another of its common fossils has been regarded as dominant. *Buchiola* (*Cardiola*, *Glyptocardia*) *speciosa* and *Manticoceras pattersoni* (*intumescens*) have both served this purpose. The fauna is conspicuous for its pelecypods, cephalopods, and gasteropods and for the almost complete absence of brachiopods. The conditions which accompanied Genesee sedimentation had left the sea bottom nearly barren of marine life, so that the new fauna expanded over a nearly unoccupied area. The Portage fauna remained for a time in undisturbed possession of the region. After the deposition of about 250 feet of strata (the Sherburne flagstone member), however, a brachiopod fauna appeared in association with it and so far exceeded it in number of species as to dominate entirely. This was the Ithaca (*Spirifer pennatus posterus*) fauna—an outgrowth of the Hamilton or *Spirifer pennatus* fauna which appears to have pushed into the region of the Catatonk quadrangle from the east, as is indicated by its much fuller representation on the east side than on the west side of the Watkins Glen–Catatonk area. In the Watkins Glen region the Portage fauna is dominant throughout the thickness of the Portage formation, except for a few thin zones within its lower 300 feet which contain more or less abundant representatives of the Ithaca fauna. In the rocks filling the same stratigraphic interval on the east side of the quadrangle the Ithaca and homeotopic faunas prevail throughout. The Ithaca fauna shows close affinity with the older Hamilton fauna, but many of its species are modifications sufficiently definite to be called distinct species. In the eastern portion of the State the Genesee shale and the limestone of the Tully are absent and do not separate the Hamilton from the Portage type of sediments. Where such conditions prevail the continuance of the Hamilton fauna, with evolution of its species, is noticed throughout that part of the geologic column represented by the Genesee and Portage in western New York.

The zone holding the Ithaca fauna on the Ithaca side of the Catatonk quadrangle is over 300 feet thick, and, although the lithology of the rocks is not sharply distinct, there is a greater proportion of clay than of sand in them. The tough, thin-bedded, locally wave-marked strata are conspicuous throughout the parts of the Portage dominated by the pure Portage fauna, while softer shale prevails in the zone of the Ithaca member, and in the soft shale the richer brachiopod fauna occurs.

CHEMUNG DEPOSITION.

After the deposition of about 1200 feet of flagstones, sandstones, and shales of the Portage formation Chemung sedimentation was begun by more or less distinct changes in the character of the sediments. The prevailing color changed from dark bluish gray to a light drab. The tough, hard, arenaceous shale with knifelike edges, which characterized the Portage, was succeeded by comparatively soft shale cracking into blocky fragments.

The change in the fauna, however, was much more pronounced than the change in the sediments. The new fauna was characterized by such alien species as *Dalmanella tioga*, *Douvillina mucronata*, *Spirifer disjunctus*, and large Productellas. After the first appearance of the Chemung fauna several incursions of a nearly unmodified Hamilton fauna took place. These faunules of Hamilton species came from the eastern part of the province, where the typical Genesee and Portage conditions had not extended and where some species of the Hamilton fauna continued with scarcely any change throughout those epochs. The great abundance of molluscan life during the Chemung, with corals and crinoids in less abundance, resulted in the development at various horizons of local layers of limestone composed largely of their shells. The presence in the upper Chemung of two or more thin lentils of conglomerate, in places showing pebbles 2 inches in diameter, attests the proximity of the lands which supplied the sediments at this time. In the upper part of the Chemung (the Wellsburg member) many thin-bedded, tough flags appear in the sections in the western part of the region, indicating the approach of the conditions which produced the thin flags characteristic of the Catskill beds.

CATSKILL SEDIMENTATION.

Such conditions prevailed in the southeastern part of the area before the Chemung type of sedimentation had ceased in the western part of the Watkins Glen quadrangle. In the high hills in the southeastern part of the Catatonk quadrangle the thin-bedded, coarse-grained micaceous sandstone and chocolate-colored barren shale afford indications that the marine conditions of Chemung time prevailing toward the west were here interrupted by brackish or fresh water conditions, which led to the disappearance of Chemung life in this region and the appearance of Catskill fishes. In this southeastern region marine conditions did not reappear, except transiently, after Catskill sedimentation had manifested itself, while in the more western area Catskill conditions only slightly and temporarily invaded the region and interrupted Chemung deposition during the period represented by the sediments of these quadrangles. The latest marine fauna occurring in the southeastern part of the Catatonk quadrangle contains *Tropidoleptus carinatus*, which is a prominent representative of the Hamilton fauna.

Throughout the deposition of more than 2500 feet of strata comprised in the Portage, Chemung, and Catskill rocks of this area the deposition of sediments on a slowly subsiding sea bottom went on without interruption. The complete record of the deposition has not been preserved, for the latest deposits which were made previous to the emergence of this region above sea level have been destroyed by erosion. It is highly probable, however, that sedimentation continued here into Carboniferous time, as it did in the adjacent portions of Pennsylvania. The emergence of the surface of this region above sea level probably occurred during the early Mississippian stage of the Carboniferous, as no rocks of later age appear in the region. The land rose over a great area in New York and the present Allegheny region, and sedimentation was replaced by surficial decay and erosion. During the subsequent history of the region the rocks have been subject to the action of mountain-building forces and to the processes of erosion. Some of the effects of the action of the former are considered under the head of structure; the latter are treated in part in the section on topography and in part that on the glacial history.

The history of the region as affected by the ice invasions of the glacial epoch is described in the section on the Quaternary system.

FAUNAL SUCCESSION.

The faunal history of this region is complex, owing to the fact that two diverse faunas (Ithaca and Portage) flourished at the same time in southern New York during the interval represented by the lower portion of the geologic section in these quadrangles. Each of these faunas in the region of its maximum development contains traces of the other, thus indicating their contemporaneity, independently of the stratigraphic evidence, which points unmistakably to the same conclusion.

To understand clearly the faunal relations existing during Portage time it is necessary to recall briefly the marine conditions which immediately preceded it. Throughout central and western New York and over a great extent of the Paleozoic sea to the west and south of New York the black shales of the Genesee were deposited at the end of the Hamilton epoch under conditions which were so unfavorable to marine life that very few species of the rich Hamilton fauna survived them in that area. Into eastern New York, however, Genesee conditions did not extend. Deposition of the Hamilton type of sediments continued there during Genesee time and the Hamilton fauna lived on in this eastern region in the unchanged and favorable Hamilton conditions until after the close of Genesee sedimentation. As a result, the conditions that prevailed at the close of the Genesee in the east were totally different from those in the west. In the east the Hamilton fauna continued to live, modified only by the evolution of certain of its species; in the west a nearly barren sea offered itself for the occupancy of any migratory fauna. This open field was promptly taken by the *Buchiola-Manticoceras* fauna in western and central New York at the close of the Genesee epoch.

As a result of the conditions which have been briefly sketched, there were at an early stage of the Portage epoch two widely different faunas contending for supremacy. These were the Ithaca fauna from the east, representing the modified Hamilton, and the Portage fauna from the west. Another element to which the complex faunal relations are due is the very gradual change in the character of the sediments. Nowhere in the section above the base of the Portage is there a distinct and abrupt change in the type of the sediments, such as usually accompanies a radical faunal change. As a result there are no abrupt general faunal changes. In this region faunas do not disappear from the higher strata entirely as faunas, but as individual species or groups of species, many species continuing after the arrival of a new fauna and forming an important element in it.

In the central part of the Watkins Glen–Catatonk area, near Ithaca, the indigenous Ithaca fauna held the field nearly to the complete exclusion of the Portage fauna throughout the deposition of about 400 feet of sediments. The Ithaca fauna then almost entirely disappeared from the Watkins Glen quadrangle, a very sparse Portage fauna taking its place in the sections. The latter, however, never extended far east of Ithaca, although to the west it prevailed throughout most of the period of dominance of the Ithaca fauna at Ithaca. In the Tioughnioga Valley the Ithaca fauna was not cut off abruptly by adverse conditions, but many of its species continued to live on throughout the Portage; a few of them even persisted into the Chemung. In this eastern region the Ithaca and associated faunas seem to have held their ground against the incursion of the Portage fauna, scarcely any trace of the latter having been recognized.

East of the Watkins Glen quadrangle the Ithaca type of sediments dominates as well as the Ithaca fauna, and west of this region the Portage type of sediments is dominant, while a prevalence of flagstones and an increase of the black even-bedded shale are characteristic throughout the Portage formation. There is therefore to be inferred some relation between the distribution of the faunas and the character of the sediments. It is probable, however, that the change in sediments is expressive of a difference in the source of the materials and thus indirectly of a difference in the ocean currents carrying the sediments. Just what the marine conditions were which accompanied the slight change in the sediments and the complete disappearance of the Ithaca fauna is not positively known; but it is very probable that the change resulted from a shifting in the position of a warm ocean current whose higher temperature may have been essential to the existence of the Ithaca fauna. The deflection of a warm northeastward-flowing current from this region would undoubtedly have resulted in the partial destruction of the fauna normal to it and its replacement by a more hardy cold-water fauna. The temporary shifting of the margin of the Gulf Stream, which, according to Verrill,[a] led to the complete disappearance of a rich "tile fish" fauna off the New England coast, is an excellent illustration of what may have occurred here on a larger scale. During the latter part of the Portage epoch (represented by the Enfield member) the western Portage fauna reoccupied the Watkins Glen quadrangle. This fauna never extended its invasion very far east of the Cayuga Lake basin. During its occupation of central and western New York the evolution of the Hamilton fauna was going on in eastern New York. Its distribution was probably influenced by a higher marine temperature prevailing there, which may have protected it from the encroachment of the Portage fauna.

The Chemung fauna, which in the eastern part of the district follows a nearly barren interval of about 600 feet, with a modified Hamilton fauna at the top and in the western part the Portage fauna, is, like the Ithaca fauna, rich in brachiopods but differs from the Hamilton and Ithaca faunas, both specifically and generically. Intercalated between the fossiliferous layers holding the pure Chemung there are, especially in the Catatonk quadrangle, several zones in which representatives of the Hamilton fauna are abundant, indicating that here the Hamilton fauna continued to a very late date. The Chemung fauna continued to hold its place until the brackish waters of Catskill sedimentation exterminated the marine fauna of this region.

Near the close of Chemung time a few species of Catskill fishes appeared in the region and they are sparingly represented in the Catskill sediments.

IGNEOUS RECORD.

By Edward M. Kindle.

After the close of the sedimentary cycle which has been described for this region and the uplift of the area, a north-south system of joints was developed. Still later, at a period which can not be fixed with certainty, the molten material of the peridotite dikes was forced upward through some of the north-south joints. Some of these dikes never reached the surface, for they are found in the sides of gorges terminating at their upper ends as mere films in the joints. Whether any of them reached the original surface is doubtful, though some of the larger ones may have done so. Long-continued erosion has removed some hundreds of feet of strata since the period of the intrusions, so that by at least that amount the present outcrops of the dikes are below the level at which the old land surface stood when the dikes were intruded. It appears probable that the dikes about the head of Lake Cayuga were due to the same causes which produced those at Syracuse and Little Falls, and these three groups of dikes were probably intruded during the same geologic period.

PHYSIOGRAPHIC RECORD.

By Ralph S. Tarr.

THE PLATEAU UPLAND.

ORIGIN OF THE PLATEAU.

The rocks of the area described in this folio are all marine sediments deposited in the Paleozoic sea that stretched away westward from the base of the ancient mountains of the east. They were laid down in successive layers of varying materials—sands and clays in the part of the sea—and in essentially horizontal position. The layers which form the upland are coarser and more resistant and contain more sandstones than the lower beds, which occupy the northern side of the quadrangles. Since their deposition all these strata have been consolidated to form durable rock beds.

During the formation of the present Appalachian Mountains by a profound and extensive uplift at the close of the Paleozoic era the neighboring sea bottom was also uplifted and added to the mountains of the east, at first doubtless as a low-lying coastal plain. Since that period the history of the region has been long and probably complex, but at present it is possible to state only its major points. No evidence exists to indicate that this later history has ever been complicated by renewed submergence of the area. On the contrary, it seems probable that throughout the long period of time represented by the Mesozoic and Cenozoic eras this region was subjected to continuous denudation.

That, since its first emergence from the sea, this region has been uplifted decidedly is proved by the fact that marine sediments cap the highest hilltops at an elevation of more than 2100 feet above the present sea level. There has, then, been at least this much uplift; and as denudation has doubtless removed a great thickness of overlying strata, 2100 feet is far too small an estimate to place upon the total post-Paleozoic uplift of the region. There is no evidence on which to base an estimate of the full amount of material removed; but it is probable that part of the Carboniferous strata, preserved in the neighboring State of Pennsylvania, were once present over the area of these quadrangles, though none now remain. The thickness of the Carboniferous beds in Pennsylvania is between 3000 and 4000 feet; but it can not be stated either that all these beds were deposited over this area or, if they were, that they maintained the same thickness as in Pennsylvania. Nevertheless the conclusion is warranted that a great thickness of overlying sediments has been stripped from this region; and it does not seem an excessive estimate to consider the amount thus removed to be equal to the entire mass now remaining from the highest hilltop down to sea level.

Whether the main uplift has been gradual, intermittent, or interrupted by periods of subsidence is not determined; but certain topographic features, considered elsewhere, prove that at a late stage in the development of the plateau there was a decided uplift following a long period of repose at a lower level. By reasoning from this fact and from known geologic changes in other regions, it seems probable that the uplift was intermittent, interrupted doubtless by periods of depression. Whatever the history in detail, it has not sufficed to deform greatly the strata of the plateau. They remain, as they were deposited, in an essentially horizontal position. There is a slight general dip to the south, and this is interrupted by a series of low folds, with gentle dips and with approximately east-west axes, locally introducing northward dips of moderate degree. There are also some small sharper folds and some minor faults; but with all this, the strata, so far as their influence on the topography is concerned, may be considered to be nearly horizontal, with a moderate southward dip. This fact is of basal importance in an understanding of the plateau.

One result of the slight deformation of the strata is of far more importance in determining topographic form than either the folds or the southerly dip. This is the abundance of joint planes, which traverse the strata in all parts of the area, and whose influence in minor degree is evident wherever the rock outcrops. Hobbs[a] has suggested that the joint systems have also profoundly influenced the major topographic features of the region.

The total result of the uplift and the long-continued denudation of the region has been to produce the present rugged appearance of the plateau. That the denudation has not been a simple cycle of uninterrupted sculpturing is evident; but just how complex the history has been is not now clear. The present streams evidently do not flow along the lines of the original consequent drainage of the uplifted coastal plain; but as this early drainage history is obscure and capable of interpretation only by hypothesis, it will not be further considered in this place. More recent episodes are more definitely interpreted on the basis of facts presented by the region itself. Some of these episodes are clear and capable of definite demonstration; others warrant the statement of hypotheses only.

DEVELOPMENT OF THE MATURE UPLAND.

The flat-topped hills of the upland and the mature divides, described in the section on relief, are so different in character from the steepened valley walls and the gorges of both the main and the tributary valleys that this upland region is believed to represent a remnant of an older erosional surface, developed through a long period of denudation that was followed by uplifts which permitted the development of the present rugged, dissected topography. (See fig. 28, illustration sheet II.)

This upland surface of mature development has been interpreted by other workers in the field as a peneplain,[b] but the irregularity in the hilltops and the decidedly hilly character of the mature divides, not to mention the still greater differences in elevation between the hilltop remnants and the old valley bottoms, now destroyed by erosion, indicate a country so hilly that the application to it of the phrase "almost a plain" gives an entirely erroneous idea of its real character. It was originally a coastal plain, later uplifted and so dissected that the valleys had become distinctly mature; but no evidence is found to indicate that denudation had ever reduced the area to a surface whose levelness approached that of the old-age stage of a plain of denudation. As a matter of fact, any evidence now remaining of a former peneplain would be most difficult to detect in a region which started as a coastal or structural plain whose surface throughout was at a nearly uniform level. The rock strata are nearly horizontal, and, as denudation removed the layers, the same underlying sheets might have been exposed throughout wide areas and have simulated a peneplain.

In the northern part of the quadrangles, where the rock strata are weaker, this mature upland surface descends decidedly. There is not everywhere a real escarpment between the two levels of different strata, because the difference in rock resistance is not sharply enough defined; but in the Fall Creek valley there is a steep slope and elsewhere there is sufficient difference in elevation to be noticeable, especially if the area which lies to the north of these quadrangles is included. The greater evenness of the topography in the north, the removal of the upper harder beds in this direction, and the descent of the surface from south to north, are interpreted as indications that the drainage of a large part of the ancient mature uplands was northward, probably into an east-west valley along the line of the Ontario basin. The fact that the upland descends not only northward, but also from both east and west toward the two great north-south troughs of the Cayuga and Seneca and other valleys, points to these valleys as the axes along which this drainage was carried northward. A belt of the plateau surface rising higher than that to the north and south of it extends in a north of east direction across the quadrangles, and south of the Susquehanna the upland surface also rises slightly, suggesting the presence of a valley approximately along the line of the Susquehanna. No facts have been discovered which make it necessary to believe that the direction of the present drainage, in its larger features, is essentially different from that of the ancient mature land surface; but no final interpretation of the ancient drainage is possible at present.

REJUVENATION OF THE MATURE UPLAND.

The steepened valley slopes and the pronounced gorges in both large and small valleys are evidence of a rejuvenation by which the streams were able to trench deeply and dissect the mature upland. This period of rejuvenation lasted long enough for the streams to carve steep-sided valleys back into the uplands, and to block out the major features of the present

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[a] Am. Jour. Sci., 3d ser., vol. 24, 1882, p. 366.

[a] Jour. Geology, vol. 13, 1905, pp. 367–374.

[b] Campbell, M. R., Geographic development of northern Pennsylvania and southern New York: Bull. Geol. Soc. America, vol. 14, 1903, pp. 277–296.

topography. The base-level in the Cayuga and Seneca valleys was then approximately at the level of the upper border of the present steepened slopes and the mouths of the hanging valleys and now stands between 900 and 1000 feet above sea level. At East Virgil the tributary valley was developed at about 1200 feet; north of Owego and at Lounsberry between 1000 and 1100 feet. During this stage the lower portions of the hanging tributary valleys were developed well toward the state of maturity, but dissection of the land was still in active progress among the headwaters. This condition may be illustrated by examining the characteristics of such a valley as that in which Odessa is situated. Although part of this valley at present is drained into the St. Lawrence and part into the Susquehanna, it is evident that this is a normally westward-sloping valley whose divide was south of Cayuta and to which both Pony Hollow and the Cayuta Lake valley are normally tributary. The valley broadens and the sides become less steep toward the west, indicating greater maturity there; but the headwaters and the smaller tributaries are far less mature, and in places even gorgelike. The same type of valley is illustrated farther north at Burdette, and elsewhere by the hanging valleys of the Cayuga and Seneca basins. With a less pronounced development of the hanging-valley condition, these same characteristics are found throughout the quadrangles.

A typical instance of headwater erosion of this cycle is found west of Watkins, at the very border of the Watkins Glen quadrangle and partly outside of it. Here there is a broad, perfect upland divide area in which lie the headwaters of the main branch of Glen Creek. Seen from several points, this area represents an apparently continuous mature slope; but in reality it is bisected by a narrow, gorgelike westward-sloping valley, which broadens rapidly in that direction. It is apparent that the westward-flowing stream in this valley was competing with the headwaters of Glen Creek and had succeeded in pushing its way across the divide into the mature upland valley in which Glen Creek rises. In many other places on the divides between smaller streams, as between Danby and Brookton, there are instances of the same kind. Some of these, however, may be due to local rejuvenation, resulting from the overdeepening of main valleys by ice erosion or by the work of powerful glacial streams.

The interpretation placed on these facts is, therefore, that after the development of a mature surface, represented by the upland remnants (by some called a peneplain), there came a rejuvenation, probably due to uplift. With a new base level the streams began their work of dissection, and in this work they succeeded so far as to form broad, fairly mature lower courses and dissect the upland into rugged form, but not completely to destroy the upland remnants of the earlier mature surface.

SECOND REJUVENATION.

The buried gorges, which have been found in many widely scattered localities, are indications of a second rejuvenation. They attain their best development and show most clearly their relation to hanging valleys in the Cayuga and Seneca troughs, in the Cayuta Valley between Van Etten and Waverly, and in the Tioughnioga Valley. Whatever the cause of this second rejuvenation, it is certainly distinct in time from that by which the upland valley slopes were steepened and the upland topography made so rugged. It is inconceivable that narrow gorges cut in the bottoms of hanging valleys, like those at Havana Glen or Watkins Glen, could have had any relation to the cutting of much broader, gorgelike valleys in the upper tributaries. The two sets of drainage features belong to two entirely different cycles, and the more recent one was in process of development when the Wisconsin ice sheet spread over the country. This latest stage in the drainage history is, without doubt, the result of the same cause, whatever it may be, that has steepened the walls of some of the main valleys, notably those of Cayuga and Seneca lakes. This question calls for some discussion.

VALLEY PECULIARITIES.

THE PROBLEM.

As a result of the complex drainage history above outlined, to which must be added the further complication of ice advance with accompanying ice erosion, outflowing stream erosion, and deposition, repeated at least twice, a very confusing system of valleys has been developed. The problems presented by this topographic complexity are numerous and interesting. The features that require explanation are the following: Why are the sides of Cayuga, Seneca, and other valleys so regular, with a steepened lower slope and hanging tributary valley with drift-filled gorges in their bottoms? Why are there hanging valleys of less distinct character, but also with buried gorges in their bottoms, as in the Cayuta Valley between Van Etten and Waverly? Why are there numerous long stretches of straight, steep-sided valley walls, as in Texas Hollow? Why is there such a uniform condition of lowered divides between not merely all the larger, but many of the smaller streams? And why do some of the streams follow such unnatural courses as that of Cayuta Creek, or of the Chemung west of Elmira?

In the course of the study of this area, three hypotheses have been advanced to account for the phenomena with which these queries deal—(1) headwater erosion, due to rejuvenation by uplift, probably accompanied by tilting; (2) erosion by the outflow of glacially supplied streams; (3) ice erosion.

HEADWATER EROSION.

The hypothesis of headwater erosion supposes that there was, just before the glacial epoch, an uplift and tilting of the land, by which the drainage of the entire region was rejuvenated. The main north-south streams were rendered very active and deepened their valleys, forming true gorges of large size, while the side streams, being less powerful, merely notched the bottoms of their valleys with gorges now found buried in the bottoms of the hanging valleys. At the same time certain of the streams deepened the notches at their divides by headwater erosion and made possible the later formation of through valleys by the grading up of the valleys with glacial drift.

The facts favoring this hypothesis are (1) the presence of so many hanging valleys in different parts of the area and at various elevations; (2) the wide distribution of through valleys extending in various directions and grading by every intermediate stage to unnotched divides; (3) the extension of narrowing but steepened valley walls from both sides up to the notch, indicating active erosion on both sides of the notch, such as might develop by headwater erosion. But no one of these phenomena is incapable of explanation by the other hypotheses.

Opposed to the hypothesis of rejuvenation are several facts, as follows: (1) In the Cayuga and Seneca valleys, where the hanging-valley condition is best known, the main valley walls are straight and smooth and the tributary valleys have so slight a development of gorges as to make it seem improbable that the main valleys could have been deepened so much in excess of the side valleys, during any known operation of general rejuvenation through uplift. (2) The main valley walls, moreover, have the form characteristic of ice erosion. Furthermore, these two valleys have not a form which can be assigned to stream work without introducing also profound modification by ice scouring. (3) The hanging-valley condition, while present in all parts of the area, is not universal, being well developed in some valleys, poorly developed in others, and absent in still others. It is best developed in the larger north-south valleys, through which either ice or glacial waters flowed freely. (4) No other region of horizontal strata outside of glaciated regions, so far as known to the author, shows such a peculiar association of through and hanging valleys. (5) It is doubtful whether headwater erosion in a region of nearly horizontal strata could notch the divides so completely as has occurred in this region. It is of course true that if the distribution of joint planes or of rock strata were favorable, such a peculiar condition of headwater valleys might be brought about.

EROSION BY GLACIAL STREAMS.

The evidence is conclusive that streams of large size outflowed from the Wisconsin glacier front during its recession.

As a complete explanation of the phenomena, glacial stream erosion fails entirely; but it is capable of explaining many specific instances. The outflowing streams from the shrinking Wisconsin ice sheet eroded but little, for on the whole they were building up their channels. Locally they cut shallow channels in the drift and even in the rock, and they even trimmed the rock slopes of some of the valley walls; but they did not cause the peculiarities of the through valleys.

That the latter statement is true is proved by the fact that the hanging valleys, left hanging by the erosion that caused the through valleys, have drift-filled gorges in their bottoms. From this it is evident that the through valleys were deepened, leaving the tributary valleys hanging; then there was an interval during which gorges were cut in the bottom of the hanging valleys; then came the Wisconsin ice sheet, and since its disappearance a new series of gorges has been cut. The period required for the formation of the older gorges was much longer than the postglacial period has been, for they are both broader and deeper than the postglacial gorges.

Although the streams from the retreating front of the Wisconsin ice sheet did little toward causing the peculiarities of the drainage of this divide region, and although the cause must be sought in some more remote time, it does not follow that ice-born streams were not the cause. In fact, the evidence that in some places this was the case is so clear as to justify the conclusion that there was an earlier ice advance, even though the deposits of this earlier ice sheet have not been found.

The nature of this evidence may be made clear by a brief consideration of three specific instances. The first of these is the gorge through which Cayuta Lake outflows. This is a deep, narrow, rock-walled gorge connecting two much broader valleys. No conceivable condition of rejuvenation by uplift could be cited in explanation of this gorge. There is no difference in rock structure to account for it. Its explanation must certainly be sought in some accident to already existing, mature drainage. Glacial erosion could not possibly form so narrow a gorge, and with the exception of erosion by an ice-born stream no other accident can be imagined. The position of the gorge is exactly where such erosion should have operated, for a tongue of ice entering from the Seneca Valley would have dammed the Cayuta Valley and forced its waters aside. The retreating Wisconsin ice did exactly this, and a great flood of water escaped along this channel. But the entire gorge was not cut by Wisconsin drainage, for there are several drift-filled gorges tributary to this gorge. It is therefore concluded that drainage of an earlier ice stage formed this gorge, by forcing water to flow across a sag in the hills where two small streams headed together.

A second example is the peculiar gorge of Chemung River back of Hawes Hill, near Elmira. Almost exactly the same argument applies here. It is not conceivable that Chemung River, entrenched in its broad valley at Big Flats, could have been diverted by headwater erosion back of this hill and into its own valley again. Glacial erosion could hardly have produced so narrow a cut, especially in such a position and direction. But glacial waters, ponded in the upper Chemung by an ice dam, might well have formed just such a gorge. The Wisconsin waters flowed this way, but they did not form the cut, for the bottom of the valley is drift and well-defined moraines are banked against the valley sides.

A third but less convincing example is the Tioughnioga Valley. A glacial-erosion origin might possibly be argued for it, as it extends in the right direction. It is, however, so gorgelike in some portions and so narrow that erosion by an ice-born stream seems the more probable origin. It was certainly the highway for a large stream in the closing stages of the Wisconsin ice sheet, and it was probably also occupied by such waters during the earlier glaciation, at which time it was formed, for there are drift-filled gorges in the bottoms of its hanging valleys.

In the first two examples the evidence of the potency of erosion by ice-born streams in connection with an earlier stage of glaciation is convincing. In the third, though less complete, the evidence at least warrants this hypothesis. Scores of examples could be added to these if space permitted. It is therefore held that, notwithstanding the lack of importance of the streams of the receding Wisconsin ice as agents of erosion, a great work was done by an earlier ice advance in causing streams to notch divides and helping to establish through valleys in this divide area. It is probable that the earlier ice did so much work in forming through valleys and establishing grades that the Wisconsin streams found little of this kind of work to do, and consequently were aggrading streams.[a]

Exactly how much importance to assign to this cause for the drainage peculiarities has not been determined. It was in many places difficult to find convincing evidence to decide between ice erosion and erosion by ice-born streams. Enough was found, however, to lead to the conclusion that glacial-stream work has been very effective here. It is probable that several of the peculiar narrow, gorgelike through valleys, with their associated hanging valleys, like those of the Cayuta and the Tioughnioga, are in the main due to erosion by glacial waters. Considering all the waters that were poured into the Susquehanna, it is probable that some of its valley peculiarities are due to the same cause. It seems safe to predict, however, that when the necessary studies have been made, it will be found that each of the processes has had an important share in the work of producing these drainage peculiarities.

GLACIAL EROSION.

The subject of glacial erosion has been discussed in the section on the Quaternary system, and but few words in addition need be said here. In many of the valleys, notably those of Cayuga and Seneca lakes, Texas Hollow, Pony Hollow, and Sixmile Creek, the topographic forms are those typical of glacial erosion. One who has seen the results of erosion by existing glaciers, at once recognizes the topographic evidences of the same agency here. Such phenomena are the straight, smooth, spurless valley walls; the rounded contour; the steepened slope so different from that of river erosion; the striking difference in topography above and below the upper edge of the steepened slope; the pronounced hanging valleys; the difference in level of neighboring hanging valleys; all these features admit of only one explanation—ice erosion.

The statement is warranted, therefore, that these valleys have been profoundly modified by glacial erosion, both by deepening and broadening. Cayuga and Seneca lakes occupy two of the troughs thus enlarged, being partly inclosed at the outlet ends by drift, but in part occupying rock basins. The ice streamed across the divides, lowering the gaps and helping to make the through valleys. Every stage in the process of ice sculpturing of divides, from the slight gap to the through valley, is present.

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[a] For a fuller and more detailed statement of this problem see Rich, J. L., Marginal glacial drainage features in the Finger Lake region: Jour. Geology, vol. 16, 1908, pp. 527-548.

But here, as in the process of glacial-stream erosion, the bulk of the work was done by an earlier ice advance. Gorges containing Wisconsin drift are cut in the bottoms of the hanging valleys. These interglacial gorges were not removed by the Wisconsin ice erosion; and in one place, just north of Ithaca, residual soil of interglacial age still remains below the steepened slope, being in a position where the ice erosion would not have been effective. The form of these valleys is the result of of at least two ice advances, the first the more powerful; and the interval between the two was far longer than the postglacial time.

GENERAL CONCLUSION.

A maturely reduced plateau was rejuvenated, probably by uplift. On the new cycle the streams had developed their valleys into the stage of early maturity when the country became glaciated. The headwaters of the streams were still cutting gorges when the ice advanced.

The ice, as it advanced, ponded the northward-flowing streams, causing them to flow over and cut down divides. Advancing farther, the glacier overrode the divide area completely and, where its current flowed most freely—that is, along the valleys—it deepened and broadened the valleys and reduced the divides between them. As the ice front receded, the ice gave birth to large glacial streams which further eroded along their lines of flow, many of them across divides. When the ice was gone, many of the valleys and divides were so deepened that their tributaries were left hanging, and in their bottoms the streams that occupied them cut gorges. After a long interval ice once more overspread the region. We have conclusive evidence of only two advances here, but there may have been more. The second of which there is evidence was the Wisconsin ice sheet, which repeated the phenomena of the earlier ice advances, but with less effectiveness. As the ice front again receded, the valleys were graded up with moraine and outwash deposits, the result being the present condition of through valleys. Since the recession of the ice, streams crossing the steepened slopes of the valleys have been engaged in cutting gorges, in some places along the lines of the interglacial gorges, elsewhere independently of them.

DIVERSION OF STREAMS.

It is not known what changes in stream courses took place during the early drainage history of this region; and the deep cover of drift in the valleys, together with the lowering of the divides during glaciation, obscures the exact locations of the divides of even immediate pre-Wisconsin time. If the narrowest parts of the valleys are interpreted as the preglacial divide regions, which they doubtless were at some period, even if not at the exact period of earliest ice advance, it is evident that there have been extensive changes of drainage. It is evident also that glacial deposits have had much to do with these changes. Several specific instances will suffice to illustrate the basis for this conclusion.

The presence of a lowered divide, cut down by a glacial stream of the earlier ice advance, permitted the passage of Chemung River through the gorge west of Elmira, when the deposits of Wisconsin moraine and outwash gravel west of Horseheads raised the valley bottom between Big Flats and Elmira above the level of the divide back of Hawes Hill. The river flows through this gorge without encountering rock, and a well 70 feet deep near the narrowest part of the gorge failed to reach rock. This well is in moraine about 60 feet above the river. The same conditions that deflected the Chemung turned Singsing Creek westward.

Post Creek heads at a point where a morainic mass forms a divide, and a southward-sloping outwash plain begins. It then flows over this outwash plain into a narrowing valley, which, near the border of the Watkins Glen quadrangle, is so narrow that the outwash plain is completely buried beneath alluvial-fan and flood-plain deposits. The Pony Hollow stream also heads on a moraine divide and flows down over an outwash plain.

The diversion of the main Cayuta Creek from the broad valley which extends past Odessa and its passage through the narrow gorge north of Alpine have already been mentioned and ascribed to the presence of moraine south of Cayuta Lake. At Alpine a low morainic area prevents the stream from turning westward again into its normal valley, and it therefore flows southeastward into a narrowing valley along the line followed by the earlier outflows from the ice tongue that occupied the Odessa Valley. Outwash deposits have so graded up this narrowing valley that there is now a slope across the divide area between Cayuta and Rodbourn, over which the stream flows without encountering rock in its bed. A similar divide area, also graded up by deposits, is crossed between Van Etten and Waverly. Streams that originally flowed eastward past Van Etten evidently headed against these divides. Thus by diversion across lowered divides, through the agency of grading by glacial stream deposits, valleys tributary to Seneca Lake, to the Spencer Valley, and to the Chemung Valley have been united into one valley occupied by a single stream entering the Chemung. Similar diversions, mentioned in the section on "Topography," occurred in the streams of the Catatonk quadrangle, and in others to the north, giving a notable accession of water to the Susquehanna.

It has already been stated that the deposit of moraines and deltas near the top of the steepened slope along the Cayuga and Seneca valleys has, in a number of places, diverted the streams of the hanging valleys, causing them to leave their older gorges and cut postglacial glens in the steepened slope. Buttermilk (Tenmile), Watkins Glen, and Havana Glen creeks, are typical examples of this type of diversion.

THE GLACIAL OCCUPATION.

Concerning the behavior of ice advances of earlier date than that of the Wisconsin stage, no facts other than those stated have been discovered in this region; nor has much been learned regarding the effect of the expanding Wisconsin ice sheet. Doubtless with the oncoming of each glacier, the ice tongues advanced up the valleys, reaching successively higher levels until the hilltops were completely covered, thus, in reverse order, repeating the events accompanying the waning of the ice sheets; and doubtless marginal lakes, with outflow channels, were associated with each ice advance and retreat. The presence on the highest hills of foreign materials from regions far to the north gives evidence that a moving ice sheet, the Wisconsin, spread over the entire region. Glacial erosion has so completely erased the records of even the advancing Wisconsin ice sheet that, with the exception of buried lake clays, no evidence of its effects has been discovered. The advance of the ice was in all probability accompanied by occasional halts and the formation of moraines, outwash plains, lake deposits, etc., as well as by the erosion of valleys where outflowing streams ran. The gorges made by these streams are the most permanent of the records left and so far the only ones discovered.

In the southern half of the area glacial erosion was not sufficient to remove the products of preglacial decay from the hills, nor, so far as any evidence goes to show, to modify perceptibly the topography even of the valleys. When, in its recession from the outermost stand in Pennsylvania, the Wisconsin ice front reached the southern part of the quadrangles the ice melted away rapidly and regularly, leaving a cover of till, thick in the valleys, but thin on the slopes and upland. Stagnant ice blocks permitted the formation of marginal moraine terraces in the larger valleys and more indefinite deposits in some of the smaller ones; and as the stagnant blocks melted away, eskers and kame deposits were built in some places.

There was a halt of the Wisconsin ice front, approximately at the location of the present divide in the main valleys; and here a distinct terminal or recessional moraine was built. North of this moraine the margin of the waning ice sheet halted at several levels, leaving morainic deposits as a record of its positions at successive stages of shrinking. The Cayuga and Seneca troughs guided the main ice lobes of the area during this time, though numerous smaller side tongues entered the tributary and neighboring valleys. Here and there nunataks emerged from the surface of the ice. The topography of the main troughs was greatly changed by the ice currents that flowed through them; and the details of the valley topography were decidedly modified by the building of moraines, the accumulation of drift in marginal lakes, and the construction of outwash gravel plains. Some of these deposits were made directly by the ice, some by the action of glacially fed streams. As the ice front receded, taking successively lower stands, the phenomena were repeated, so that there is a broad area of complex drift topography in this region of recurrent halting. Extensive moraines in the valleys and moraine terraces connecting these with less distinct hillside and hilltop moraines prove that this halting of the ice was made up of a series of stands successively lower and lower as the ice front receded northward. This statement represents the simplest interpretation of the observed phenomena; but that there were periods of readvance is probable.

In some places these glacial accumulations made the valley bottoms exceedingly irregular through the strong development of moraine loops, hummocks, kettles, and kame areas; in other places, where the outflowing streams filled marginal lakes or spread outwash gravels in the valley bottoms, the floors of the valleys were both raised and leveled. The latter result of filling has produced some of the most striking topographic features of the quadrangle—the remarkably flat-bottomed valleys of the larger streams, notably the Chemung. The valley deposits are in some places several hundred feet deep, so that by this accumulation the relief of many sections has been decreased.

Many of the lateral moraines and morainic deposits on the slopes of nunataks are mere undulations in the drift; and outside of the larger valleys most of the moraines are too weak and low to find expression on the topographic map. Usually the till sheet itself merely veneers the rock, though its greater depth in the valleys lessens the topographic irregularity of the entire region. The maps and the description of the Quaternary geology more fully explain these phenomena.

The minor irregularities in drift deposit have clogged the drainage in many places, forming a large number of small swamps and ponds, among which are Spencer Pond and Cayuta Lake. The larger lakes, Cayuga and Seneca, are also held up by drift dams across their north ends; but the troughs they occupy are river valleys deepened by ice erosion. As already stated, ice erosion, glacial-stream erosion, and drift filling have combined to produce many through valleys and to divert much drainage from the St. Lawrence to the Susquehanna system. These causes have also given to the streams, even the Susquehanna, their present grades.

When the ice tongues of the Cayuga and Seneca troughs had withdrawn north of the divides between the St. Lawrence and Susquehanna drainages, marginal lakes appeared; and as the ice fronts receded northward, these lakes expanded, dropping to successively lower levels as new outlets were uncovered. Records of these high-level glacial lakes, the latest results of the glacial invasion of this area, are abundant on the margins of both Cayuga and Seneca valleys in the form of hanging deltas and sheets of lake clay. The complete key to this lake history lies beyond the area of these quadrangles, where the ice front stood when most of the lake levels were formed; and therefore discussion of it is deferred until the region farther north is studied.

POSTGLACIAL CHANGES.

CHANGES DUE TO MOVEMENTS OF THE EARTH.

Even while the ice was disappearing, a slow rise in the north was changing the level of the land. Elevated and inclined lake beaches north of these quadrangles prove that this tilting has amounted to 2 or 3 feet a mile in a northeast-southwest direction, and there is evidence that the tilting may still be in progress. On a lake nearly 40 miles long this amount of tilting must have produced an important effect. Indeed, as the author has elsewhere shown,[a] the borings of artesian wells at Ithaca have revealed evidence that there was at this point, when the ice-dammed lake disappeared, either no water or else very shallow water, 75 feet below the present lake level.

CHANGES DUE TO EROSION.

As soon as the ice melted from any part of the land, stream erosion began its task of removing the drift, at first in some localities with marked effect because of the absence of a general cover of vegetation. Carried by streams to the edge of the ice tongues and stagnant ice blocks, some of the drift was again incorporated in glacial deposits; and later, during the glacial-lake stages, some was deposited as hanging deltas and lake clay in the ice-dammed lakes.

Stream erosion has in some places deeply trenched the drift deposits; for instance, where streams cross the moraines and deltas on the slopes of Cayuga and Seneca lakes, and where the inlet streams to these lakes pass through the heavy moraine deposits south of Watkins and Ithaca. In places the streams have progressed in reexcavating buried gorges and other valleys, but this work has been completely accomplished in only the most favorable situations. The most nearly complete and most effective erosion is doubtless that accomplished where the streams that descend the steepened slopes of the Cayuga and Seneca valleys have cut postglacial gorges below the level of the hanging-valley bottoms. The amount of erosion performed by these streams is, however, likely to be overestimated, for many of the gorges which the postglacial streams occupy were formed before the last ice advance, during the period of earlier gorge cutting, the postglacial work being largely excavation of drift from older buried gorges. A postglacial gorge in the valley of Sixmile Creek, illustrated in figure 36, is cut entirely in bed rock.

Where the streams have not been active the glacial deposits have been but slightly altered by postglacial erosion. For the most part the till sheet remains nearly as it was laid down; the moraines away from the streams have suffered little alteration, the ridges and hummocks being nearly perfect in form, and the inclosed kettles only slightly altered by inwash of sediment; the channels over the outwash plains are still preserved; and, where not dissected by the streams that built them, the hanging-delta forms are still perfect. Everywhere there is evidence that, except in scattered places, denudation has accomplished little work since the ice left; and this evidence proves very plainly that the period since the withdrawal of the ice has been relatively brief. The fact that the delicate striation and polishing of the weak shales have been left in so many places, even where covered by only a thin blanket of till, is further proof of the same conclusion.

CHANGES DUE TO DEPOSITION.

The deposits removed by postglacial erosion have in part been accumulated on flood plains and in alluvial fans built where the upland streams emerge into the larger valleys. The most extensive deposits occur where streams pass through morainic or other deep drift areas and have cut deeply into them; but even there the accumulations are not extensive, being

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[a] Jour. Geology, vol. 12, 1904, p. 69.

further witness of the brevity of postglacial time and the small amount of erosion during that time compared to the great changes accomplished in the plateau before the advent of the glacier.

The streams that enter Cayuga and Seneca lakes have dropped their load in the lakes, building deltas near their mouths, and supplying clay which the currents have drifted out into the lake. Erosion by lake waves has slightly trimmed the lake shores, depositing the coarser fragments on narrow beaches at the base of the cliffs, while the finer clay is spread over the lake bottoms. The deposit of this lake clay must have perceptibly shallowed these lakes and leveled their bottoms, making a beginning toward the filling of the lakes, and therefore their ultimate extinction.

ECONOMIC GEOLOGY.

By Ralph S. Tarr.

SAND AND GRAVEL.

Deposits of both sand and gravel are widely spread over the area, and many pits, small and large, are opened in the outwash gravel, delta, esker, kame, and moraine deposits. The supply far exceeds the demand, and almost everywhere sand and gravel are conveniently located for use. Naturally these deposits are most extensively exploited near the larger towns. At Ithaca sand and gravel are taken from some very large sand pits in the high-level deltas. At Owego sands and gravels are obtained from outwash kame and esker deposits. Just west of East Corning, in the environs of Elmira, and just east of Waverly, there are extensive gravel pits. There is also a good-sized sand pit in a morainic loop near the mouth of Latty Brook, southeast of Horseheads. The outwash gravels make excellent road material, and are extensively used both in road and railroad bed construction.

CLAY.

Clay is also widely distributed, but owing to the general lack of large centers of population in these quadrangles and to the difficulties of transportation, the clays are worked in only a few places. One of these is near the East Ithaca station of the Elmira and Cortland branch of the Lehigh Valley Railroad, at Ithaca. The pit is in a lake-clay deposit just in front of a high-level delta of Cascadilla Creek. It is a shallow deposit and contains numerous scratched stones, many of them limestone, drifted to their present position in floating ice. There are less accessible places where the lake-clay sheet is distinctly thicker than here.

At Nina, 5 or 6 miles south of Ithaca, on the Lehigh Valley Railroad, there is a brickyard which has a large output. The clay used is a stratified lake clay with thin layers of sand, greatly crumpled by ice shove and forming a part of a pronounced morainic hummock. In it are numerous angular, scratched stones and some large bowlders. This deposit is but one of many in the morainic areas which occupy the valley of Sixmile Creek, the inlet valley south of Ithaca, and the valley south of Watkins, in all of which lake clay forms a conspicuous part. If there were a demand, other brickyards could be opened in these areas.

At a brickyard in the Nanticoke Creek valley about 2 miles north of Union clay has been obtained from a hanging fan and associated moraine. The pockets of clay are irregular and small, and the yard when examined was making use of a rather stony flood-plain clay at the base of the hanging fan. A brickyard on the northwestern edge of Horseheads produces a large amount of brick from a clay that occurs in a low morainic ridge built at the terminus of an ice tongue. The clay is poorly stratified and contains some angular stones.

In the Newton Creek valley, about 2 miles west of Breesport, there is an abandoned brickyard which utilized a blue clay from a marginal morainic terrace. Another abandoned brickyard is situated along the Elmira and Cortland branch of the Lehigh Valley Railroad about a mile southwest of Spencer. To judge from the old, weathered cuts the clay deposit was very shallow, and it seems to rest on outwash gravels. It is apparently a lake clay deposited in a shallow lake after the outwash gravels were formed, the swamp farther west being the last remnant of this lake.

There are many unworked clay deposits in these quadrangles, some in the morainic areas, others where marginal glacial lakes formerly stood. For example, an extensive clay deposit occurs in the flat between Varna and Etna, and borings show a deep layer of clay in the Cascadilla Valley east of Ithaca. It is possible that some of these clay deposits may prove suitable for brickmaking.

WATER RESOURCES.

SPRINGS.

There are large numbers of springs on the hill slopes of the Watkins Glen quadrangle, and these are utilized for water supply on many farms. Some of these springs emerge from the rock at the base of rock terraces, but many of them emerge from drift deposits after seepage along relatively pervious layers. A large number of springs are not utilized, forming swampy patches on the hill slopes, and many of them supply water only when the ground is thoroughly wet.

A number of mineral springs exist in the area, some iron bearing, others carrying sulphur. The only springs at present utilized to any extent, except for domestic purposes, are those on the western outskirts of Dryden, where a summer hotel is situated on the site of two springs, near together, one chalybeate, the other sulphur bearing; and those at Watkins.

A series of springs on the west side of the valley south of Ithaca have been improved and incorporated into the municipal water supply. They really represent the waters of the Coy Glen stream, which sinks into its alluvial fan, emerging at the periphery as springs after natural filtration in the alluvial fan gravels.

SHALLOW WELLS.

Wells almost everywhere find water at shallow depths. On the hill slopes and hilltops water is usually found at depths of less than 25 feet, sometimes in the drift, but often at or near the contact of drift and bed rock, or, where the rock is disintegrated, a few feet below the top of the rock. The occurrence of water near the contact of drift and bed rock is due to the fact that the rock surface, normally sloping and smoothed by ice erosion, gives rise to a zone of percolation between the drift and the nearly impervious, horizontally bedded shale and sandstone. Where the bed rock is disintegrated, as in much of the southern upland, the water more easily finds passageways into the rock; but nearly everywhere on the uplands a good supply of water is easily obtained.

In the larger valleys the drift is not only thicker, but also usually more porous than the upland till. This is especially true in the valleys occupied by outwash gravels. Here there are many driven wells, but few of them are more than 100 feet in depth.

ARTESIAN WELLS.

In a few places the driven wells developed artesian water. It is difficult to get exact and trustworthy records of these wells; moreover, they are not numerous enough to warrant generalizations regarding artesian water in the glacial deposits. It is certain, however, that the drift in the larger valleys is so deep and so variable in texture that artesian water is a possibility in favorable localities in any of them. In only one place in the quadrangles, at Ithaca, have there been sufficient borings, with carefully kept records, to warrant conclusions concerning the conditions favoring artesian water.[a] In this city numerous wells find water in a gravel bed at depths of 50 to 100 feet, from which the water rises in many places to form flowing wells. The gravel underlies a bed of clay which is interpreted as a modern lake deposit and a continuation of which is now being laid down in Cayuga Lake. The gravel is believed to represent a series of coarse beds laid down either on the land or in shallow water during the existence of glacial Lake Iroquois, when the depression of land in the north so tipped the basin of Lake Cayuga that deep lake water did not exist on the site of Ithaca. Not merely the coarseness of the sediments, but the presence of mollusks which inhabit running water and of logs in a number of the borings, have led to this conclusion; and at the known rate of tilting of the land since the glacial period the level at which these gravels occur is in harmony with this explanation. It is believed that the water in this gravel series is supplied by seepage from the valley sides, especially through the alluvial fans at the creek mouths.

Thirteen wells, deeper than the one first put down at this place, are clustered together in the southwestern outskirts of Ithaca. The records of these wells and carefully collected samples were studied with the idea of determining the nature of the sections; and in each case a great thickness of clay is found beneath the upper water-bearing gravel series, usually between 100 and 200 feet above sea level. This material is interpreted as a lake clay deposited in the glacial lake which occupied the Cayuga Valley after the ice left and before the Lake Iroquois stage. Beneath the clay, at varying depths, is found a complex and variable series of sand, gravel, clay, and till beds which are interpreted as moraine deposits and in which nearly all the wells have found water whose source is evidently the extensive sandy and gravelly moraine area in the Cayuga Inlet valley to the south. The borings show a great difference of conditions within very short distances, demonstrating the uncertainty of wells in drift. They also show that a large amount of water is stored in the lower members of the drift series.

It was thought by the Ithaca water board that these wells would furnish an ample supply for the city (from 1,000,000 to 2,000,000 gallons a day); but when the air lift was applied, it was found that the limit of water available was soon reached and that heavy withdrawals affected a well a mile or two farther south, which shows clearly that the storage capacity or the rate at which the water can reach these wells is limited. This is interesting in view of the facts that the pioneer well, the Illston well, which was developed several years earlier, had a flow of about 300,000 gallons a day, and that some of the new wells had an equal flow before pumping was begun. The possible supply to be obtained from this limited reservoir seems to have been overestimated.

Recent explorations for artesian water have been carried on by the city of Ithaca east of the city, in Fall and Cascadilla Creek valleys. One well about a mile northeast of Etna, on the Pierson farm, passed through 170 feet of drift of varying character and then entered the rock. The record of this well is as follows: Hard clay and bowlders, 15 feet; water gravel, 3 feet; hard clay and stone, 16 feet; clay, 22 feet; hard clay and gravel, 10 feet; gravel, 2 feet; hard clay, 16 feet; hard clay and some sand, 5 feet; clay, 7 feet; hard clay and gravel, 8 feet; clay, 2 feet; hard clay and gravel, 4 feet; sand, 2 feet; hardpan, 14 feet; gravel, 1 foot; hardpan, 5 feet; clay, 19 feet; hardpan, 19 feet; shale rock, 7 feet. Unfortunately samples of the drillings were not preserved.

Three-quarters of a mile south of this well, about half a mile east of Etna, on the Euer farm, rock was reached at a depth of 54 feet through hard stony clay, probably till. These wells gave no artesian water. A group of three wells on the Snyder farm, 3½ miles east of Ithaca, in the Cascadilla Valley, were put down near an old well which had a slight flow. The first of the three found water after passing through 54 feet of clay; the second passed through 65 feet of clay and 2 feet of gravel, from which there was a slight flow, then passed through 48 feet of "hardpan" (probably till), reaching bed rock at a depth of 115 feet; the third passed through 55 feet of clay, 3 feet of clay and stone, and 50 feet of hardpan, then reached rock at a depth of 108 feet, having a slight flow of water from the top of the bed rock. About three-quarters of a mile farther east, on the Genung farm, three wells were put down, with the following records: First well, soft clay 60 feet, water gravel 2 feet (with slight flow); second well, creek gravel 5 feet, clay 45 feet, fine gravel 2 feet, slight flow; third well, clay 52 feet, slight flow of water. Since the field work for this area was completed other wells have been put down in the Cascadilla Valley, with better success, and the city of Ithaca is planning, if possible, to utilize this supply for some of the higher levels of the city. The records of these wells have not been obtained.

Borings have been made for artesian water in some of the larger valleys, especially in and near the cities and towns; and in a number of places the water rises to the surface. In the Watkins Valley a well one-half mile north of Montour Falls encountered flowing water in a gravel bed at a depth of 400 feet. Farther north, at the fair grounds, a water-bearing gravel was encountered at a depth of 105 feet. Five wells at Montour Falls, used for fire-department supply, find abundant water at a depth of 50 to 65 feet in a gravel bed beneath blue clay, and all flow a little. In the Newtown Creek valley, 2 miles west of Breesport, there is an artesian well which has a steady flow of water from a depth of 75 feet. At Breesport two artesian wells obtain water from a gravel 195 feet below the surface, having first passed through sand, clay, and quicksand.

There is a notable artesian area at Slaterville Springs, where a number of small wells reach a moderate supply of chalybeate water in gravel 45 to 75 feet beneath the surface. This water has a local reputation and was much used in Ithaca before and during the typhoid epidemic of 1903. It is still sold in that city, and its reputation as a medicinal water has been largely responsible for the success of Slaterville Springs as a summer resort. Two deeper wells (76 and 110 feet) at the creamery procure artesian water free from these mineral impurities.

Another artesian area is in and near the town of Danby, where water rises from a gravel bed at a depth of 25 to 30 feet. There are also scattered artesian wells, as in Cascadilla Valley 4 miles east of Ithaca, near Brookton, at Newark Valley, and at Tioga Center; and in many other places water rises part way to the surface. There is an important artesian area at Freeville, northeast of Etna, in the quadrangle north of the Catatonk; but efforts to find the extension of this area in the Watkins Glen quadrangle have so far resulted in failure.

Except in a few localities, the artesian-well possibilities in this area have never been thoroughly tested by borings, nor is it possible to predict what success would attend borings at any particular place. In general, it may be said that outside of the larger valleys the possibility of obtaining an extensive artesian flow is slight; but the thick and extremely variable drift deposits of the larger valleys indicate the possibility of obtaining artesian water at almost any point in them. Owing to the variability of the deposits, however, failure is as probable as success. The waters of some of the artesian wells, like those at Watkins, Montour Falls, Ithaca, Breesport, and Slaterville Springs, have mineral properties which give them reputation; and doubtless other mineral waters would be found by boring.

STREAMS.

All the streams of this quadrangle are highly variable in volume, for after storms the water runs quickly from the

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[a] Tarr, R. S., Artesian-well sections at Ithaca, N. Y.: Jour. Geology, vol. 12, 1904, pp. 69-82.

denuded hills. It sweeps much sediment with it, a part of which accumulates in the alluvial fans and flood plains. This causes frequent changes in the stream courses, which do much damage to roads, fields, and even buildings. In summer the streams are ordinarily very low and the smaller ones are dry.

Little use is made of the streams. Being polluted by passage through a settled country, they are ill fitted for municipal water supply without filtration, and their use for this purpose is fortunately rapidly diminishing. Until the typhoid epidemic of 1903 unfiltered water from Sixmile and Fall creeks was used in Ithaca and at Cornell University; but now the university uses filtered Fall Creek water, and the city uses artesian water and spring water, with filtered Sixmile Creek water as an accessory to complete the necessary supply.

The streams of these quadrangles are not well suited for water power. All the larger and many of the smaller streams which have an abundant and regular supply have a slight grade; but a moderate amount of power is obtained from them at a number of points, as at Marathon, Newark Valley, Brookton, Candor, and Owego. Most of the hanging-valley streams, which have a high grade, are of too small volume and too irregular in flow to furnish reliable water power, though there are some gristmills and sawmills, as at East Virgil and Montour Falls. Where they descend the steepened slope of the Cayuga Valley the three streams in the hanging valleys at Ithaca—Fall, Cascadilla, and Sixmile creeks—have sufficient gradient for excellent power, but a meager and variable water supply. There is a descent of 400 feet in a mile in Cascadilla and Fall creeks. The power of Sixmile and Cascadilla creeks is employed in small mills; and the Fall Creek power is utilized extensively, being employed to run several mills and factories, to generate electricity for Cornell University, and to supply water for the university shops and hydraulic laboratory. To maintain more steady flow a small lake has been made by the university in the amphitheater where the postglacial stream crosses the older buried gorge. Fall Creek power was formerly used to run the street cars, but, as the impounding area was not large, the water was found to be too variable in amount, being low both in summer and winter; and the power plant was consequently abandoned.

SOILS.

The soils of these quadrangles are characterized by marked variability from place to place. By far the most uniform type is the till sheet, which veneers the hills and covers most of the uplands, being especially uniform in the southern half of the area. The region covered by the till sheet is indicated on the surficial geology maps. It is a compact bowlder clay, though the percentage of bowlders, or "hard heads," is not excessive; but it is by no means absolutely uniform in character, varying in depth, surface form, and composition. For the most part it is smooth, thinly spread, and not very stony; but there are areas where it is thick, roughened, or very stony.

A peculiar variation in the till sheet is found on much of the upland, especially in the southern half of the area. Here the bed rock is disintegrated at the surface, the shale layers being reduced to a residual clay and the sandstone layers greatly decayed and broken, but still in large fragments. The ice, sweeping over this region, removed some of the residual clay and sandstone fragments and mixed them with its burden of drift derived from regions to the northeast. The till thus accumulated is therefore a mixture of normal till, residual clay, and sandstone fragments, the last being so abundant in many places as to interfere seriously with agriculture. Where this till sheet is very thin, as it is on many hilltops, ordinary plowing reaches through the soil to the bed rock and the plow pries off the broken sandstone fragments, adding them to the soil, of which these fragments form in places fully one-half.

In the valleys the soil is much deeper and far more variable in surface form and composition. In the morainic areas it is especially variable, many single fields having soils as different as dense clay and coarse gravel and also showing the hummocky topography of hillock and hollow characteristic of well-defined valley moraines. There is variability vertically, as well as at the surface, and consequently these areas show marked irregularity in soil drainage, the effect of which may often be seen in a dry spell, when one part of a field is fresh and green and another part parched and brown.

Other valley drift deposits are characterized by a fair degree of uniformity in soil characteristics; the eskers are ridges of coarse gravel; the kames are hummocky areas of sand and gravel; the outwash plains are fairly level deposits of coarse, rounded gravel, grading in places into sand and loam, with a few kettles and with many steep terrace fronts toward the stream; the deltas are flat-topped, steep-faced areas of sand and gravel; the lake clays form a sheet or veneer of compact, fine-grained clay, which cakes and dries in lumps and is remarkably free from stones. The lake clay grades into loam and is underlain by other drift, usually bowlder clay, at depths varying from a few inches to several feet. Its surface is gullied by broad valleys extending down the slopes, in many of which no water now runs.

Small pebbles are exceedingly abundant in some of the soils, especially in the deposits of stratified drift, notably deltas, kames, eskers, and outwash gravels. Even in such deposits, made of a mixture of sand and pebbles, much of the soil is of excellent quality. The great outwash gravel plain of the Elmira and Big Flats valley, for example, is very well adapted to tobacco culture, which is a flourishing industry; and the delta deposits along Seneca Lake are extensively used for vineyards. The fact that many of the pebbles, and even the sand grains, are really shale fragments, which readily disintegrate under the weather, renders the top soil much better adapted to agriculture than the more quartzose sands of other glaciated regions. As a result of this decay of the shale fragments, the sand and gravel top soil always contains a considerable percentage of clay.

There are some areas of very fertile, black muck in the swampy tracts. These are, as yet, mainly undrained, though in some places they have been drained and utilized for raising celery and other garden truck. One of the most extensive areas of this type is the bottom of the overflow channel of the glacial Lake Newberry along the electric railroad between Horseheads and Pine Valley. Parts of the delta-swamp areas at Ithaca and at the head of Seneca Lake are utilized in a similar way.

Along the streams there is usually a ribbon of flood-plain deposit on each side, varying in width and in characteristics, but everywhere consisting largely of worked-over glacial deposits laid down by the streams. At one extreme, in the smaller hill valleys, this soil is coarse, pebbly detritus; at the other, in the bottoms of the larger valleys, it is a fine loam, usually poorly drained for a part of the year.

Where the hill streams enter the valleys to which they are tributary, there is in many places so abrupt a change in grade that the coarser detritus is deposited, making a stony loam soil, fan shaped and sloping radially outward from the point where the stream emerges from the hills. Such alluvial-fan soils are usually fairly fertile; the surface has a uniformly gentle slope; the drainage is good; and the soil is subject to fertilization by occasional overflows during floods. On the other hand, the fan-building stream sometimes does great damage by cutting away fields or by piling stony débris upon them.

FORESTS.

Practically none of the primitive forest remains in this region; but over large areas the land from which the forest has once been stripped is now forest covered again. This is especially true of some of the uplands and of the steeper valley slopes, which in places present an unbroken forest growth for miles. A very considerable proportion of the southern half of the area is clothed in forest, some of it in the form of wood lots that furnish a fuel supply for the farmers, some of it so extensive as to warrant lumbering operations on a fairly large scale. A view from any of the high hills shows a large percentage of forest-covered surface, especially on the valley slopes that are too steep for farms, but in some parts of the area even on the hilltops.

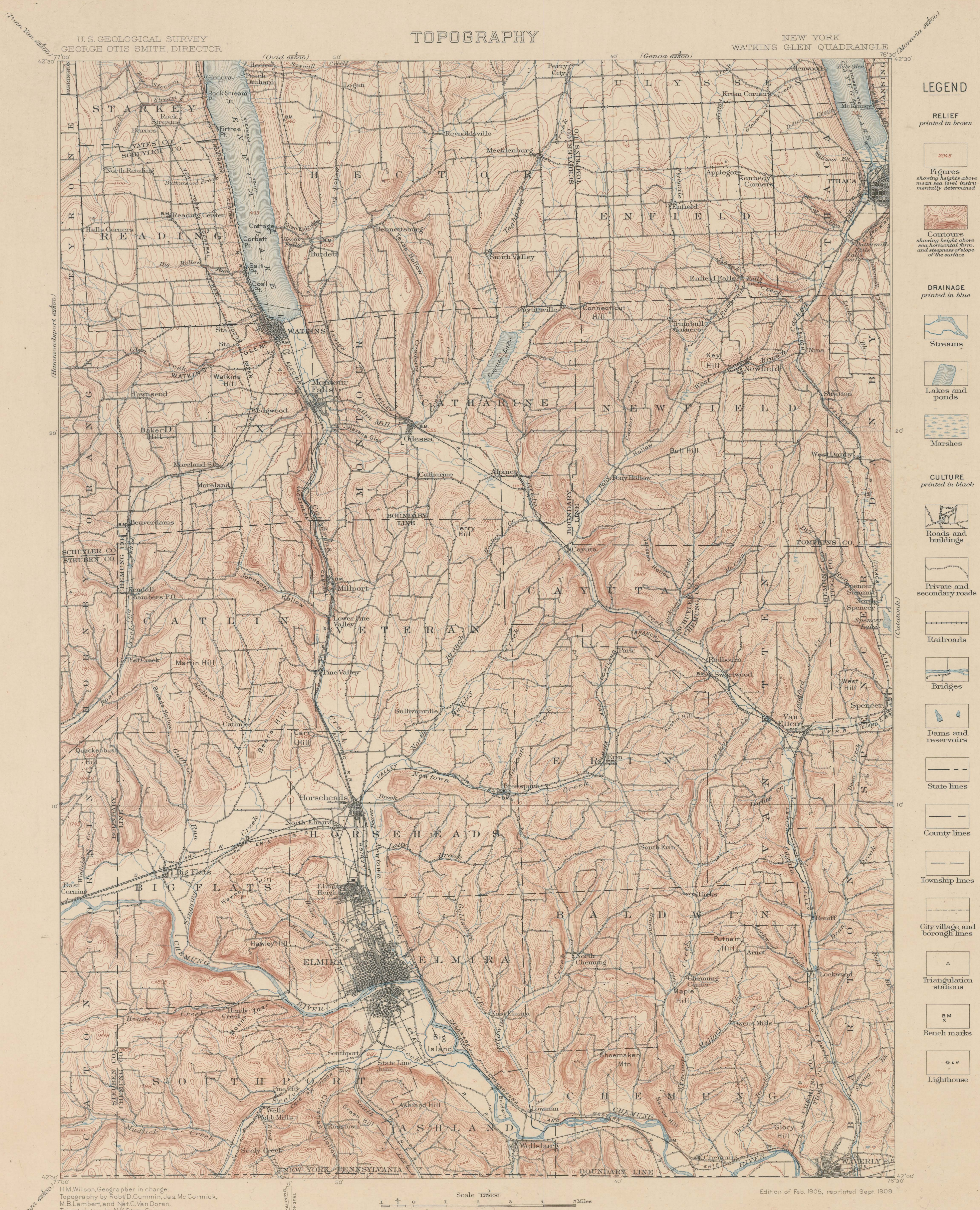
There seems little tendency at present to enlarge the farming area by removal of the forest; but there are numerous places where the forest is being allowed to encroach on lands formerly cleared for farming. From more than one standpoint it would seem wise to extend this forest area in the southern half of the quadrangles so as to include an even larger proportion of the poorer soil of the upland; for there are many farms where the pastures are red with sorrel, where patches of sweet fern give clear indication of the poverty of the soil, and where hay fields are left uncut because of the sparseness of the grass. Ultimate good would also be accomplished by an increase of the forest area both through increasing the future supply of lumber and through decreasing the destructiveness of the floods, which the farmers in the more fertile and productive valleys keenly feel and which, as they state, occur with increasing effect.

March, 1909.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

NEW YORK
WATKINS GLEN QUADRANGLE



H.M. Wilson, Geographer in charge.
Topography by Robt. D. Cummin, Jas. McCormick, M.B. Lambert, and Nat. C. Van Doren.
Triangulation by N.Y. State Survey.
Surveyed in 1893 and 1898-99.

SURVEYED IN COOPERATION WITH THE STATE OF NEW YORK.

TRUE NORTH
MAGNETIC NORTH
7½°
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 40 feet.

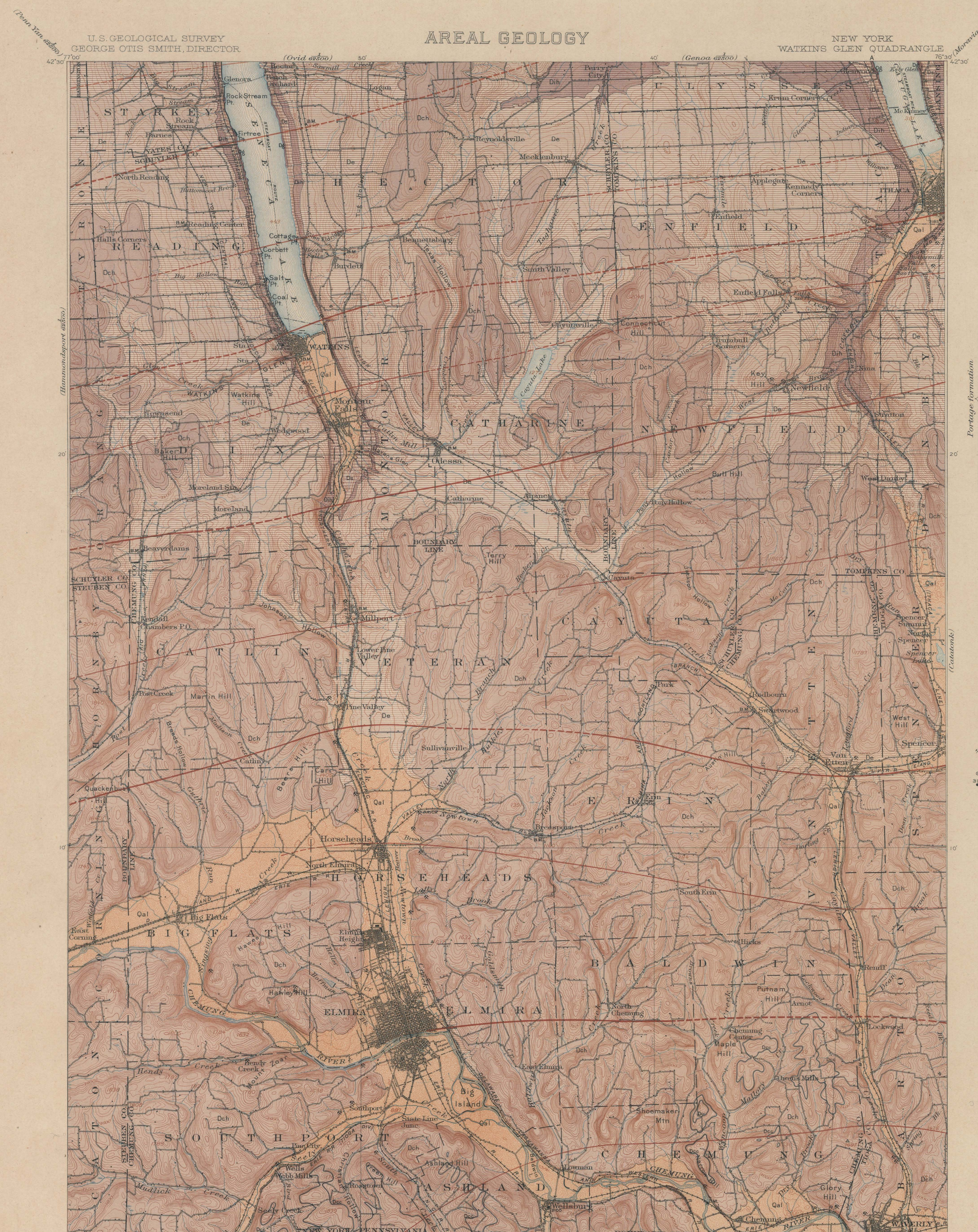
Datum is mean sea level.

Edition of Feb. 1905, reprinted Sept. 1908.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

NEW YORK
WATKINS GLEN QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines; subaerial deposits by patterns of dots and circles)

QUATERNARY

Qal

Alluvium
(shown in larger stream bottoms only)

DEVONIAN

Dch Dcc

Chemung formation
(dark-gray shale and thin sandstones, with some calcareous beds, and lentils of coarse sandstone and fine conglomerate, Dcc)

Portage formation

De

Enfield shale member
(dark-gray argillaceous shale with thin-bedded sandstones)

Dih

Ithaca shale member
(dark-gray argillaceous shale generally very fossiliferous, with few thin sandstones)

Ds

Sherburne flagstone member
(flaggy sandstones with gray shale partings and some finely laminated black shale)

Dg

Genesee shale
(black, finely laminated, evenly bedded, arenaceous shale)

IGNEOUS ROCKS

POST-DEVONIAN

II

Dikes of mica peridotite

STRUCTURAL DATA

ANTICLINE
SYNCLINE

Anticlinal and synclinal axes
(dashed lines indicate approximate location)

⚒ *Quarries*
building stone, road material, and shale for brick.

◎ *Salt wells and works*

3185 ● *Other deep borings*

H.M.Wilson, Geographer in charge.
Topography by Robt. D. Cummin, Jas. Mc Cormick, M.B. Lambert, and Nat. C. Van Doren.
Triangulation by N.Y. State Survey.
Surveyed in 1893 and 1898-99.

SURVEYED IN COOPERATION WITH THE STATE OF NEW YORK.

TRUE NORTH
MAGNETIC NORTH
7½°
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 40 feet.
Datum is mean sea level.

Edition of Feb. 1909.

Geology by Henry S. Williams
and Edward M. Kindle.
Surveyed in 1903-05.

U.S. GEOLOGICAL SURVEY
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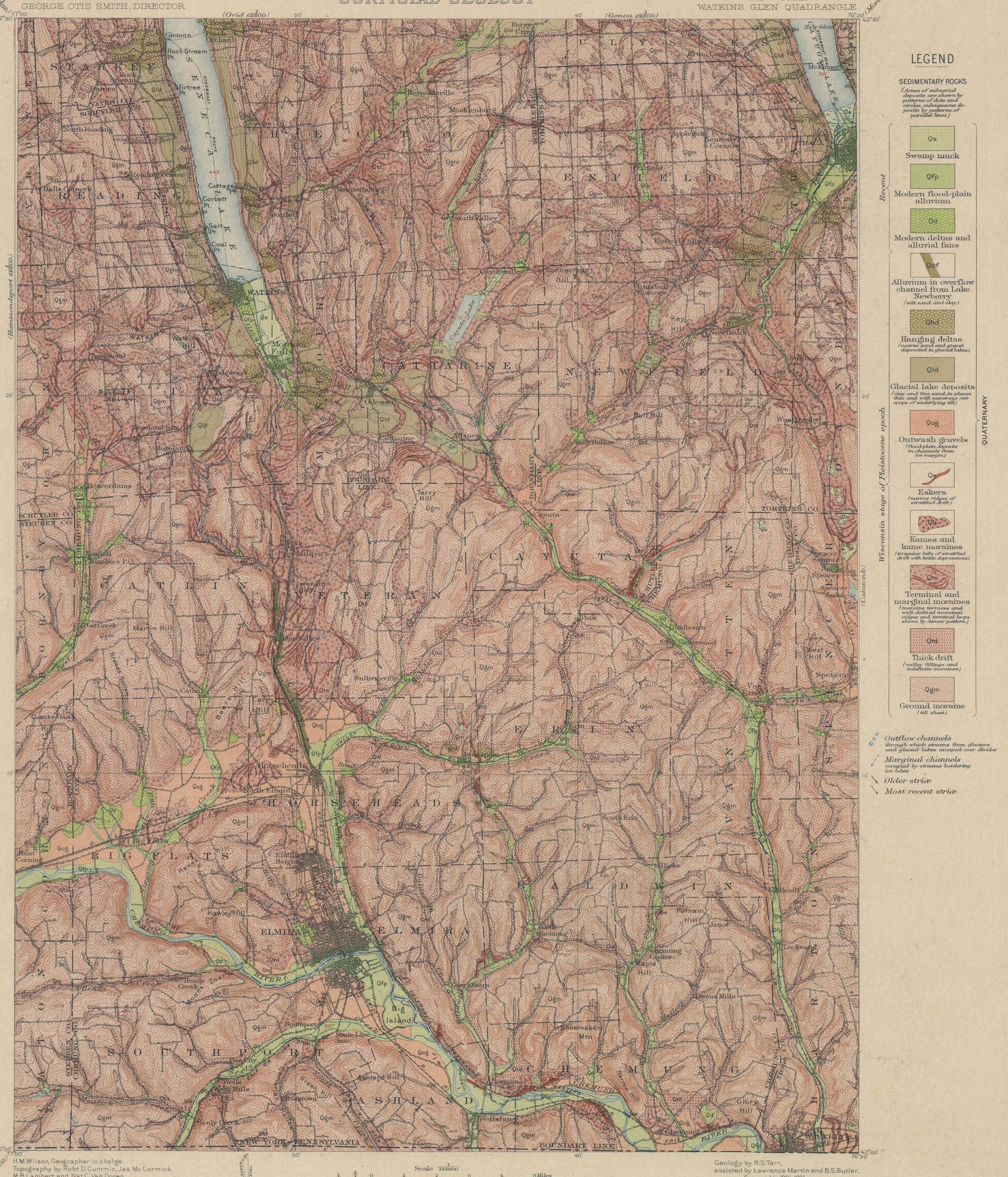
SURFICIAL GEOLOGY

NEW YORK
WATKINS GLEN QUADRANGLE



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SURVEYED IN COOPERATION WITH THE STATE OF NEW YORK.

TRUE NORTH
MAGNETIC NORTH
$7\frac{1}{2}°$
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 40 feet.

Datum is mean sea level.

Edition of Dec. 1908.

Geology by R.S. Tarr,
assisted by Lawrence Martin and B.S. Butler.
Surveyed in 1901-1904.

U.S. GEOLOGICAL SURVEY
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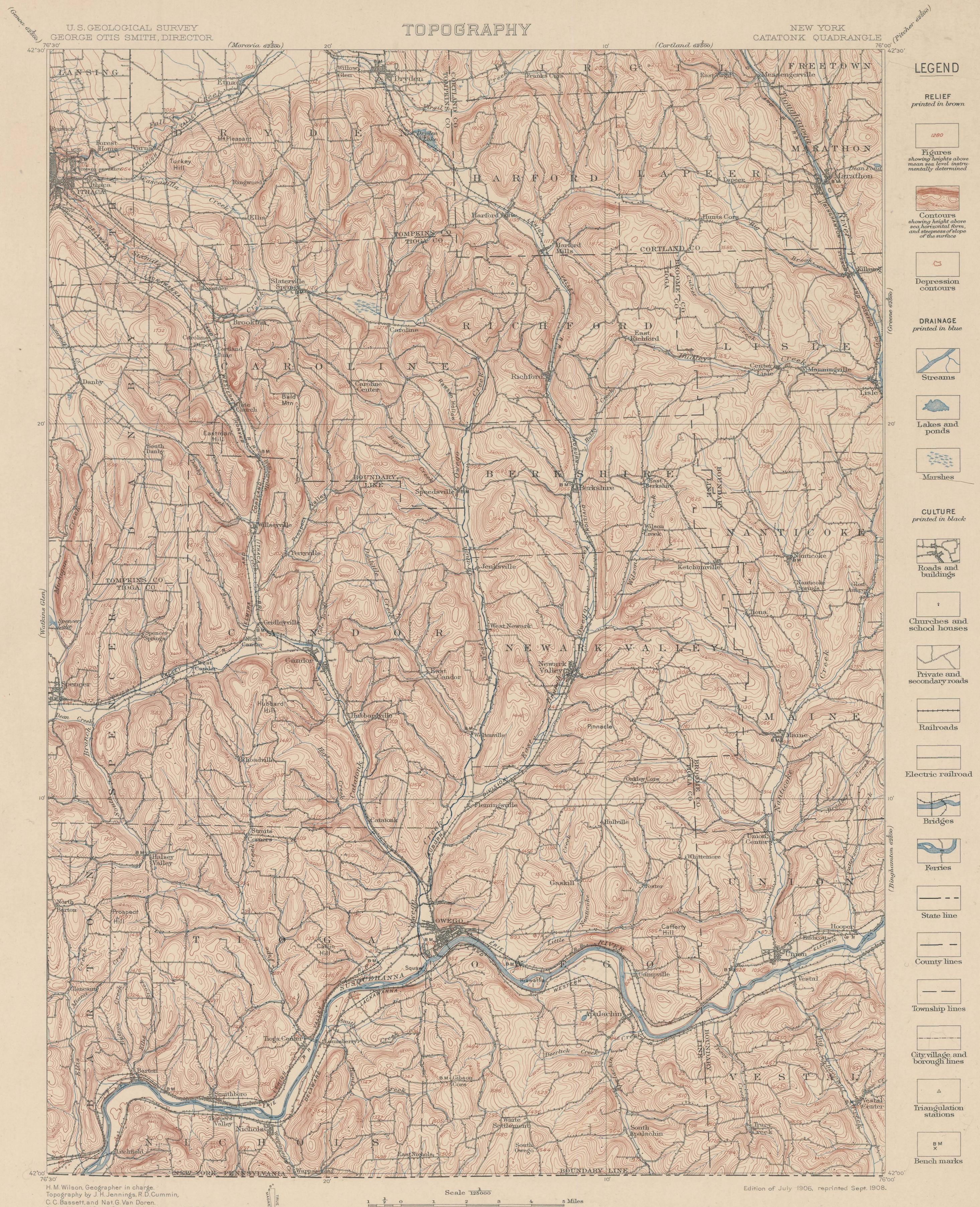
TOPOGRAPHY

NEW YORK
CATATONK QUADRANGLE



H. M. Wilson, Geographer in charge.
Topography by J. H. Jennings, R. D. Cummin,
C. C. Bassett, and Nat. G. Van Doren.
Control by N. Y. State Survey, W. W. Gilbert, and H. B. Paige.
Surveyed in 1898 and 1900-1901.

SURVEYED IN COOPERATION WITH THE STATE OF NEW YORK.

TRUE NORTH
MAGNETIC NORTH
8°
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 40 feet.

Datum is mean sea level.

Edition of July 1906, reprinted Sept. 1908.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

NEW YORK
CATATONK QUADRANGLE

H. M. Wilson, Geographer in charge.
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Edition of Feb. 1909.

Geology by Henry S. Williams
and Edward M. Kindle.
Surveyed in 1905-06.

LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines; subaerial deposits by patterns of dots and circles)

QUATERNARY

Qal
Alluvium
(shown in larger stream bottoms only)

DEVONIAN

Dck
Catskill formation
(cross-bedded lamellar gray sandstone, coarse-grained sandstone, and dull-red shale)

Dch
Dce
Chemung formation
(dark-gray shale and thin sandstones, with some calcareous beds; toward the east the more sandy beds characteristic of the Chemung extend below the base of the Spirifer disjunctus zone, indicated by a blue line, and are represented by a distinct pattern, Dce)

Portage formation

De
Enfield shale member
(dark-gray argillaceous shale with thin-bedded sandstones; toward the east the upper beds are more sandy, and, being lithologically indistinguishable from the Chemung, are mapped with it as Dce)

Dih
Ithaca shale member
(dark-gray argillaceous shale, generally very fossiliferous, with few thin sandstones)

Ds
Sherburne flagstone member
(flaggy sandstones with gray shale partings and some finely laminated black shale)

IGNEOUS ROCKS

POST-DEVONIAN

Dikes of mica peridotite

STRUCTURAL DATA

ANTICLINE
SYNCLINE

Anticlinal and synclinal axes
(dashed lines indicate approximate location)

⚒ *Quarries, building stone*
⊙ *Salt wells and works*
1350 ● *Other deep borings*
MS *Mineral springs*

U.S. GEOLOGICAL SURVEY
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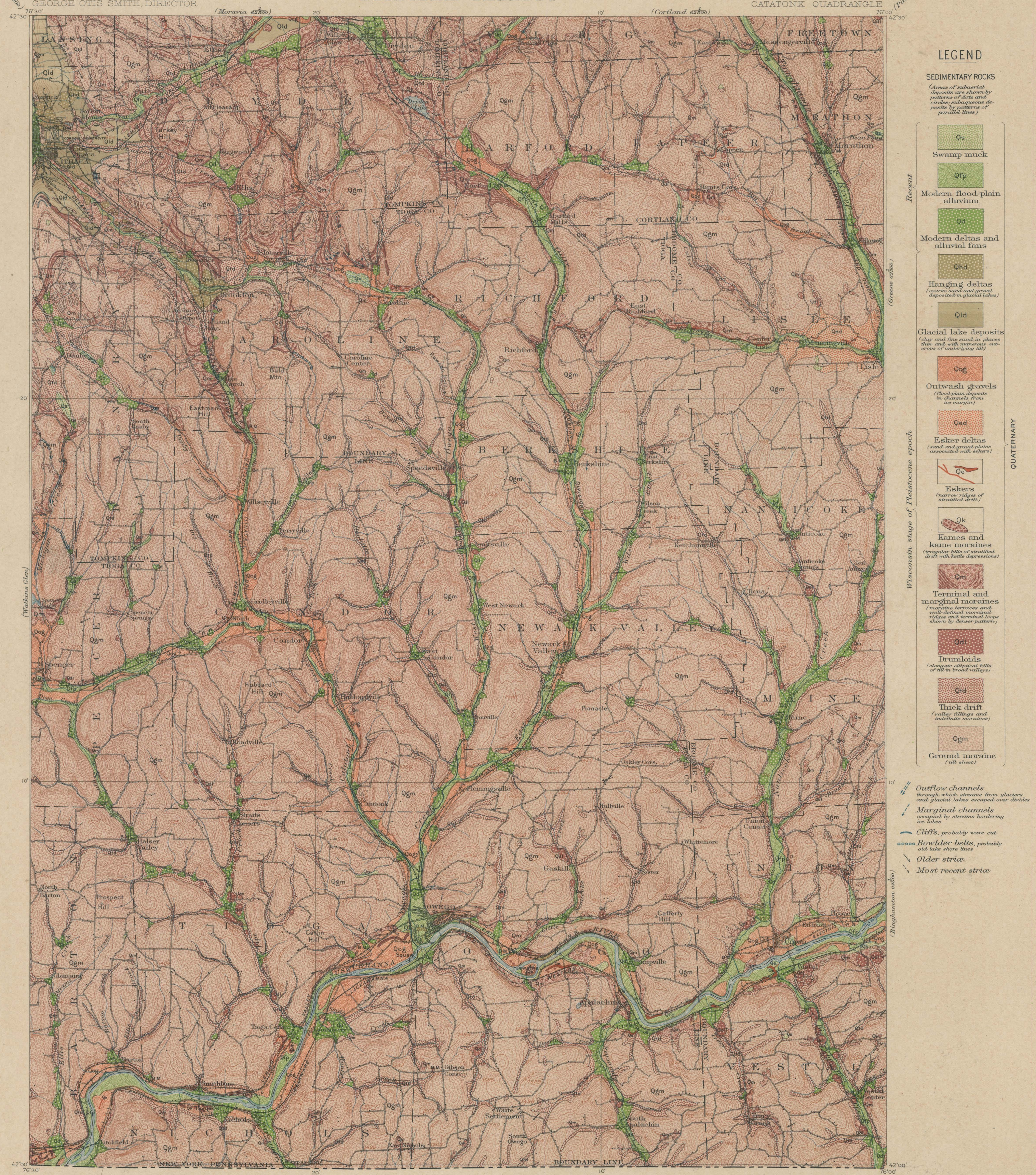
SURFICIAL GEOLOGY

NEW YORK
CATATONK QUADRANGLE



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Contour interval 40 feet.
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Edition of Dec. 1908.

Geology by R. S. Tarr,
assisted by B. S. Butler and G. D. Hubbard.
Surveyed in 1904-1905.

ILLUSTRATIONS I

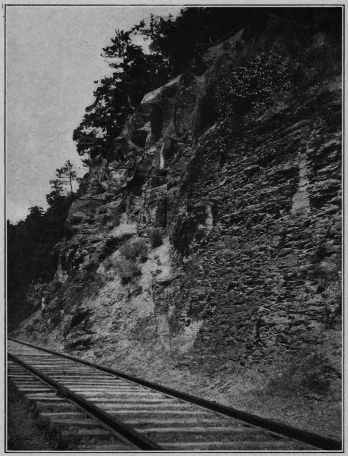

FIGURE 14.—GENESEE SHALE, EAST SHORE OF LAKE CAYUGA.

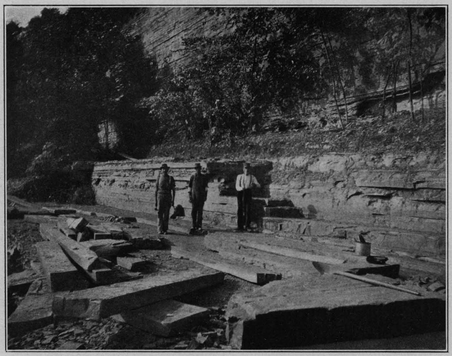

FIGURE 15.—FLAGSTONES IN THE PORTAGE FORMATION; QUARRY SOUTH OF WATKINS.

The quarried blocks are delimited by joint planes.

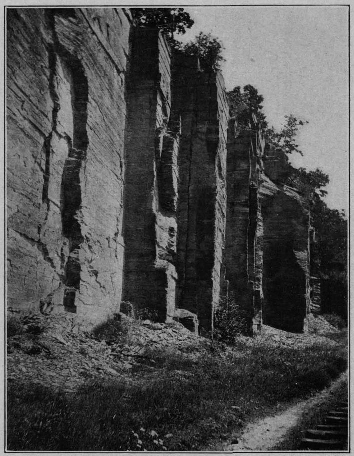

FIGURE 16.—JOINT STRUCTURE IN SHERBURNE FLAGSTONE MEMBER OF THE PORTAGE FORMATION EAST SHORE OF LAKE CAYUGA.

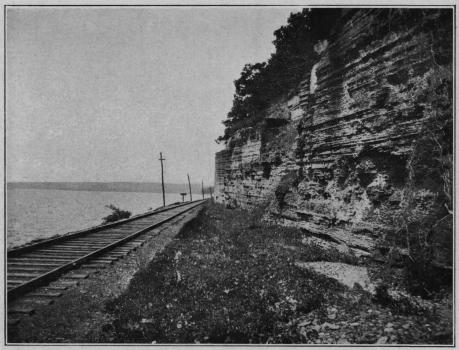

FIGURE 17.—NATURAL EXPOSURE OF SHERBURNE FLAGSTONE MEMBER, EAST SHORE OF LAKE CAYUGA.

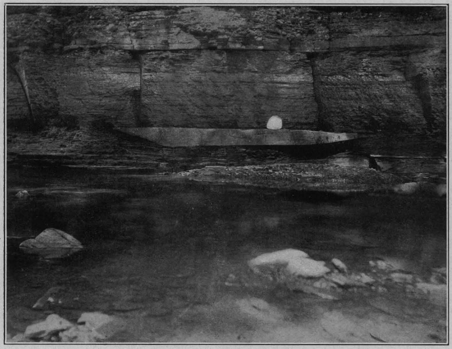

FIGURE 18.—SANDSTONE LENS IN ITHACA SHALE MEMBER, NEAR MESSENGERVILLE.

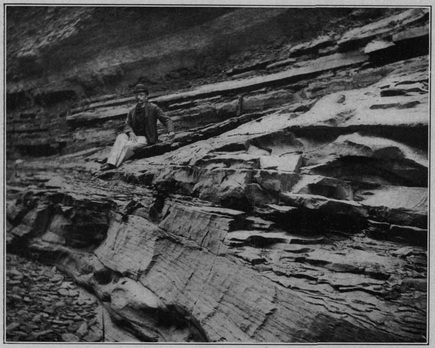

FIGURE 19.—SUBMARINE UNCONFORMITY IN SHERBURNE FLAGSTONE MEMBER, CATHEDRAL HALL, WATKINS GLEN.

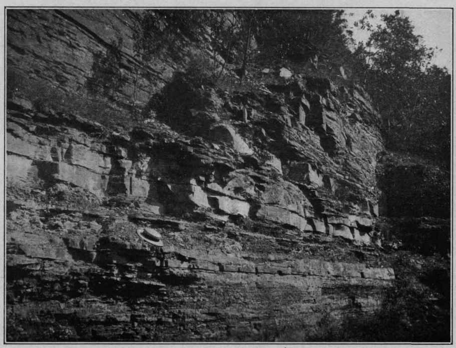

FIGURE 20.—TYPICAL CHEMUNG EXPOSURE, CAYUGA CREEK, NORTH OF WAVERLY.

FIGURE 21.—LARGE CONCRETIONS WITH FOSSIL BAND ON PERIPHERY, IN CHEMUNG FORMATION, ROSSTOWN.

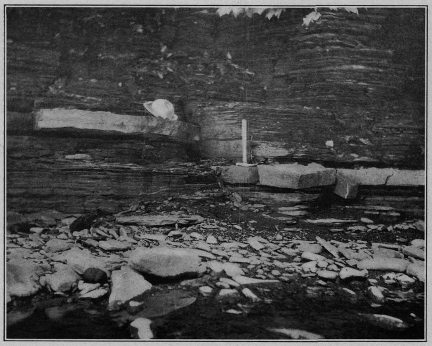

FIGURE 22.—SMALL FAULT OFFSETTING SANDSTONE BED IN ENFIELD SHALE MEMBER, GLEN CREEK.

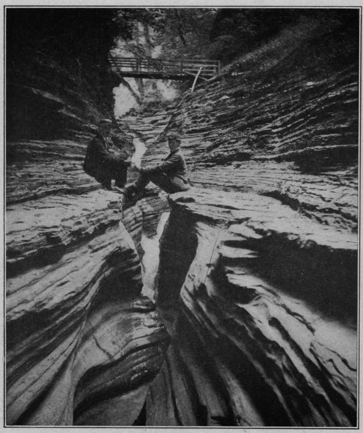

FIGURE 23.—WATKINS GLEN, A NARROW, TORTUOUS GORGE IN THE PORTAGE FORMATION.

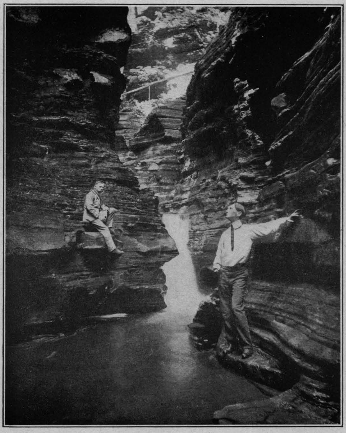

FIGURE 24.—WATKINS GLEN, SHOWING A SWELL IN THE NARROW GORGE.

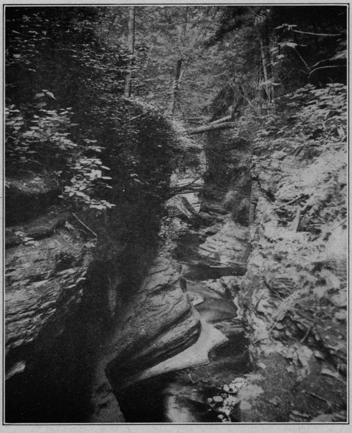

FIGURE 25.—UPPER PORTION OF WATKINS GLEN.

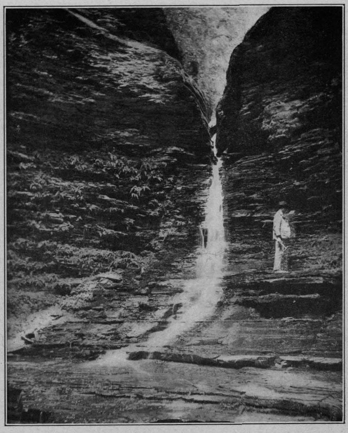

FIGURE 26.—MOUTH OF EXCELSIOR GLEN, SHOWING V-SHAPED CHANNEL IN ITHACA SHALE MEMBER.

ILLUSTRATIONS II

FIGURE 27.—MORAINE ON EAST SIDE OF CAYUGA INLET VALLEY, JUST SOUTH OF THE MOUTH OF BUTTERNUT CREEK.
Shows characteristic hummocky surface of morainal deposits.

FIGURE 28.—VIEW UP WEST BRANCH FROM THE TOP OF THE STEEP SLOPE OF CAYUGA INLET VALLEY EAST OF NINA, 1400 FEET ELEVATION.
Shows the plateau upland in the background, in which is sunk the flat-bottomed hanging valley of West Branch, and the morainal topography on the west side of the deeper Cayuga Inlet valley.

FIGURE 29.—DISINTEGRATED SANDSTONE AND SHALE NOT REMOVED BY THE GLACIERS, 1 MILE EAST OF BERKSHIRE.
The sandstones are cracked and stained by iron. The shale has weathered to spheroidal forms and residual clay.

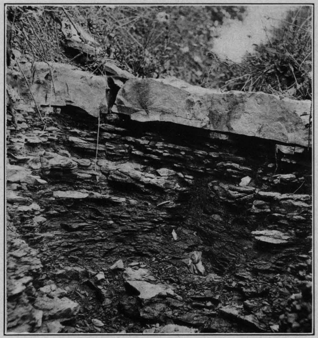

FIGURE 30.—GLACIATED SANDSTONE CAP WHICH PROTECTED THE UNDERLYING DECOMPOSED SHALE FROM EROSION BY THE GLACIERS; WATKINS GLEN QUADRANGLE.

FIGURE 31.—JOHNSON HOLLOW OUTFLOW CHANNEL, 2 MILES WEST OF MILLPORT.
Large valley, formerly the outlet of glacial Lake Newberry, now occupied by ponded waters.

FIGURE 32.—ESKER RIDGE BETWEEN CENTER LISLE AND EAST RICHFORD.
The turnpike follows its crest.

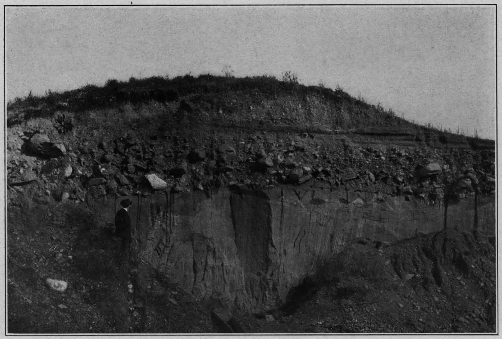

FIGURE 33.—OLDER, SLIGHTLY FAULTED SAND, ICE ERODED AT THE TOP, COVERED BY A SANDY AND GRAVELLY TILL, ABOVE WHICH ARE STRATIFIED DEPOSITS; FOREST HOME, JUST EAST OF CORNELL UNIVERSITY CAMPUS.
The ice-eroded sand may represent an earlier ice invasion than that of the overlying till.

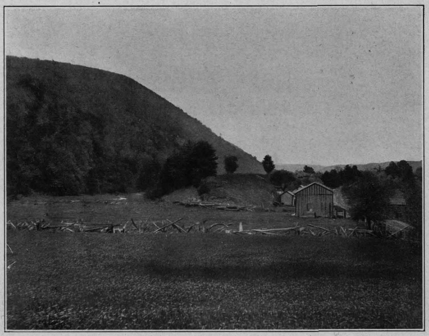

FIGURE 34.—OUTLET CHANNEL OF GLACIAL WEST DANBY LAKE, 4 1-2 MILES SOUTH OF DANBY, LOOKING TOWARD THE SOUTH.
The channel lies between the narrow rock ridge to the left of the barn and the high wooded ridge in the background.

FIGURE 35.—CRUMPLED GLACIAL-LAKE CLAY IN THE MORAINIC AREA OF SIXMILE CREEK.

FIGURE 36.—POSTGLACIAL GORGE OF SIXMILE CREEK ABOVE ITHACA.
The stream flows through the gap from one section of the old buried valley to another. Site for dam and reservoir under construction.

FIGURE 37.—GLACIAL-LAKE CLAY IN THE MORAINIC AREA OF SIXMILE CREEK.
Jointed by shrinkage from drying. Contains small scratched pebbles.

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