DEPARTMENT OF THE INTERIOR
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GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS
OF THE
UNITED STATES

WARREN FOLIO

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BY

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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.

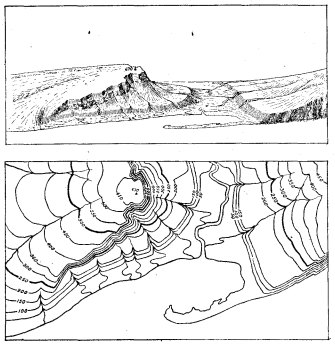


FIGURE 1.—Ideal view and corresponding contour map.

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.

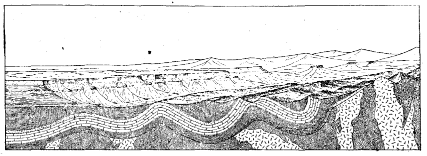
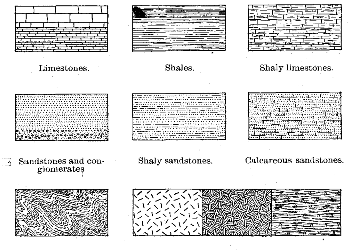


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

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.

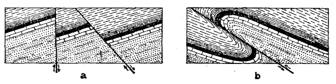


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

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 WARREN QUADRANGLE.

By Charles Butts.

INTRODUCTION.

LOCATION AND AREA.

The Warren quadrangle lies in the basin of Allegheny River, in northwestern Pennsylvania. It extends from latitude 41° 45′ to 42° north, and from longitude 79° to 79° 15′ west (see fig. 1), and thus includes one-sixteenth of a square degree and has an area of $222\frac{1}{2}$ square miles. It is wholly in Warren County and receives its name from the most important town within its boundaries. It lies in the grand physiographic and geologic division of the United States known as the Appalachian Province and its detailed description is therefore preceded by a general description of that province.

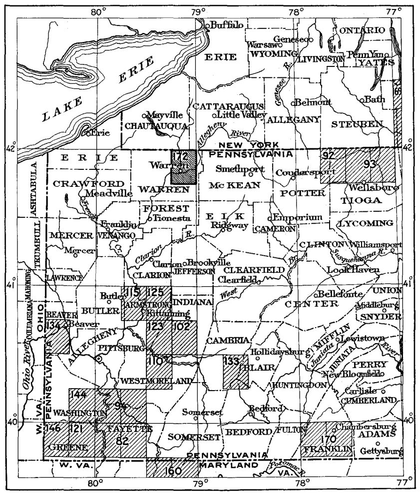


FIGURE 1.—Index map of western Pennsylvania and New York.

Darker ruled area covered by Warren folio. Other published folios indicated by lighter ruling as follows: Nos. 82, Masontown-Uniontown; 92, Gaines; 93, Elkland-Tioga; 94, Brownsville-Connellsville; 102, Indiana; 110, Latrobe; 115, Kittanning; 121, Waynesburg; 123, Elders Ridge; 125, Rural Valley; 133, Ebensburg; 134, Beaver; 144, Amity; 146, Rogersville; 160, Accident-Grantsville; 169, Watkins Glen-Catatonk; 170, Mercersburg-Chambersburg.

APPALACHIAN PROVINCE.

The Appalachian Province extends from the Atlantic Coastal Plain on the east to the Mississippi lowlands on the west, and from Alabama to Canada.

With respect to topography and geologic structure it is divided into two nearly equal parts by the eastward-facing escarpment in Pennsylvania, Maryland, and West Virginia known as the Allegheny Front and the eastern escarpment of the Cumberland Plateau from Virginia to Alabama. (See fig. 2.) East of this escarpment the rocks are greatly disturbed by folds and faults;. west of it they lie nearly flat, the few folds that break the regularity of the structure being so broad that they are scarcely noticeable. Immediately east of the Allegheny Front is a series of alternating ridges and valleys, designated the Appalachian Valley, and still farther east is a somewhat dissected upland known as the Piedmont Plateau. Between the Appalachian Valley and the Piedmont Plateau are the Appalachian Mountains and the Blue Ridge. West of the Allegheny Front lie more or less elevated plateaus, greatly dissected by streams and broken by a few ridges where minor folds affect the rocks. In contradistinction to the lowlands of the Mississippi Valley on the west and the ridges and valleys of the Appalachian Valley on the east, this part of the province has been called by Powell the Allegheny Plateaus. By a recent decision of the United States Geographic Board, however, the name Appalachian Plateau has been applied to this region and it will be here so designated. As the Warren quadrangle is located on the Appalachian Plateau that division of the province will be somewhat fully described.

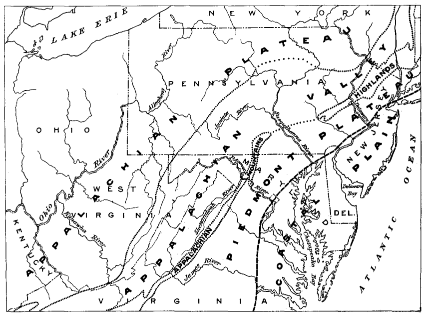


FIGURE 2.—Map of the northern part of the Appalachian Province, showing its physiographic divisions and its relation to the Coastal Plain Province.

APPALACHIAN PLATEAU.

TOPOGRAPHY.

Drainage.—The Appalachian Plateau drains almost entirely into the Mississippi, only the waters in its northeastern part draining into the Great Lakes or into the Atlantic Ocean through Susquehanna, Delaware, and Hudson rivers. The Warren quadrangle drains wholly to the Mississippi.

In the northern part of the province the arrangement of the drainage is due largely to former glaciation. Before the Pleistocene epoch all the streams north of central Kentucky probably flowed northwestward and discharged their waters through the St. Lawrence system. The encroachment of the great ice sheet, as shown in figure 11, closed this northern outlet and led to the establishment of the existing drainage lines.

In the southern half of the province the westward-flowing streams not only drain the Appalachian Plateau, but many of them have their sources on the summits of the Blue Ridge and flow across the Appalachian Valley.

Relief.—The northern part of the Appalachian Plateau is highest along its southeastern margin, the general surface rising from an altitude of 1700 feet in southern Tennessee to 4000 feet in central West Virginia and thence descending to 2200 feet in southern New York. The surface also slopes in a general way to the northwest and southwest and merges into the Mississippi and Gulf plains. The Cumberland Plateau in Tennessee and Alabama forms the southeastern part of the Appalachian Plateau. The Highland Plateau lies west of and lower than the Cumberland Plateau, in Tennessee and Kentucky, at an altitude of about 1000 feet. The broad elevated belt lying along the southeastern margin of the Appalachian Plateau north of the Cumberland Plateau, and extending to southern New York, is so greatly dissected that its plateau character becomes apparent only in a wide view from some high point, where on account of the nearly uniform heights of the highest ridges and hills and the concealment of the valleys the effect is the same as in a view across a widely extended plain.

The surface of the Cumberland Plateau and perhaps also the summits of the higher ridges and hills, as well as extensive tracts of level surface that stand at high altitudes along the eastern margin of the Appalachian Plateau, as described above, are probably elevated remnants of a once extensive peneplain, which may possibly be correlated with the Schooley peneplain, now preserved on Schooley Mountain, in northern New Jersey.[a] In the Allegheny and Monongahela drainage basins of western Pennsylvania the general surface may be regarded as a plateau, not named but possibly corresponding to the Highland Plateau of Tennessee and Kentucky. The higher divides and ridges of this plateau probably coincide approximately with the former surface of a second peneplain, younger than the Schooley and at a lower level. This old surface has recently been called by Campbell[b] the Harrisburg peneplain, in the belief that it was of the same age as a peneplain that was well developed near Harrisburg, Pa. Along Monongahela, Allegheny, and Ohio valleys are extensive areas in which the hilltops and ridges appear to be remnants of a still lower and younger plain, which has been uplifted and dissected just as the Schooley and Harrisburg peneplains have been, but which is lower, younger, and less extensive. This has been named by the writer the Worthington peneplain (see Kittanning folio, No. 115), because it is well developed between the town of Worthington and Allegheny River, in Armstrong County, Pa., where its elevation is about 1100 feet above the sea.

GEOLOGY.

Stratigraphy.—The surface rocks of the Appalachian Plateau are mostly of Carboniferous age. About the northern end and along the southeastern margin of the plateau the Carboniferous rocks are bordered by the upper formations of the Devonian system, which lie beneath the Carboniferous rocks throughout the region. The Carboniferous rocks are divided into two series, the Mississippian below and the Pennsylvanian above. The rocks of the Mississippian series are mainly sandstones and shales in the northern part of the region but comprise thick limestones in the southeastern and southwestern parts. They outcrop around the margin of the plateau and underlie the rocks of the Pennsylvanian series in the interior. The Pennsylvanian series is coextensive with the Appalachian coal field. It consists essentially of sandstones and shales but contains extensive beds of limestone and fire clay; it is especially distinguished by its coal beds, one or more of which is present in nearly every square mile of its extent from northern Pennsylvania to central Alabama. The rocks of the Warren quadrangle include portions of both the Mississippian and the Pennsylvanian series, as well as Upper Devonian rocks.

Structure.—The geologic structure of the Appalachian Plateau is very simple, the rocks forming, in a general way, a broad, flat, shallow trough, particularly at the northern extremity of the plateau.

The axis of the trough extends southwestward from Pittsburg across West Virginia to Huntington, on Ohio River. In Pennsylvania its deepest part is in the southwest corner of the State, and the inclination of the rocks is generally toward that locality. The rocks lying southeast of the axis dip northwest; those lying northwest of the axis dip southeast; those outcropping in a rudely semicircular belt around the northern end of this trough dip at all points toward its lowest part. The northern end of the trough may be compared to the prow of a boat or the point of a spoon.

Although in general the structure is simple, there are, on the eastern limb of the trough, a number of low parallel folds that somewhat complicate the structure by reversing and obscuring the prevailing westward dip. These undulations are similar to the great folds east of the Allegheny Front, but they are much gentler and very much smaller and are not broken by faults. They are present along the southeastern margin of the trough from central West Virginia to southern New York. Most of these minor folds are at the northern extremity of the trough, near the northern boundary of Pennsylvania; the folded region extends at least halfway across the State. In the southern part of the State there are only six pronounced anticlines, two of which die out near the West Virginia line. Still farther south the number further decreases until on Kanawha River the regular westward dip is interrupted by only one or two small folds. Moreover, west of the Allegheny Front each trough, as well as each arch, lies lower than the one on the east, so that formations or beds which are more than 2000 feet above the sea at the Allegheny Front lie below sea level in the central part of the basin.

TOPOGRAPHY.

DRAINAGE.

The Warren quadrangle is wholly drained by Allegheny River and its tributaries. The Allegheny, which is the main headwater tributary of the Ohio, drains an area of about 11,500 square miles lying in southwestern New York and northwestern Pennsylvania. It flows westward across the quadrangle from Big Bend to Irvineton. At Warren it is joined by Conewango Creek, a good-sized stream which drains Chautauqua Lake. Tionesta Creek drains the southern part of the quadrangle. It is noteworthy that the Tionesta flows northwestward to Clarendon, within 4 miles of the Allegheny, and then, instead of continuing northward along the wide valley of Dutchman Run to Glade, turns southward and joins the Allegheny at Tionesta, 20 miles southwest of the quadrangle. It is also noteworthy that although some of the affluents of the Allegheny in Cattaraugus and Chautauqua counties, N. Y., and in Erie County, Pa., have their sources on the southern slope of an elevation that overlooks Lake Erie and is only 7 to 15 miles distant from it, yet they flow directly away from the lake and form no part of the St. Lawrence drainage. These anomalous features will be discussed under the heading "Historical geology," page 9.

The general drainage pattern is branched, and the branches are rather symmetrical, both as to number, size, and spacing.

The streams have uniformly graded beds, with neither falls nor notable rapids, though all of them are divided into reaches or pools connected by riffles or rapids of small descent. The lengths of the principal streams and their fall, total and relative, within the quadrangle are shown in the following table. The distances on the smaller streams are measured from the

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[a] Davis, W. M., Proc. Boston Soc. Nat. Hist., vol. 24, 1890, p. 377.

[b] Campbell, M. R., Bull. Geol. Soc. America, vol. 14, 1903, pp. 277–296.

flood plains at their mouths to the margin of the quadrangle or to the sharp declivities near their heads.

Length and fall of streams in the Warren quadrangle.

	Length.	Fall.	Fall per mile.
	Miles.	*Feet.*	*Feet.*
Allegheny River	15	60	4
Conewango Creek	12	50	4⅙
Tionesta Creek	6¾	90	13
Jackson Run	5½	180	33
Morrison Run	5½	460	85
Ackley Run	4¾	490	103

Allegheny River and Conewango and Tionesta creeks are permanent streams, whose flow is good, though diminished, in seasons of drought. The minor streams probably go dry or nearly dry at such times.

RELIEF.

General character.—The surface of the Warren quadrangle is hilly, the topography being of the ridge and valley type. With the questionable exception of Fox Hill, there are no isolated hills. The rocks are fairly uniform in character and lie nearly flat, so that the ridges and spurs, unlike those in regions of strongly dipping rocks of varying hardness, are disposed irregularly and have no common trend. Topography of this type is exemplified by Quaker Ridge, from which spurs of the first order project and in turn give off spurs of the second order. Most of the ridges are rather broad and comparatively level on top. The spurs also are generally rather broad, straight, and flat topped, though some are narrow and sharp pointed. Their shape and disposition are determined solely by the drainage. Quaker Ridge and the ridges south of the river have been to some extent conditioned or modified by the conglomerates and sandstones of the Knapp and Pottsville formations, which have in places acted as a protective capping. In Stone Hill, for example, the cap rock until recently has been the Connoquenessing sandstone member of the Pottsville, large isolated masses of which still remain on the crest. Just beneath the Connoquenessing lies the upper part of the Knapp formation, which now and for the future will act as a cap to protect the spur from the rapid denudation that takes place on unprotected elevations. (See fig. 3.)

FIGURE 3.—View up Indian Hollow from a point near Warren, showing rounded shale slopes and terrace on Snyder Hill made by the lower ferruginous conglomerate member of the Knapp formation.

Most of the main valleys are narrow and rather deep and are bounded by steep walls. The uplands, however, are more level or are undulating, and the valley slopes become gentler toward the headwaters of the smaller streams and along their tributaries. Gentle slopes, due to smoothing by ice and to partial filling of the valleys, prevail in the northern part of Farmington Township, and wide bottom lands and terraces lie in the valleys of the larger streams.

Peneplanation.—To a superficial view the present irregular surface of the quadrangle offers but little suggestion that it was once nearly level. On a wide view from some high hilltop, however, the surface irregularities become inconspicuous and the country a little distance away presents the appearance of an extensive plain. This appearance is emphasized by the fact that the sky line is straight and almost horizontal, the hill and ridge crests rising to a common level and apparently merging in the distance. (See fig. 4.) The topographic map shows that in the southwestern part of the quadrangle there are many hilltops, ridges, spurs, and divides with altitudes of about 1880 feet, that in the northern part similar features exist with altitudes of 2160 feet, and that the heights are intermediate over much of the intervening area. Probably three-fourths of the whole would lie at or close below a plane sloping from 1880 feet in the southwestern part to 2160 feet in the northeastern part of the quadrangle, only some small areas standing above it. The quadrangle surface is thus essentially a plateau that is deeply dissected by the streams that traverse the region.

If we conceive the parts of the quadrangle that lie below this imaginary plane to be so filled as to coincide approximately with it, and the higher areas to remain as at present, an undulating surface would result. It is believed that such a surface once existed in this region at a much lower level than the present plateau, constituting what is known as a peneplain, and that it was uplifted and concomitantly dissected by stream erosion. The former surface, known as the Harrisburg peneplain, has been briefly described under the heading "Appalachian Plateau" (p. 1) and will be again discussed in the section on "Historical geology" (p. 9).

The Harrisburg peneplain was probably the result of subaerial erosion that continued for a very long time, during which the crust of the earth in this region moved neither up nor down. Erosion working on a land surface under such conditions tends to reduce it to a plain lying practically at sea level, with some small areas rising above it in places where the rocks are harder and more resistant to erosion, or in places near the headwaters of streams and therefore less subjected to erosion. If there is no upward movement of the region even these slight eminences will finally be eroded away. Such a plain could have been formed by marine erosion, but there is no evidence that the supposed Harrisburg peneplain was so formed. It might also be coincident with the surface of some resistant stratum, such as a hard sandstone; but generally in this region the peneplain appears to have been developed on hard and soft strata alike and does not coincide with the dip of the beds.

Stream terraces.—Gravel terraces exist at two levels and are striking features in the topography. The tops of the upper terraces lie between 1360 and 1380 feet and those of the lower at 1200 feet above the sea. They are well developed at Warren, the cemetery and the golf links being on terraces at the upper level and Warren being built on a terrace at the lower level. (See, further, p. 7.)

Triangulation.—Descriptions of triangulation stations and data of precise leveling in the quadrangle are given in Bulletins 288 and 310 of the United States Geological Survey.

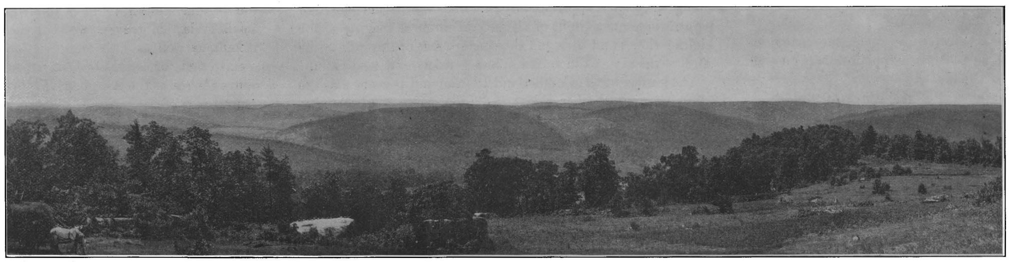

FIGURE 4.—View looking south from Cobham Hill over the surface of the dissected Harrisburg peneplain. Shows the even sky lines due to peneplanation.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

The rocks exposed or known in the Warren quadrangle are mainly of Devonian and Carboniferous age. The Devonian rocks, most of which are known from well borings, probably comprise beds as low as the Marcellus shale and include the Portage and Hamilton formations. The Carboniferous rocks include parts of the Mississippian and the Pennsylvanian series. There are also Quaternary deposits of glacial origin. The rocks are described in order from the bottom upward, or in the order of their accumulation, from the oldest to the youngest.

DEVONIAN SYSTEM.

GENERAL STATEMENT.

The most accurate information as to the thickness of rocks referred to the Devonian was obtained from the log of a well drilled at Starbrick, about 3 miles west of Warren. This well was started at 1180 feet above sea level and was drilled to 2490 feet below sea level and is thus 3670 feet deep. Drillings were saved from each kind of rock penetrated, and from the study of these the following section has been made up:

Section of deep well at Starbrick, Pa.

			Thickness.	Depth.
			Feet.	*Feet.*
Chemung formation.	Sand and gravel, etc. (drive pipe)		100	100
	Greenish-gray shale and micaceous fine-grained sandstone	"Pink rock"	100	200
	Chocolate shale		100	300
	Greenish-gray shale and fine-grained micaceous sandstone; fragments of shells		100	400
	Greenish-gray shale and fine-grained micaceous sandstone; fragments of shells and some chocolate sandstone (gas)		147	547
	Light-gray shale and fine-grained micaceous sandstone		67	614
	Gray sand, medium grained, siliceous. Glade sand (gas)		26	640
	Gray shale and fine-grained sandstone; includes horizons of Clarendon and Gartland sands		260	900
	Gray fine-grained micaceous sandstone		20	920
	Gray shale and fine-grained micaceous sandstone; some siliceous sandstone like that immediately below; probably alternating thin layers of shale and sandstone		300	1220
Portage formation.	Gray shale and siliceous sandstone, called Cooper sand		10	1230
	Gray shale and micaceous sandstone		370	1600
	Dark-gray shale		50	1650
	Dark-gray shale and thin gray micaceous sandstone		375	2025
	Dark-gray shale		25	2050
	Soft dark clay shale (pyrite)		10	2060
	Dark clay shale		115	2175
	Dark clay shale with flakes of black shale in drillings		25	2200
	Dark clay shale, micaceous; a little pyrite		100	2300
	Soft dark shale		36	2336
	Stiff gray shale or fine-grained sandstone		10	2346
	Stiff dark gray clay shale		204	2550
Hamilton shale.	Soft dark-brown or olive-green clay shale		200	2750
	Soft bluish-gray clay shale		100	2850
	Soft chocolate clay shale		210	3060
	Dark bluish-gray clay shale, calcareous		60	3120
	Bluish-gray shale		97	3217
	Dark shale		10	3227
	Soft bluish-gray clay shale, highly calcareous		141	3368
	Dark clay shale, highly calcareous		22	3390
	Black clay shale, highly calcareous		8	3398
	Gray limestone		7	3405
	Pinkish-gray limestone		7	3412
	Pinkish-gray limestone, a little pinker than the above		4	3426
	Bluish-gray limestone		4	3430
	Soft dark shale, highly calcareous		90	3520
	Soft dark shale, slightly calcareous		140	3660
	Black shale with calcite (Marcellus shale)		10	3670

It is believed that the Marcellus, Hamilton, Portage, and Chemung formations of the Devonian system can be recognized in the above well section and in outcrop.

MARCELLUS SHALE.

The bottom 10 feet of rock penetrated in the Starbrick well consists of black clay shale, the upper 5 feet being blacker and softer than the bottom 5 feet. The drillings contain about 10 per cent of translucent calcite fragments and a few small crystals of pyrite. It is uncertain whether the calcite occurs as a bed at the top of the shale or as veins or thin plates scattered throughout the shale. As the samples from the upper and the lower 5 feet were taken separately and the calcite is equally distributed in both samples, it appears that the latter mode of occurrence is the more probable. According to Bishop[a] the top of the Marcellus is defined by a more or less persistent horizon of calcareous rock in Erie County, N. Y., the nearest point to the Warren region at which the Marcellus shale outcrops. The Marcellus of western New York is also very black and contains much pyrite. It thus appears that there are substantial grounds for regarding as Marcellus the black shale at the bottom of the Starbrick well section.

HAMILTON SHALE.

Above the Marcellus lie 1110 feet of dark and gray clay shales, which are assigned to the Hamilton. These beds contain much more dark than gray shale. In Erie County, N. Y., the Hamilton is 164 feet thick.[b] At Altoona, Pa., it is 800 feet thick, as determined by the writer in the survey of the Hollidaysburg quadrangle.

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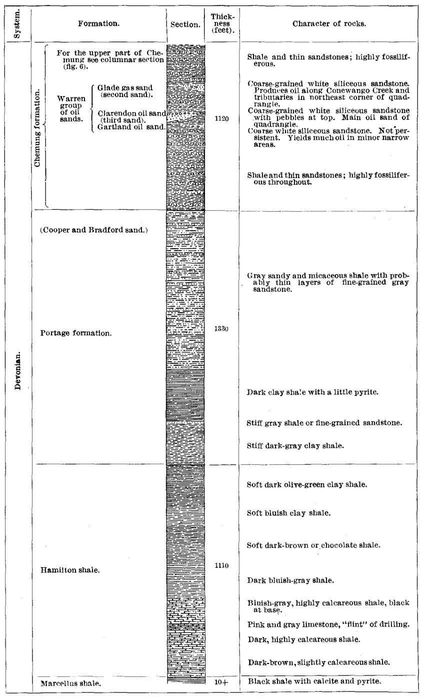
[a] Fifteenth Ann. Rept. New York State Geologist, for 1895, 1897, pp. 315-316.

[b] Luther, D. D., Bull. New York State Mus. No. 99, 1906, pp. 17-22.



System.	Formation.	Section.	Thickness (feet).	Character of rocks.
Devonian.	Chemung formation. For the upper part of Chemung see columnar section (fig. 6).		1120	Shale and thin sandstones; highly fossiliferous.
	Warren group of oil sands. Glade gas sand (second sand).			Coarse-grained white siliceous sandstone. Produces oil along Conewango Creek and tributaries in northeast corner of quadrangle.
	Clarendon oil sand (third sand).			Coarse-grained white siliceous sandstone with pebbles at top. Main oil sand of quadrangle.
	Gartland oil sand.			Coarse white siliceous sandstone. Not persistent. Yields much oil in minor narrow areas.
				Shale and thin sandstones; highly fossiliferous throughout.
	(Cooper and Bradford sand.)			
	Portage formation.		1330	Gray sandy and micaceous shale with probably thin layers of fine-grained gray sandstone.
				Dark clay shale with a little pyrite.
				Stiff gray shale or fine-grained sandstone.
				Stiff dark-gray clay shale.
	Hamilton shale.		1110	Soft dark olive-green clay shale.
				Soft bluish clay shale.
				Soft dark-brown or chocolate shale.
				Dark bluish-gray shale.
				Bluish-gray, highly calcareous shale, black at base.
				Pink and gray limestone, "flint" of drilling.
				Dark, highly calcareous shale.
				Dark-brown, slightly calcareous shale.
	Marcellus shale.		10+	Black shale with calcite and pyrite.

FIGURE 5.—Generalized section of unexposed rocks in the Warren quadrangle, based on the record of the Starbrick well,

Scale, 1 inch=500 feet.

The bottom 230 feet of shale included in the Hamilton in the well sections is dark, calcareous, and argillaceous. It is overlain by 22 feet of gray and pinkish limestone, which was found to be so very hard that it required seven days drilling to penetrate it. It probably lies in the horizon of the basal limestones of the Hamilton in western New York or possibly represents the Onondaga limestone of New York. Above it is 170 feet of blue-gray, very calcareous clay shale. Most of the upper 650 feet of the Hamilton consists of gray and dark clay shales in alternating thick strata. The character of the formation is exhibited in the well section.

GENESEE SHALE.

The Genesee shale can not be recognized in the well sections, and it is probably absent, as it is in Erie County, N. Y., where the formations above and below it outcrop.

PORTAGE FORMATION.

Above the Hamilton shale is about 2000 feet of rock that, so far as the drillings show, is a nearly homogeneous mass of greenish-gray sandy shale, with interbedded thin fine-grained bluish or greenish gray sandstones. The boundary between the Portage formation and the succeeding Chemung lies in the midst of these rocks; it is drawn here at a horizon noted in the log of the well as the top of a sandstone 10 feet thick, called the Cooper sand, the top of which lies at a depth of 1220 feet. This 10 feet of rock may have been a little harder than the contiguous rock and may have been called a sandstone on that account, but the drillings indicate no more sand than there is in the rocks for 400 feet above and below. This so-called sand, however, is about 400 feet below the probable horizon of the Clarendon oil sand in the Starbrick well and lies about at the horizon of the Bradford oil sand. As the Bradford oil sand is probably the same as the sandstone which forms the top of the Portage at Portageville, N. Y., this determination of the top of the formation in the well section appears to be justified.

The thickness of the Portage formation as defined above is 1330 feet, which accords well with the thickness of 1000 feet determined by Hall in Portage Gorge of Genesee River and with the thickness of 1400 feet determined by Hall along the shore of Lake Erie.[a] The formation is more than 1500 feet thick in Erie County, N. Y., according to Bishop,[b] and is 2000 feet thick at Altoona, Pa., 100 miles southeast of Warren.

The Portage formation, as here delimited, has at the base about 200 feet of gray shale, overlain by about 300 feet of dark clay shale, which may correspond to Luther's Rhinestreet black shale, of Erie County, N. Y. The upper 800 feet of the formation consists of greenish-gray sandy and micaceous shale, interbedded with thin sandstone, and is probably much like the upper Portage in Portage Gorge of Genesee River.

CHEMUNG FORMATION.

Character.—In the well sections in this region the lower part of the Chemung formation can not be distinguished lithologically from the Portage formation, and the same statement holds for central Pennsylvania, where the division between the two formations has been made on paleontologic grounds.[a] At Portageville, on Genesee River, New York, a thick sandstone may mark the boundary between the Portage and the Chemung, and, as stated in the description of the Portage formation, the boundary in the Warren quadrangle is placed at the supposed horizon of this sandstone.

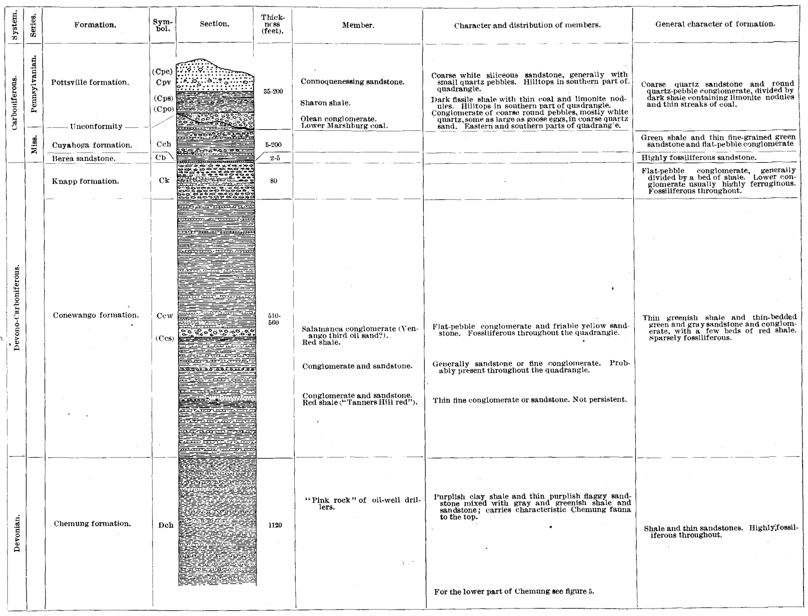
The top of the Chemung is placed at the top of a varying thickness of strata known to the driller as the "pink rock." The upper part of the Chemung thus characterized outcrops along Allegheny River northeast of Kinzua and along Conewango Creek. Within the limits thus defined the formation is 1120 feet thick.

The rocks of the Chemung formation are mostly greenish-gray micaceous and sandy shale and thin, fine-grained argillaceous sandstone, very much like the upper shales and sandstones of the underlying Portage formation. In the midst of the Chemung are from one to three beds of medium to coarse oil-bearing quartz sandstone, which are described below.

Gartland oil sand.—About 350 feet above the base of the Chemung lies the Gartland oil sand, supposed to be the equivalent of the Cherry Grove or Garfield sand. A sand at this horizon has been generally noted in the southeastern part of the quadrangle in wells that are deep enough to reach it. Where best known the sandstone is composed of coarse transparent quartz sand and is probably pebbly.

Clarendon oil sand.—In areas where the Gartland sand is oil bearing the Clarendon oil sand lies 15 to 30 feet above it, the intervening rock probably being shale. So far as shown by samples examined, the Clarendon is a comparatively fine grained light-gray quartz sandstone 20 to 50 feet thick, carrying at its top in places a hard pebbly layer known to well drillers as "shell." It is a persistent member of the Chemung formation over the southeastern quarter of the quadrangle, in which it generally yields either oil or gas, being the main oil-bearing sand of the region.

Glade oil sand.—From 40 to 75 feet above the Clarendon lies the Glade oil sand, running from 10 to 50 feet thick. At East Warren this sand is said to be soft, gray, friable, and pebbly. Though noted in the logs of wells here and there as far south as Stoneham, it yields oil only in the region from the mouth of Dutchman Run to North Warren, and in this area it is the only producing sand of importance.



System.	Series.	Formation.	Symbol.	Section.	Thickness (feet).	Member.	Character and distribution of members.	General character of formation.
Carboniferous.	Pennsylvanian.	Pottsville formation.	(Cpc) Cpv (Cps) (Cpo)		35-200	Connoquenessing sandstone.	Coarse white siliceous sandstone, generally with small quartz pebbles. Hilltops in southern part of quadrangle.	Coarse quartz sandstone and round quartz-pebble conglomerate, divided by dark shale containing limonite nodules and thin streaks of coal.
						Sharon shale.	Dark fissile shale with thin coal and limonite nodules. Hilltops in southern part of quadrangle.	
						Olean conglomerate. Lower Marshburg coal.	Conglomerate of coarse round pebbles, mostly white quartz, some as large as goose eggs, in coarse quartz sand. Eastern and southern parts of quadrangle.	
		Unconformity						
	Miss.	Cuyahoga formation.	Cch		5-200			Green shale and thin fine-grained green sandstone and flat-pebble conglomerate
		Berea sandstone.	Cb		2-5			Highly fossiliferous sandstone.
Devono-Carboniferous.		Knapp formation.	Ck		80			Flat-pebble conglomerate, generally divided by a bed of shale. Lower conglomerate usually highly ferruginous. Fossiliferous throughout.
		Conewango formation.	Ccw (Ccs)		510-560	Salamanca conglomerate (Venango third oil sand?). Red shale.	Flat-pebble conglomerate and friable yellow sandstone. Fossiliferous throughout the quadrangle.	Thin greenish shale and thin-bedded green and gray sandstone and conglomerate, with a few beds of red shale. Sparsely fossiliferous.
						Conglomerate and sandstone.	Generally sandstone or fine conglomerate. Probably present throughout the quadrangle.	
						Conglomerate and sandstone. Red shale ("Tanners Hill red").	Thin fine conglomerate or sandstone. Not persistent.	
Devonian.		Chemung formation.	Dch		1120	"Pink rock" of oil-well drillers.	Purplish clay shale and thin purplish flaggy sandstone mixed with gray and greenish shale and sandstone; carries characteristic Chemung fauna to the top. For the lower part of Chemung see figure 5.	Shale and thin sandstones. Highly fossiliferous throughout.

FIGURE 6.—Generalized columnar section for the Warren quadrangle.

Scale, 1 inch=250 feet.

"Pink rock."—About 225 feet above the Glade sand is the bottom of what is called by the well drillers of the region the "pink rock." This is a purplish or chocolate-colored rock, either shale or thin fine-grained sandstone, which is interbedded with green and gray shale and sandstone and makes a large part of the upper 450 feet of the Chemung formation. The top of the formation is here placed at the top of the "pink rock." (See columnar section, fig. 6.) Immediately east of the Allegheny Front, near Altoona, Pa., where the Chemung rocks emerge from the trough holding the Carboniferous rocks of Elk and Clearfield counties, the upper 1000 feet of the Chemung is characterized by a large proportion of similar chocolate or purplish shale and sandstone.

Upper limit of the Chemung.—The Chemung formation was originally described by Hall as extending up to the base of the "Coal Measures" or Pennsylvanian series of the Carboniferous system. It has been discovered more recently, however,[a] that in western New York and Pennsylvania the characteristic Chemung fauna terminates at about the top of the chocolate shales and sandstones described above. Furthermore, in the Olean region this horizon is marked by the Wolf Creek conglomerate of the New York State Survey reports; the noted Panama conglomerate of the New York and Pennsylvania reports also probably lies at the same horizon. These conglomerates mark the beginning of a different phase of sedimentation in the region, presently to be described.

The faunal changes mentioned above are stated in some detail in the report[a] referred to, and their significance is discussed by Clarke.[b] It is necessary to state here only that such highly characteristic Chemung species as *Spirifer mesacostalis*, *Schuchertella* (*Orthotetes*) *chemungensis*, *Athyris angelica*, *Chonetes scitulus*, *Grammysia communis*, *Mytilaria chemungensis*, a number of species of *Productella*, *Leptodesma*, *Aviculopecten*, and *Pterinopecten* disappear at or below the Wolf Creek conglomerate of the New York State Survey reports in the Olean region, and at the top of the chocolate or purplish rock in the Warren region. Furthermore, there appears at this horizon a distinctly different fauna, which, from its most highly characteristic lamellibranch genus, *Ptychopteria*, may be very appropriately called the *Ptychopteria* fauna. Besides *Ptychopteria*, the pelecypod genera *Modiola* and *Palæanatina* and the brachiopod genus *Œhlertella* make their first appearance in the section at this horizon. This faunal change is made more striking by the fact that of 128 species of fossils collected in the Olean quadrangle, 60 species occur only below the Wolf Creek conglomerate and 59 species only above it, while 9 species are common to the beds above and below the conglomerate. There appear, therefore, to be adequate lithologic and faunal grounds for taking the top of the chocolate beds and the base of the Wolf Creek conglomerate of the New York State Survey reports as the top of the Chemung formation.

Distribution of the Chemung formation.—In the Warren quadrangle the Chemung formation outcrops near the base of the hills along Conewango Creek and tributaries from Warren northward, its top rising to about 200 feet above the valley bottom at the north edge of the quadrangle. It also outcrops in a small area on Stateline Run, in the northeast corner of the quadrangle. The chocolate beds near the top are well exposed along a cut on the road one-half mile north of the asylum at North Warren, and in places on the highway along the east side of the Conewango as far north as Russell.

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[a] Survey of Fourth Dist.: Nat. Hist. New York, Geology, 1843, p. 229.

[b] Fifteenth Ann. Rept. New York State Geologist, 1897, p. 389.

[a] Butts, Charles, Jour. Geology, vol. 14, No. 7, 1905, pp. 626–627.

[a] Butts, Charles, Fossil faunas of the Olean quadrangle: Fifty-sixth Ann. Rept. New York State Mus., for 1902, vol. 2, 1904, pp. 990–991.

[b] Clarke, J. M., Fifty-sixth Ann. Rept. New York State Mus., for 1902, vol. 2, 1904, p. 985.

DEVONO-CARBONIFEROUS ROCKS.

GENERAL DISCUSSION.

It is a mooted question whether the Conewango and Knapp formations, next to be described, should be included in the Devonian or in the Carboniferous system. They have generally been included in the Devonian and they certainly contain Devonian fossils. As explained elsewhere, however (p. 3), a marked faunal change takes place at the base of these rocks. Most of the forms occurring so abundantly in the Chemung do not appear in later beds but are succeeded by new forms, some of which have decided Carboniferous affinities. When this fauna was first studied at all carefully, by Clarke and Butts, the opinion was expressed that these rocks might best be regarded as Carboniferous, a view that has since been supported by more thorough study. It seems best to treat them, therefore, under the term Devono-Carboniferous rocks, by which their doubtful position is indicated.

CONEWANGO FORMATION.

Name and limits.—The name Conewango is here proposed for about 550 feet of rock between the top of the Chemung, as just defined, and the base of the Knapp formation, later to be described. The name is appropriate because the rocks make most of the valley walls and the uplands bordering Conewango Creek south of the state boundary.

Character and distribution.—The Conewango formation consists mainly of greenish sandy shale, with thin layers of very fine grained greenish micaceous and argillaceous sandstone. The lower half contains beds of gray sandstone, rather fine grained, made up mainly of quartz sand, with thin and probably lenticular beds of fine conglomerate and scattering thin beds of bright-red shale. In the middle of the formation is a persistent conglomerate 20 feet thick, which is designated the Salamanca conglomerate member.

The 250 to 300 feet of the Conewango formation lying above the Salamanca conglomerate member and below a conglomerate along the river bluffs, heretofore known as the "sub-Olean conglomerate," consists of thin, fine-grained greenish argillaceous sandstone and sandy shale, like the rocks below the Salamanca. About 40 feet below the top of this mass of shale and sandstone is a bed of thin sandstone or, rather, of thick-layered mud rock, which is crowded with casts of fossils. This fossiliferous layer was seen exposed in place at only one point, where it was about 6 inches thick, and it is probably nowhere more than a foot or two thick, its presence being known only by débris. The bed is persistent throughout the quadrangle north of the river, loose pieces of it, full of fossils, being found on the surface nearly everywhere at its horizon.

The Conewango formation outcrops along the hillsides bordering Conewango Creek and makes nearly all of the upland surface west of the Conewango and much of it east of that stream. South of the Allegheny its outcrop is confined to the valley walls, and at the south margin of the quadrangle only the part above the Salamanca member outcrops.

The thickest bed of red shale seen in the quadrangle is exposed at the head of Liberty street in Warren. This is the "Tanners Hill red" described by Carll in his report on the geology of Warren County. It is 15 to 20 feet thick, is overlain by greenish-gray flags, and is essentially argillaceous, though containing a little sand and mica. This bed is about 100 feet above the bottom of the Conewango formation.

Just west of Warren, in a cut of the Dunkirk, Allegheny Valley and Pittsburg Railroad, is an exposure showing about 10 feet of red shale and sandstone, which appears to be the same bed as at Warren. Red shale is reported also by Carll at the mouth of Sill Run and at the mouth of Ott Run. Thin layers occur here and there at the horizon of and in association with the Salamanca conglomerate member, near the middle of the formation. This shale is exposed in the quarry on the spur overlooking East Warren, in the north bank of Browns Run about a mile above the mouth, and on Fourmile Run in the southeast corner of the quadrangle.

A thin, small quartz-pebble conglomerate 2 to 4 feet thick, lying about 120 feet above the bottom of the Conewango formation, is exposed in a cut of the Erie division of the Pennsylvania Railroad just south of Glade. A bed 1 foot thick, probably the same as this one, shows by the roadside north of the river about a mile southwest of the mouth of Hemlock Run. Another conglomerate of the same character, lying about 200 feet above the bottom of the formation, appears in the road on the hillside nearly west of the Pennsylvania Railroad station at Warren, at an elevation of 1360 feet. A similar conglomerate shows in the road one-half mile south of Kinzua, 1½ miles east of the quadrangle. In Cable Hollow, two-thirds of a mile west of the town line, a mass of conglomerate is exposed, indicating a bed 5 to 8 feet thick, that may be in place or may be a slumped mass of the Salamanca conglomerate outcropping on the hillside above. If in place, it probably lies at the horizon of the second conglomerate just described. These conglomerates are thin, are perhaps local, and are unimportant except as showing a change in the character of sedimentation, which probably indicates the beginning of terrestrial changes of considerable magnitude in adjacent regions.

It is well to mention here that at the base of the Conewango in the Olean region of New York is a conglomerate that in its best development is 20 feet or more thick and is largely composed of quartz pebbles of considerable size. This is described as the Wolf Creek conglomerate by Glenn[a] in the New York State Survey reports. On the south branch of Stateline Run, about 500 feet west of the quadrangle boundary, a ledge of conglomerate, 3 feet thick and apparently in place, crosses the road at an elevation of 1600 feet. If in place, this lies near the horizon of the Wolf Creek conglomerate. The well-known Panama conglomerate at Panama, N. Y., a few miles north of the Warren quadrangle, described in the New York and Pennsylvania State reports, appears to lie at about the same horizon.

Salamanca conglomerate member.—The Salamanca conglomerate member lies 260 feet above the bottom of the Conewango formation and varies in thickness from 10 to 20 feet, or possibly more. Although exposed at only a few points, it appears to be persistent throughout the quadrangle, its presence generally being made known by bowlders and masses of large size strewing the hillside below the line of its outcrop. In places within the glaciated area of the quadrangle bowlders of the conglomerate have been shoved up the slopes above the line of outcrop.

The Salamanca varies from a coarse conglomerate to a medium-grained, medium thick bedded, rather soft, free-working sandstone. The sandstone is generally white or pale yellow, mottled and banded with deeper yellow and reddish tints. The conglomerate consists of pebbles that are almost wholly of white quartz embedded in a finer groundmass of white quartz sand; most of the pebbles are under 1 inch in longest diameter, and they range down to the size of a wheat grain. Scattered pebbles of jasper occur, a fact of much significance as affording a clue to the possible source of the material and the physical geography of this part of the continent at the time of its deposition. (See section "Historical geology.")

FIGURE 7.—Slope below the outcrops of Salamanca conglomerate, covered by bowlders of that formation. Rhine Run, 1 mile south of Putnamville.

Like all pebbles contained in the conglomerates of the Conewango formation, including those in the Wolf Creek conglomerate of the New York State Survey reports, the pebbles of the Salamanca conglomerate are prevailingly flat, a fact which is believed to indicate that the material had been subject to long-continued movement to and fro on a sea beach.

Good exposures of the Salamanca are rare in the Warren quadrangle. One of the best is about one-third mile north of Stoneham, 50 feet above the road, where there is a continuous outcrop of the stratum extending about 20 rods along the base of the hill. On the south end of a spur 1½ miles northeast of Ackley the member outcrops at 1760 feet above the sea as a ledge of interbedded sandstone and fine cross-bedded conglomerate 15 feet high. Near the top of the hill one-half mile north of Trinity Church, on Johnny Run, is a good ledge at 1700 feet elevation, and on the north bluff of the river above the schoolhouse 1 mile west of Starbrick is a ledge 10 feet high 200 feet above the river road.

The quarry from which rock was obtained for building the asylum at North Warren is on the hillside a mile northwest of Warren, in the Salamanca conglomerate member, about 370 feet above Conewango Creek and 1560 feet above the sea. At various points the rock, both above and below the horizon of the Salamanca, is flaggy sandstone, making a deposit 50 feet thick, and where in such places the conglomerate is thin and fine its true position is determined with difficulty. A case of this kind may be seen at the quarry on the point of the spur northeast of East Warren and overlooking the town, where the section is as follows:

Section of quarry at East Warren.

	Ft.	in.
Interbedded shale and sandstone	12	
Highly ferruginous layer, with fish remains		2
Green flaggy sandstone	2	
Purple shale pockets	5	
Green flaggy sandstone	8	
Coarse gray sandstone, with streaks of quartz pebbles (Salamanca)	15	
Thin greenish-gray flaggy sandstone	10	
	52	2

The white bowlders and large masses of sandstone and conglomerate that are so abundant and conspicuous on the hillsides bordering the Conewango and its tributaries come from this stratum. (See fig. 7.)

The name Salamanca conglomerate was first used by Carll[a] on account of the fine development and exposure of the conglomerate north of Salamanca, N. Y., where its blocks make a rock city on the hills. He correctly identified the Salamanca rock with the conglomerate outcropping in Popes Hollow, near the head of Cass Run, 4 miles north of the Warren quadrangle. He also, correctly, it is believed, correlated the Salamanca with a conglomerate outcropping at Wrightsville. Carll[b] and White[c] suggested the identity of the Salamanca with the Venango first oil sand, supposing that the first oil sand at Tidioute, with which the Salamanca conglomerate can almost certainly be correlated, was the same as the first oil sand at Oil City and in Venango County generally. It has been shown by the writer, however, that this correlation is probably incorrect, and that the Tidioute first sand, and therefore the Salamanca conglomerate, is the same as the Venango third oil sand.[d]

Fossils and correlation of the Conewango formation.—As already stated (p. 3), there is a marked change in the fossils at the boundary of the Conewango and Chemung formations. The most characteristic fossils of the Conewango are species of the genus *Ptychopteria*, which come in at the base of the formation and continue to the top but are unknown in this region either above or below the Conewango. The fauna of the formation may therefore be appropriately designated the *Ptychopteria* fauna. Other characteristic genera are *Modiola*, *Palæanatina*, and *Pararca*, the first two coming in at the bottom of the Conewango and *Pararca* first appearing in the Salamanca conglomerate member. Westward, in Ohio, the presence of *Ptychopteria* in the Chagrin ("Erie") shale indicates the equivalence of parts, at least, of the Chagrin ("Erie") and Conewango formations. The *Ptychopteria* fauna persists eastward into the region of Olean, N. Y., and even into Potter County, Pa. In the Olean region the 500 feet of strata with *Ptychopteria* contain much red shale, beds of which occur as high as 100 feet above the Salamanca conglomerate. It is probable that southeastward from the Olean-Warren region the proportion of red beds increases until they compose most of the formation. From this it appears that the Conewango is the equivalent of some part of the Catskill formation, as it comes up on the Allegheny Front near Altoona, Pa., from beneath the trough occupied by the bituminous coal fields of Pennsylvania. The actual transition horizontally appears to be of the nature of an interfingering of red and green beds, the green beds with a marine fauna thinning out southeastward and the red beds with fish remains thinning out northwestward. Hall, in his report on the geology of the fourth district of New York, noted the disappearance of the red beds to the northwest, but apparently did not apprehend the real stratigraphic conditions in the case; and where the red beds were absent, or very thin, he regarded the Chemung as extending up to the base of the Olean conglomerate member

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[a] Glenn, L. C., Devonic and Carbonic formations of southwestern New York: Fifty-sixth Ann. Rept. New York State Mus., for 1902, vol. 2, 1904, pp. 971-972.

[a] Second Geol. Survey Pennsylvania, Rept. I4, Warren County, 1883, p. 203.

[b] Idem, Rept. III, 1880, p. 180.

[c] Idem, Rept. Q4, 1881, p. 71.

[d] Pre-Pennsylvanian stratigraphy: Rept. Pennsylvania Topog. and Geol. Survey Comm. for 1906-1908, 1908, p. 195.

of the Pottsville formation. Hall thus included beds that, as has been shown above, are the equivalent of strata included by him in the Catskill formation farther east.

In the Olean and Salamanca quadrangles in New York Glenn divided the Conewango formation into the Cattaraugus and Oswayo formations, the dividing line being at the top of the red beds occurring in that area 100 to 175 feet above the Salamanca conglomerate member. As there are no red beds above the Salamanca in the Warren quadrangle the division made by Glenn and therefore the names used by him are not applicable to this area. Furthermore, the Salamanca conglomerate and all the red beds practically disappear farther west, and the rocks equivalent to the Conewango formation become still more homogeneous, so that it is clearly advantageous to treat them as a unit in this and more western quadrangles, however it may be found desirable to class them farther east.

KNAPP FORMATION.

Name.—The name Knapp "beds" was applied by Glenn to the conglomerate and shale lying between the Oswayo formation and the base of the Olean conglomerate member. Beds of conglomerate and shale believed to be strictly equivalent to the Knapp beds are present throughout the larger part of the Warren quadrangle, where they have been known as the "sub-Olean conglomerate."

Character and distribution.—The maximum thickness of the Knapp formation is about 120 feet. It is composed of three members, a conglomerate 20 to 30 feet thick at the bottom, a bed of shale and thin fine-grained sandstone 10 to 40 feet thick in the middle, and a conglomerate 20 to 60 feet thick at the top.

The Knapp conglomerate caps a number of hills south of Jackson Run and immediately northeast of Warren and occupies the surface of Quaker Ridge north of Scandia. It makes conspicuous cliffs high up on the bluffs for considerable distances along the north side of the Allegheny from Glade to Big Bend and is the rock outcropping and yielding large blocks at Stony Lonesome, 1 mile east of Glade. It outcrops in conspicuous fashion along the brow of the spur east of Clarendon and yields large blocks that are striking objects on the hillsides near that place. It yields some large bowlders or masses on the road at the head of Ott Run. In the southwestern part of the quadrangle it is supposed to be present and is mapped, but it can not be seen because it outcrops low on the hillsides and is covered by the detritus from the conglomerate and sandstone of the Pottsville formation, which caps the ridges. The finest display of the Knapp is along the east bluff of the river from Big Bend to Kinzua, where its cliffs are easily visible from the Pennsylvania Railroad.

Lower conglomerate member.—The lower conglomerate is generally made up of very small iron-stained quartz pebbles in a matrix of ferruginous sand. In places it is almost wholly composed of pebbles of the size of millet grains or smaller. Some of its thin layers are locally so charged with iron oxide as to make them a lean iron ore. Generally on the outcrop this material is fractured or jointed into irregular angular small pieces, so that it can be easily dug out, and it is used to some extent for road metal. The bed is fossiliferous, crinoid stems being especially abundant and generally present in it throughout the quadrangle. A large number of species of brachiopods and lamellibranchs also occur in it. In places the bed becomes a coarser and more resistant conglomerate and outcrops in ledges; a ledge on Cobham Hill is composed of this stratum in its coarser and more resistant phase, and similar coarse beds occur in other localities, but as a general thing the character of the stratum is as first described.

Isolated patches of the Knapp formation on the knobs along the ridge between the river and Jackson Run belong to the lower part of this conglomerate. It is also well exhibited on Snyder Hill, northeast of Warren, and makes the little patches of conglomerate on the knobs west of Page Hollow and along the road north of that place. The long, narrow, level spurs running north, west, and south from the summit of Snyder Hill and terminating in abrupt escarpments are capped by this stratum. The spur south of Snyder Hill is a conspicuous feature in the landscape looking northeast from Warren up Indian Hollow. (See fig. 3.) The same topographic features are everywhere associated with the outcrop of this bed.

The conglomerate continues to the north margin of the quadrangle, its outcrop being shown on the map by the lower part of the area mapped as Knapp formation. South of the river it is thin to the west, being noted in the character described above only along the hills bordering the river west of Warren. Farther south, on the heads of Morrison Run and Tionesta Creek, it appears to be thin and a distinct hard conglomerate. In the southeastern part of the quadrangle it is probably in contact with the upper conglomerate member of the Knapp formation, or nearly so, owing to the thinning or disappearance of the separating shale. In such places the two beds make a good sandstone and conglomerate stratum 80 feet thick, as in the cliff highest up on the bluff at Big Bend.

Shale member.—The shale parting in the formation is thickest in the southwest, is thin in the northeast, and appears to be absent in the southeastern part of the quadrangle. Along the ridge from Scandia to Clendenning school the shale is apparently present throughout, as indicated by débris at its horizon, but it is probably less than 10 feet thick. As a general thing, the presence of the shale is known only by its débris on the surface at its outcrop. It does not differ from the ordinary shale of the region, being yellowish green, micaceous, and sandy or clayey and containing thin layers of yellowish-green argillaceous sandstone.

Upper conglomerate member.—The upper conglomerate member of the Knapp formation varies from a rather thin-bedded, more or less yellow, reddish, or brown mottled, white-weathering sandstone, to a dense conglomerate of small flat quartz pebbles one-half inch or less in largest dimension. The bed reaches a thickness of perhaps 100 feet on the hill a mile north of Clendenning school, and diminishes southwestward to probably less than 20 feet on the hills about the head of Sill Run, where it is mainly sandstone. Scandia is built on this conglomerate and it yields blocks in the vicinity of Germany. The ledge along the north bluff of the Allegheny, above the mouth of Hemlock Run, is made by the outcrop of this stratum, which is here about 30 feet thick. At Big Bend it forms the upper 80 feet of the cliff, the lower part being probably formed by the lower conglomerate member of the Knapp. The conspicuous ledge on the point of the spur east of Clarendon is also made by the outcrop of the upper member. On the north side of Dutchman Run, about a mile a little northeast of Clarendon, there is a ledge 70 feet high which is probably formed by the outcrop of the two united conglomerates of the formation. All over the southeastern part of the quadrangle the presence of the bed is shown by abundant débris, but no exposures were seen and nothing was learned as to its thickness.

Correlation.—The Knapp formation throughout the northern part of the Warren quadrangle and eastward throughout the northern part of McKean County has long been known in the Pennsylvania state reports as the "sub-Olean conglomerate." The geographic name Knapp was introduced by Glenn because the beds outcrop at Knapp Creek station, southwest of Rock City, N. Y., in the Olean quadrangle. The Knapp formation was regarded by geologists of the Pennsylvania Second Geological Survey as the equivalent of the Shenango sandstone of I. C. White, in Mercer and Crawford counties. Glenn also, following the Pennsylvania geologists, correlated the Knapp with that sandstone. It has been shown by the writer, however,[a] that White's Shenango sandstone is about 350 to 400 feet higher stratigraphically than the Knapp and that it has been removed from the Warren-McKean county region by erosion.

CARBONIFEROUS SYSTEM.

General statement.—The rocks of the Carboniferous system are divided into the Mississippian series below and the Pennsylvanian series above. The first series is the same as the "Lower Carboniferous" of the earlier writers of the country, and the second the same as their "Upper Carboniferous" or "Coal Measures." The former name is taken from the Mississippi Valley and the latter from Pennsylvania, because in these regions the respective series are typically developed.

MISSISSIPPIAN SERIES.

NOMENCLATURE.

It is probable that the Mississippian series along the northwestern outcrop of the rocks underlying the "Coal Measures" of western Pennsylvania is the equivalent of the Pocono formation east of the Allegheny Front, but it seems preferable to use here the names applied to these rocks in Ohio and western Pennsylvania, as there is a general resemblance throughout and greater certainty is possible in their correlation.

BEREA SANDSTONE.

Nothing that can be identified as the red Bedford shale of Ohio has been seen in the Warren region. In Ohio the Berea sandstone (grit) overlies the Bedford shale and is 5 to 175 feet thick. The Berea sandstone has been traced eastward from Ohio by Girty and found to be the same as the "Corry" sandstone at Corry, Pa. Identifying it by its abundant and highly characteristic fauna, he was able to follow it still farther east into this quadrangle. It has not been seen exposed in place in the quadrangle, but loose pieces of sandstone, crowded with its fossils, have been found at many points in such position as to indicate that their parent bed immediately overlies the upper member of the Knapp formation, whether that be conglomerate or sandstone. These fossil-bearing sandstone fragments have been found as far east as the mouth of Hemlock Run and southward to the margin of the quadrangle. They are generally rather soft and yellowish and appear, from blocks seen in the southern part of the area, to have been derived from a layer only 1 or 2 feet thick. Probably the stratum thins eastward, coming to a feather edge in this region and disappearing. South of Allegheny River its characteristic fossils can be found abundantly at the top of the Knapp formation. The outcrop of the Berea is shown on the geologic map by a heavy line at the top of the Knapp.

CUYAHOGA FORMATION.

The name Cuyahoga was given by Newberry in 1869 to a mass of shale and sandstone 150 to 250 feet thick, lying between the Berea sandstone and the base of the Pottsville formation in eastern Ohio. The name is used here for what is believed to be the stratigraphic equivalent of the Cuyahoga of Ohio, as the term was originally applied.

In the Warren quadrangle the Cuyahoga varies in thickness from a few feet north of Allegheny River to more than 200 feet at the south margin of the quadrangle, there being a gradual increase in thickness southward, presently to be explained. The rocks are dark-bluish sandy shales, thin bluish fine-grained argillaceous sandstones, thin fine-grained quartz sandstones, and thin conglomerate layers with small flat pebbles. The shale predominates, the other rocks being layers in the shale. The conglomerates are present only in the region south of Browns Run and east of Tionesta Creek, where there are at least two and probably three beds from 2 to 10 feet thick and about 60 feet apart vertically. It is likely that each of these beds has passed as "sub-Olean conglomerate" at some point or other in the region, the uppermost one being at least 200 feet above the Knapp formation, which is also called "sub-Olean conglomerate" where it outcrops along the river bluffs. The presence of these conglomerates gives to the Cuyahoga formation an aspect quite different from that which it has farther west and southwest.

The Cuyahoga is not present north of the Allegheny west of the Conewango. Outliers of the formation exist on some of the hills north of the river east of Warren. It is generally present south of the river near the tops of the hills.

By White[a] and Carll[b] the lower part of the Cuyahoga of Warren County was regarded as the Shenango shale of White, the true position of which, however, is above the Cuyahoga of Ohio. This classification was caused by the correlation of the Knapp formation with the Shenango sandstone of White, whence naturally the rocks overlying the Knapp were correlated with that author's Shenango shale, which overlies the Shenango sandstone in Crawford and Mercer counties. Really, however, except for the thin layer of Berea sandstone, the rocks above the Knapp formation in Warren County are the stratigraphic equivalents of the Orangeville shale and Sharpsville sandstone described by White for Crawford County, and perhaps of his Meadville shale.

PENNSYLVANIAN SERIES.

UNCONFORMITY AT BASE.

In the Warren quadrangle the Pottsville, the lowest formation of the Pennsylvanian series, does not lie everywhere upon the same bed but is in contact with successively younger beds from north to south. (See geologic map.) On the ridge 1 mile north of Smith school the basal bed of the Pottsville lies upon the lower member of the Knapp formation, but on the ridges south of Allegheny River the lowest Pottsville rests on beds as much as 200 feet above the lower Knapp. In the southeast corner of the quadrangle there are at least 220 feet of Mississippian rocks above the upper member of the Knapp, and the Pottsville is absent, probably having been removed by erosion, together with a considerable thickness of Cuyahoga beds that originally underlay it. Figure 8 shows the conditions that probably existed at the time of the Pottsville deposition, taking no account of the subsequent deformation and erosion.

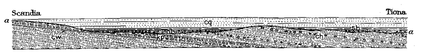

FIGURE 8.—Ideal section from Scandia to Tiona, showing the conditions at the close of Pottsville sedimentation.

cq, Connoquenessing sandstone, sh, Sharon shale, ol, Olean conglomerate, members of the Pottsville formation; ch, Cuyahoga formation and Berea sandstone; kp, Knapp formation; cw, Conewango formation; a-a, unconformity representing the pre-Pottsville land surface and the sea bottom during Pottsville submergence. Vertical scale and dip of pre-Pottsville formations greatly exaggerated.

At some points in the quadrangle the Pottsville and Mississippian rocks can be observed in such positions as to leave no doubt that the younger Pottsville members overlap the older and that they all come into contact with an eroded slope of Mississippian rocks substantially as shown in figure 9. These relations are well displayed along Booker Mill road on the ridge north of Morrison Run. On the north Mississippian rocks extend to the top of a spur; a little farther south, on nearly the same level, 20 feet or so of the Connoquenessing sandstone member caps the summit of the ridge; and on the slope to Morrison Run to the south the Sharon shale member and the Olean conglomerate member appear, having clearly the relations shown in figure 9.

The same relations are also strikingly displayed along the road from Scandia to the Dinsmoor farm, where the Quaker Hill coal bed is mined.

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[a] Pre-Pennsylvanian stratigraphy: Rept. Pennsylvania Topog. and Geol. Survey Comm. for 1906–1908, 1908, p. 193.

[a] Second Geol. Survey Pennsylvania. Rept. Q4, 1881, p. 77.

[b] Idem, Rept. I4, 1883, p. 197.

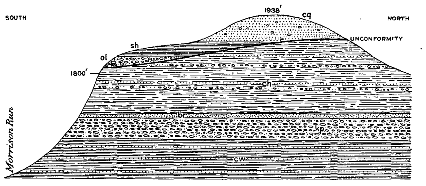

FIGURE 9.—Ideal section across ridge north of Morrison Run along the road from Booker Mill to Warren.

cq, Connoquenessing sandstone. sh, Sharon shale, ol, Olean conglomerate, members of the Pottsville formation lying unconformably on older strata; ch, Cuyahoga formation; br, Berea sandstone; kp, Knapp formation; cw, Conewango formation. Vertical scale exaggerated about 10 times.

An estimate of the thickness of rocks and a judgment as to the part of the general geologic section represented by the Mississippian-Pennsylvanian unconformity at Warren may be reached by comparing the Warren section with the Carboniferous sections to the east and the west. (See fig. 10.)

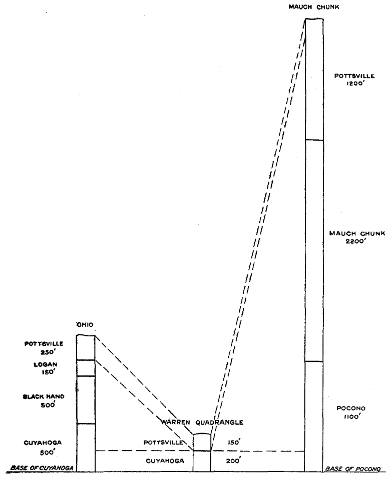

FIGURE 10.—Diagrammatic sections showing the thickness of rocks represented by the Mississippian-Pennsylvanian unconformity in the Warren quadrangle.

At Mauch Chunk, in the anthracite region, the Pocono is over 1000 feet thick, the Mauch Chunk 2200 feet, and the Pottsville 1200 feet. If the correlations made in figure 10 are correct, approximately 4000 feet of these rocks (all but the basal 200 feet or so of the Pocono and the upper 200 feet of the Pottsville) are absent in the Warren section. Likewise nearly 1000 feet of Mississippian rocks that are present in Ohio are not represented in the Warren section. It is probable from these facts that a considerable part of the rocks now absent in the Warren section were once present but were eroded before the deposition of the upper beds of the Pottsville. This supposition is supported by the fact that southward successively higher beds come in between the horizon of the uppermost Mississippian rocks of this quadrangle and the Pottsville, so that in the section at Oil City fully 400 feet of rocks that are absent in the Warren quadrangle lie immediately below the Pottsville. This fact can be clearly established by tracing the rocks southward along the river from Warren to Oil City, as has been done by the writer. This unconformity will be discussed further under the heading "Historical geology."

POTTSVILLE FORMATION.

As stated above, the Pottsville was laid down unconformably upon the eroded surface of the Cuyahoga formation. It consists of three well-defined members—the Olean conglomerate at the bottom, the Sharon shale, and the Connoquenessing sandstone at the top.

Olean conglomerate member.—The Olean conglomerate, the lowest member, takes its name from Olean, N. Y., 7 miles south of which it is typically developed with a thickness of about 60 feet in Rock City. The names "Garland" and "Sharon" have also been applied to this stratum, on the supposition that it is the same as the quarry rock at Garland and the conglomerate at Sharon. The name Olean has priority, however, as it was used by Ashburner[a] before either "Sharon" or "Garland" was used and is, furthermore, more appropriate on account of the fine development and exposure of the conglomerate at Rock City near Olean.

The Olean is a coarse conglomerate, being composed almost everywhere of well-rounded pebbles of white quartz ranging up to 2½ inches in diameter though for the most part measuring 1½ inches or less. These pebbles are embedded in a fine groundmass of quartz grains and are cemented by iron oxide and silica. The round shape of the pebbles serves to distinguish the Olean from all the underlying conglomerates of Mississippian or older age, the pebbles of which, as already noted, are almost universally flat. The thickness of the Olean necessarily varies on account of the irregular surface upon which it was deposited, 50 feet being the maximum thickness observed. It apparently thins southward, for it measures only about 2 feet west of Sheffield, 4 miles south of Tiona, and only about 6 feet so far as observed a little south of Tidioute, nearly due west of Sheffield. It probably thins out southward against an old shore line which would be roughly defined by a line drawn from Sheffield to Sharon in Mercer County.

The Olean is well displayed at the well-known Gardners Rocks, north of Hatch Run, at the "pass" between Smith school and Scandia, at the head of Sill Run on the Warren-Tidioute road, and around the head of Hedgehog Run, west of Liberty school. At Gardners Rocks a clean face of 50 feet is exposed. The pebbles are smaller than usual here and the cross-bedding, due to strong currents, is well displayed.

Sharon shale member.—The Sharon shale member is best displayed along the Warren-Tidioute road, south of Liberty school, where it is more than 40 feet thick and is composed of soft dark shale with limonite nodules and a few thin sandstone layers. It is said to contain one or more thin beds of coal, but the only evidence of this seen by the writer was at an old opening just east of the road half a mile northwest of Liberty school, where a few fragments of coal and a few fossil ferns were obtained. The Sharon shale member was not seen on the eastern side of the quadrangle, but it is supposed to occupy a concealed space of 20 to 30 feet between the Olean and the Connoquenessing members, and it has been mapped as if present in that position.

Connoquenessing sandstone member.—The name Connoquenessing was introduced by White for a coarse white sandstone that is well exposed along the lower part of Connoquenessing Creek in southern Lawrence County. The sandstone overlying the Sharon shale member in Warren County is identified as the Connoquenessing, and the same name is therefore used for it. Ashburner later used the name Kinzua Creek sandstone for the same stratum. The Connoquenessing is uniformly a very coarse, saccharoidal white quartz sandstone, with a few small pebbles in places. Poorly preserved plant stems are common in it. Its greatest thickness in the Warren quadrangle is about 100 feet, on the ridge south of Allegheny River just west of Big Bend; in other places it is 20 feet thick or less. It caps the highest ridges north and south of the river and is very well displayed in the residual masses on Stone Hill, south of Browns Run. It is the youngest of the Carboniferous rocks in the quadrangle.

QUATERNARY SYSTEM.

GENERAL STATEMENT.

Upon the indurated rock formations throughout a large part of the northern half of the North American continent lies a mantle consisting of unconsolidated deposits of various kinds, formed during the Quaternary period. These deposits may be grouped into three classes, depending on the conditions of their deposition. The deposits of two of these classes were formed during the Pleistocene epoch. The first includes the glacial deposits known as drift, which were laid down either directly by great sheets of glacier ice overspreading the region, or by waters associated with these glaciers and in large part derived from their melting; with these are grouped certain other deposits made through the combined action of glaciers, water, and wind. The second class includes deposits formed by various agencies during intervals when the land was free from ice; these are the interglacial deposits. The third class is the alluvium of the flood plains of present streams. This has been deposited during the Recent epoch.

PLEISTOCENE DEPOSITS.

DRIFT.

Glacial drift consists of all those materials gathered up by the glaciers during their advance across the country, transported greater or less distances, and finally deposited.

The arrangement of the greater part of drift is most heterogeneous, fine and coarse material, clay, and bowlders being intimately mixed, in striking contrast with the assorted and stratified beds deposited by water. Yet from the numerous occurrences of stratified material in this deposit it is evident that considerable water must at times have aided in its deposition.

The pebbles and bowlders of the unstratified drift, in contrast with those of stones worn by fluvial or lacustrine waters, are partly angular, partly rounded, but mostly subangular in form, with numerous flat faces or facets. The facets usually show the polishing and parallel grooving and scratching that is produced when pebbles are firmly held in various positions and rubbed over hard and gritty surfaces.

When all the glacial phenomena of this and adjacent regions are taken into consideration it becomes apparent that the glaciers depositing the drift came from the north, moving southward along the lake troughs and spreading thence over the surrounding areas. On retracing the course of this movement it is found that some of the foreign rock constituents of the drift have been derived from formations not known to occur less than 150 miles away. The sandstones, the quartzites, and the crystalline rocks such as granite and gneiss, over which the glaciers passed and from which they gathered the pebbles and bowlders now found in the Warren quadrangle, occur north of Lakes Erie and Ontario, in Canada.

GLACIAL AND INTERGLACIAL DEPOSITS.

The great North American ice sheets appear to have had more than one center of growth. One main center lay east of Hudson Bay and another west of it (fig. 11), and there were perhaps other minor centers. Ultimately the snow fields extending from the various centers united and the resulting ice sheet is spoken of as a unit. Other smaller ice caps accumulated in the West and Northwest, but the present discussion has to do only with deposits made by the ice of the main sheet.

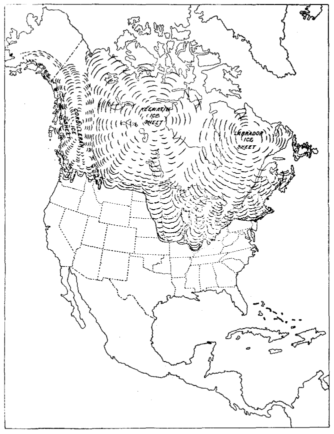

FIGURE 11.—Map of area covered by the North American ice sheet of the Pleistocene epoch at its maximum extension, showing the approximate southern limit of glaciation, the three main centers of ice accumulation, and the driftless area within the glaciated region.

Study of these deposits has led to the conclusion that they were made or reworked during a series of glacial and interglacial stages (see "Historical geology," p. 9), and the following classification has been adopted to portray the relative times and manners of their deposition, beginning with the youngest:

Late Wisconsin drift sheet.
Fifth interval of recession, shown by the shifting of the ice lobes.
Early Wisconsin drift sheet.
Peorian soil and weathered zone; fourth interval of recession or deglaciation.
Iowan drift sheet and main loess deposit.
Sangamon soil and weathered zone; third interval of recession or deglaciation.
Illinoian drift sheet.
Yarmouth soil and weathered zone and Buchanan gravel; second interval of recession and deglaciation.
Kansan drift sheet.
Aftonian gravel and soil deposit; first interval of recession or deglaciation.
Sub-Aftonian drift sheet.

In addition to the classification of glacial deposits according to age as given above, they may be classified according to their mode of origin and topographic expression, as moraines, terraces, till, outwash deposits, etc., this classification being applicable to the deposits of each age.

The distribution of glacial deposits in Pennsylvania and southern New York, and the relative position of the Warren quadrangle are shown in figure 12.

GLACIAL DEPOSITS OF KANSAN OR PRE-KANSAN AGE.

Character.—With the exception of scattered pebbles on the uplands, the oldest drift is confined to the valleys, in which it varies from 100 to 250 feet in thickness, as shown in many wells along the valley from Sheffield to Warren. The surficial material contains a considerable proportion of medium-sized gravel, but the deeper parts of the valley filling appear to be largely of fine material, such as clay, silt, and sand. Carll reported a well 215 feet deep at Clarendon, in which the thickness of loose material was 215 feet, mostly clay; he noted two beds of gravel and sand about 12 feet thick, one at 150 and the other at 208 feet, but found no pebbles of crystalline rocks in them. Probably most of the filling along the river consists of this oldest drift, which, west and north of Warren, is covered with a mantle of material from the Wisconsin ice sheet. The surficial gravel of this oldest drift is made up largely of pebbles of country rock or of similar rock from points farther north. It contains some quartzite pebbles and a few pebbles of composite crystalline rocks, all derived from the Canadian areas of such rocks. Some of these composite crystalline rocks are so much

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[a] Second Geol. Survey Pennsylvania, Rept. R, 1880, pp. 56–57.

decayed that they crumble easily in the fingers. Limestone pebbles are notably absent from the surface material, though plentiful in places in the deeper part of the deposits.

Terrace deposits.—Along the margins of the valleys in the vicinity of Warren and of Glade Run are a number of terraces whose tops are approximately 1400 feet above the sea. The golf links are on one of these and the cemetery on another. There is also a notable terrace, with gravel extending up to over 1300 feet, near the west side of the quadrangle, just south of the river. The material of the terrace is similar to the material filling the valleys, the upper layer consisting of coarse gravel and the lower of fine gravel, sand, and silt. In the deeper part of this material, 50 to 100 feet below its top, there are many small pebbles of limestone and of crystalline rock, which appear to be comparatively fresh and little decayed. The materials are perfectly assorted, stratified, and, in some parts at least, cross-bedded. These features are well exhibited at the sand and gravel bank in East Warren, just north of the Indian Hollow road (fig. 13); other gravel banks, notably the one at the asylum at North Warren, show the coarse upper material rudely stratified. Much of the material has been cemented into beds and irregular masses of coarse conglomerate, by lime carbonate probably derived by solution from limestone pebbles in the upper parts of the deposits and redeposited around the pebbles and finer material lower down.

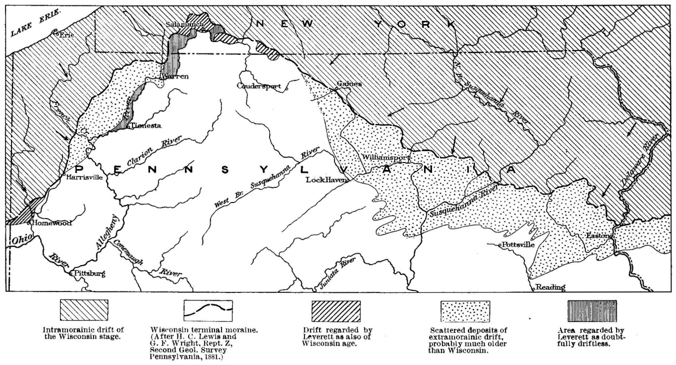

FIGURE 12.—Map showing the distribution of the glacial deposits of Pennsylvania and adjoining portion of New York. Compiled by Wm. C. Alden, 1901.

Arrows indicate direction of glacial striæ. The Warren quadrangle is a narrow rectangle including the town of Warren and extending north to the New York state line. Scale, 1 inch=approximately 40 miles.

DEPOSITS OF WISCONSIN AGE.

Character and distribution.—The Wisconsin drift occurs chiefly as till, terminal moraine, and valley outwash. The material is much less weathered than the older drift, bowlders and pebbles of granite, etc., abounding everywhere on the surface and showing only a film of decay on the outside. Limestone pebbles also are plentiful. This fresh aspect of the Wisconsin drift contrasts strongly with the extensive weathering of the older drift, and it is partly on account of this difference that two periods of glaciation in the region have been recognized. All rocks slowly disintegrate or dissolve under the influence of weathering and, other conditions being equal, those most disintegrated and dissolved are the oldest.

Three kinds of Wisconsin drift may be distinguished, viz, till or ground moraine, terminal moraine, and outwash from the terminal moraine. The drift covering the country rock back of the ice front and the terminal moraine is either till or ground moraine—till if unassorted and ground moraine if assorted and stratified. This drift was deposited mainly underneath the ice sheet, but whatever material was inclosed in the ice or lay on its surface when it melted was left as a mantle on the subglacial deposit. The drift of this class is of varying thickness. In the Conewango Valley north of Ackley it is 100 to 200 feet deep, or perhaps more. The deeper parts, however, may have been and probably were deposited during the first epoch of glaciation. At Lander and at the points around the head of Kiantone Creek the drift is 50 to 60 feet deep, and on the ridge at Mahan Corners it is said to be 20 feet deep. The Wisconsin drift therefore probably ranges in depth from 10 to 60 feet in the glaciated area outside of the Conewango Valley.

Terminal moraine.—The Wisconsin terminal moraine is confined to the Conewango Valley, extending from Ackley to a point 1½ miles south of Russell. Its surface has all the characteristics of such deposits, including typical kettle holes, hillocks, etc. Such moraines are formed at points along the melting margins of glaciers, where the rate of melting just about balances the onward movement of the ice, so as to make the edge nearly stationary. Under such conditions the detritus borne by the ice accumulates for a long time in a small area and is heaped up in the irregular forms distinguishing such deposits from all others. The sections of the moraine observed indicate that it is composed largely of rudely stratified country material.

Outwash.—From the margin of the terminal moraine, both during and after the occupancy of the valley by the ice sheet, great quantities of material were washed out and carried down the Conewango and the Allegheny and spread out over the older drift that already occupied their valleys to considerable depth. Such material is spoken of as glacial outwash, or, in such places as this, as a valley train. It formed the original surface of the valleys, which sloped from an elevation of 1250 feet at the edge of the terminal moraine at Russell to 1170 feet at the west margin of the quadrangle near Irvineton. Subsequently it was trenched to a depth of 30 to 40 feet by the streams, leaving the marginal parts of the original deposit as terraces. The terrace at 1200 feet upon which Warren is built was formed in this way. The thickness of the Wisconsin outwash was probably once 40 to 50 feet. Leverett[a] describes the contact of the fresh Wisconsin material with the deeply stained material of the older drift at a point on the east side of the river 1½ miles west of Warren. The exact elevation of this older drift is not now known, but to have been observed it must have been above river level. It follows that the overlying Wisconsin material could scarcely have been more than 60 feet thick, for the height of the remaining portions in the vicinity scarcely exceeds 60 feet above the river.

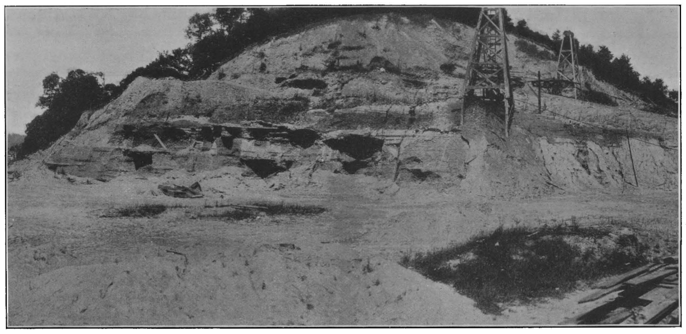

FIGURE 13.—Terrace deposits of Kansan or pre-Kansan age at quarry in the eastern part of Warren. Finely laminated and cross-bedded sand, clay, and small gravel, overlain by coarse gravel and bowlder deposits. Depth of cut 100 feet.

RECENT DEPOSITS.

The original surface of the Wisconsin outwash has been somewhat obscured in places by recent deposits, constituting alluvial fans at the mouths of side streams entering Conewango Creek or the river. This is notably the case at the mouths of Jackson and Hatch runs.

STRUCTURE.

REPRESENTATION.

The geologic structure of the Warren quadrangle is shown in figure 14 by contour lines indicating the elevation above sea level of the top of the Salamanca conglomerate member (which is taken as a reference surface) and is also shown in the structure section forming figure 15. The elevation above sea level of the surface of the conglomerate was determined at as many points as possible, and lines were drawn at vertical intervals of 50 feet through points having the same elevation. For example, a line is drawn through points having an elevation of 1700 feet above the sea, the next higher through points having an elevation of 1750 feet, and so on. By this means the shape and relative height of the reference surface in all parts of the quadrangle are shown, and the details of structure are portrayed as closely as they can be determined. It is not claimed that the contours are absolutely accurate in the delineation of the structure, but they are so nearly correct that the elevation of the reference surface shown by the contours will not vary from the true elevation at any point by more than a contour interval, or 50 feet.

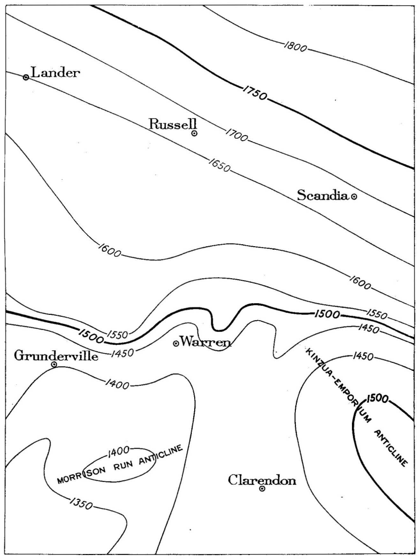

FIGURE 14.—Structure of the rocks of the Warren quadrangle shown by contours on the top of the Salamanca conglomerate member which represent the approximate elevation of this member above sea.

Figure 15 shows the attitude of the rocks as they would appear in a deep trench cut along the line of the section. It gives a very clear idea of the structure, but holds good only for the particular belt near it and does not show the structure of distant territory.

ANTICLINES.

As shown by the structure contours, the rocks of the Warren quadrangle have a general dip to the south, the top of the Salamanca conglomerate member being 1800 feet above sea level in the northeast corner and about 1300 feet above in the southwest corner. The regular southerly dip is broken by the northwest end of the Kinzua-Emporium cross anticline on the east side of the quadrangle south of the river, and by the Morrison Run anticline near the west side.

The Kinzua anticline, lying as it does nearly at right angles to the main Appalachian folds of northwestern Pennsylvania, is an abnormal feature that apparently has no duplicate in the region. The Morrison Run anticline lies parallel to the main east and west structure of western New York and Pennsylvania but is a rather unusual feature in this section, although farther east, in the Watkins Glen region, such structures are common. (See Watkins Glen-Catatonk folio, No. 169.) These folds are probably due to compression arising in the general continental uplift by which the southern dip of the rocks in western New York and Pennsylvania was effected.

KINZUA-EMPORIUM ANTICLINE.

The Kinzua-Emporium cross anticline was described and mapped by Ashburner.[a] Its northwest end enters the Warren quadrangle 1½ miles south of Big Bend and pitches northwestward to the vicinity of Allegheny River between Verbeck and

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[a] Mon. U. S. Geol. Survey, vol. 41, 1902, p. 230.

[a] Second Geol. Survey Pennsylvania, Rept. R, 1880, pp 38-40.

Harmon Islands, where it dies out. The rise of the rocks from the river at Big Bend to the crest of the anticline is only about 100 feet. From the crest southward the general southerly dip of the region prevails.

MORRISON RUN ANTICLINE.

The Morrison Run anticline seems to extend in a slightly northeast and southwest direction along the upper part of Morrison Run in Pleasant Township. The belief in its existence is based on the logs of a group of oil wells extending in a narrow belt along Morrison Run from the east boundary of Pleasant Township westward for 3 miles. These wells are believed by their owners to be in the Clarendon oil sand, and if that belief is correct they show a rise of the oil sand westward of 150 feet in about 1 mile, then a gradual westward dip of about 60 feet for the next 2 miles. The interpretation of these facts, as expressed in the contours, is that there is slight doming of the rocks here, but the representation of the structure to the north and to the south of the line of wells is purely conjectural and of little value. There are practically no surface data from which the structure of the southwest corner of the area can be determined. Along Allegheny River, however, about 3 miles west of the quadrangle, an apparently regular southerly dip prevails, the Salamanca conglomerate member descending from about 1300 feet at Irvineton to 1100 feet at Tidioute.

The existence of the anticlines just described necessarily calls for the existence of corresponding slight synclines, one of which extends along the river from Big Bend to the vicinity of Glade and thence southwestward nearly to the southwest corner of the quadrangle. Another shallow syncline lies to the north of the Morrison Run anticline.

HISTORICAL GEOLOGY.

DEVONIAN PERIOD.

During the whole of the Devonian period western New York and Pennsylvania were beneath the sea and were receiving sediments. The shores of the Devonian sea are believed to have lain to the southeast in eastern Pennsylvania and Maryland, on the one hand, and to the north from Lake Superior through New York, just south of Lake Ontario, on the other. The Warren region, being at considerable distance from either shore, received only fine clayey or sandy sediments which would be borne in suspension far from shore. These materials on induration became the shales of the Marcellus, Hamilton, Portage, and Chemung formations of the region. The coarser materials, if any were borne to the sea from the bordering lands at the same time, were deposited nearer the shore lines, probably as beds of sand. It is possible that toward the close of this period the shores had advanced toward the Warren region to such an extent that at times coarser sands, which now constitute the oil-bearing sandstones of the Chemung formation, were deposited. In general it appears that the sediments became progressively more sandy from the beginning of Portage deposition. These rocks, so far as they can be observed in this and other regions, bear evidences of shallow water and exposure to the air, such as ripple marks and sun cracks. The Chemung rocks of this region and elsewhere and the Hamilton rocks on their outcrop at distant localities are abundantly fossiliferous, brachiopods and lamellibranchs predominating. These organisms, which inhabited the bottom of the sea while the sediments in which their remains are preserved were deposited, probably indicate water of moderate depth, for such organisms generally live in water of no great depth at the present time. The dark color of the shales of the Marcellus and Hamilton is due to the presence of carbonaceous matter, probably derived from the organic matter of animals that lived on the sea bottom. These shales are supposed to have been the source of much of the petroleum, which was distilled from the entombed organic matter and which in some way accumulated in the oil-bearing sandstones of the time.

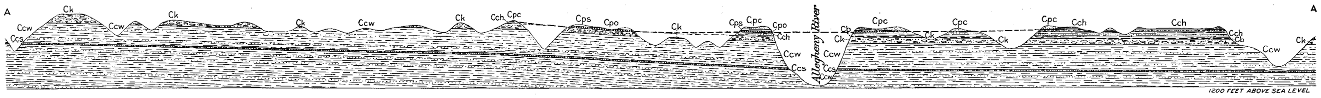

FIGURE 15.—Cross section along the line A-A on areal geology map. Vertical scale exaggerated five times.
Cpc, Connoquenessing sandstone, Cps, Sharon shale, Cpo, Olean conglomerate, members of the Pottsville formation; Cch, Cuyahoga formation; Cb, Berea sandstone; Ck, Knapp formation; Ccw, Conewango formation; Ccs, Salamanca conglomerate member of the Conewango.

DEVONO-CARBONIFEROUS PERIOD.

CONEWANGO AND KNAPP TIME.

Conewango time was marked by the deposition of beds of conglomerate and red shale. Sedimentation appears to have continued without interruption from the Chemung into and during the Conewango and Knapp, but the presence of beds of conglomerate and red shale appears to indicate certain terrestrial changes that are worthy of remark. Not less notable is the faunal change which probably also denotes a physical change, at the beginning of the Conewango. (See p. 3.)

The conglomerates are consolidated gravel beds, and the flat shape of their pebbles shows that they were probably transported along a coast by a sort of push, causing them to slide rather than to roll. Such motion could result from currents set up by waves oblique to the shore. The ordinary lapping of the waves upon the shore would also cause a to and fro movement of the pebbles, which would tend to make them flat. The pebbles are thought to have come from the Lake Superior region, because that appears to be the most probable source of the jasper pebbles which occur in the conglomerates. A northern source is probable, too, because the conglomerates disappear to the southeast, there being none in the contemporaneous rocks where they outcrop on the Allegheny Front near Altoona. It is inferred from these facts that a coast extended from the Lake Superior region into western New York, along which and upon the bordering shelf of which the gravel of the conglomerates was transported at little depth.

The sediments composing the red shale beds, on the other hand, were clearly derived from the region to the southeast, for in that direction the proportion of red shale increases and on the Allegheny Front red rocks make practically all the upper part of the Catskill formation, which is probably the equivalent of the Conewango and Knapp formations of the Warren region. The southeastern shore line was so near that red sediment was borne northwestward to the Warren region at times of exceptional supply from the land due to heavy rains, or at times of great storms which set up strong currents, and this sediment composes the layers of red shale now interbedded with the usual green and gray sandy shales and sandstones.

The red shale known as the "Tanners Hill red," which shows in the Conewango formation at the head of Liberty street, Warren, is an example of extreme northwestward transportation of the red sediment. The red shale associated with the Salamanca conglomerate member, brought in at a later time, is another example. In the Olean region there are several other beds of red shale in the strata between the horizon of the "Tanners Hill red" and the Salamanca, as well as a number of beds above the Salamanca. In the vicinity of Bradford the proportion of red rock is much greater and the beds are much thicker. The red shale is always destitute of fossils or nearly so, and the marine fossils which are abundant at some horizons in the Conewango formation in Warren County but are progressively scarcer to the southeast are inclosed in the green and gray rocks. Recently marine faunas have been discovered by the writer in the gray bands of the Catskill on the Allegheny Front, in Blair County, Pa. It does not appear probable that such red beds as occur in the Warren region indicate fresh-water conditions, however, their lack of marine organisms being due to the unfavorable character of the waters containing this sediment. Near the close of Conewango time a notable invasion of marine forms took place, and their shells, accumulating in myriads, made the layer of highly fossiliferous rock described on page 4.

CARBONIFEROUS PERIOD.

MISSISSIPPIAN EPOCH.

BEREA AND CUYAHOGA TIME.

During Berea and Cuyahoga time, so far as the record is preserved in this area, the deposition of fine sandy sediments and, at times, of small flat quartz pebbles continued, the fine sediment becoming shale or fine-grained sandstone and the pebble deposits forming conglomerates. The epoch was ushered in by the deposition of the Berea ("Corry") sandstone and was accompanied by the complete change in the marine fauna already described. The new fauna is of unequivocal Carboniferous age and leaves no doubt that the Berea and succeeding rocks should be included in the Carboniferous system. It is probable that very much, if not most, of the sediment deposited during this epoch came from the northwest, the conglomerates being similar to those of Conewango and Knapp time and indicating the same source. The Berea is very thin in the Warren quadrangle but thickens westward to as much as 175 feet in places in Ohio, a fact that indicates a western or northwestern origin and a shore in that direction along which the sandstone accumulated.

The Cuyahoga rocks now remaining in the Warren quadrangle do not represent the full thickness as deposited in the region during Cuyahoga time. Probably at least 200 feet of Cuyahoga rocks were laid down above the highest rocks of that formation now present, making the formation in this area originally as thick as it now is to the west and southwest in Venango and Crawford counties, of Pennsylvania, and in northwestern Ohio.

BURGOON AND MAUCH CHUNK TIME.

Sedimentation continued not only through Cuyahoga time but probably also through the time represented by the Burgoon sandstone and its supposed equivalents, the Logan and Black Hand formations of Ohio and White's Shenango group of Crawford and Erie counties, and possibly through that of the Mauch Chunk shale of eastern Pennsylvania. Many hundreds if not thousands of feet of Mississippian rocks were laid down above the highest rocks of that age now remaining in the quadrangle, and were later eroded away.

It appears probable that sedimentation was continuous over a slowly subsiding trough bounded by the shores described above, from Marcellus time to the end of Mauch Chunk time, and that during that interval more than 6000 feet of sediment was accumulated. The belief in subsidence, either continuous or intermittent, is based on the fact that the rocks at various horizons bear marks of deposition in shallow water, and from that fact, together with their thickness, it necessarily follows that they could have been deposited only in a subsiding area. The Mauch Chunk rocks especially are said to show abundant rain prints, sun cracks, ripple marks, reptilian footprints, and like evidences of shallow-water accumulation. At the close of Mauch Chunk time the surface of western Pennsylvania and New York must have been one of extensive mud flats and sand bars near sea level and of sluggish streams and shallow lagoons.

PENNSYLVANIAN EPOCH.

POTTSVILLE TIME.

The physical conditions prevailing at the close of Mauch Chunk time were terminated by the beginning of an extensive but apparently not violent warping of the earth's crust throughout the eastern United States. As a result of this movement there was depression near and parallel to the old coast on the southeast, forming a trough in which sedimentation was not interrupted; and there was relative uplift of an extensive region to the northwest from western New York to Alabama, forming a land area. By denudation of this land during early and middle Pottsville time the rocks now lacking in the Warren section, as described above, were removed.

Toward the close of Pottsville time the encroaching waters again overspread the land and sedimentation was again resumed. The Olean conglomerate member was first laid down upon a more or less uneven land surface as the waters gradually crept landward and then, in turn, was overlapped by succeeding Pottsville beds. Inasmuch as erosion of the Mississippian rocks extended to successively deeper and deeper beds northward, the overlying Pottsville rocks necessarily lie upon lower and lower beds in that direction, while southward there is a constant divergence between the Pottsville and any given stratum of Mississippian rocks. This is well shown in the Warren quadrangle by the fact that a mile or so southwest of Scandia the Pottsville rests upon the lower Knapp, although at the south margin of the quadrangle the lowest Pottsville and the Knapp are separated by 200 feet or more of the Cuyahoga formation. Thus came about the unconformable relations between the Pottsville and the lower rocks of the region.

Fresh-water conditions appear to have prevailed during most of Pottsville time throughout the Appalachian trough, for many coal beds were laid down there, the vegetal matter of which probably grew to a large extent in fresh-water swamps and marshes.

The bordering land to the southeast of the Appalachian trough appears to have been the scene of active erosion and transportation, for the abundant large well-rounded quartz pebbles in the Pottsville rocks appear to have been derived from the masses of crystalline rocks in that direction. Possibly that region was uplifted, with consequent renewed activity of the streams, giving them power to transport large quantities of coarse quartz gravel and sand to the bodies of water by which they were finally distributed and deposited to form the beds of conglomerate in the Pottsville.

POST-POTTSVILLE TIME.

No record is preserved in the Warren region of events occurring between the deposition of the Connoquenessing sandstone member and the beginning of glaciation. In southwestern Pennsylvania the Connoquenessing is overlain by higher beds of Pottsville age and by more than 2000 feet of younger coal-measure rocks, and it is highly probable that a large part, if not all, of these rocks once extended as far north as New York State. After the deposition of these coal-bearing rocks a great upward movement of the earth's crust in the eastern United

States began, accompanied by intense folding and mountain building in the Appalachian Valley and by gentler folding in the Appalachian Plateau. What had been for ages an area of sedimentation became dry land and has remained so ever since; consequently it has been subject to denudation and has been stripped of a great thickness of rocks. Probably by the end of Jurassic time the land had been worn down nearly to a plain lying close to sea level. This was the Schooley peneplain. The land was again uplifted and again worn down by subaerial erosion over extensive areas to form the Harrisburg peneplain, which is believed to be of Tertiary age. Then the land was again elevated and the valleys eroded so as to form the present upland before the beginning of the Quaternary period. There are evidences that there were other and briefer periods of uplift and erosion before the advent of glaciation.

The preceding statements show that a great thickness of rocks originally present in this quadrangle has been eroded from above the highest hills, and that, just previous to the first ice advance in the region, the valleys had been eroded 900 to 1000 feet below the level of their summits.

QUATERNARY PERIOD.

PLEISTOCENE EPOCH.

GENERAL STATEMENT.

During the Pleistocene epoch a great change in the climate of North America took place, the temperature becoming much colder, with the accompanying accumulation of great ice fields. The centers of accumulation were in British America (see fig. 11), whence the ice extended southward into the United States.

As long as accumulation exceeded the waste by melting and evaporation, the ice continued to advance, but when it reached a region where the waste equaled the rate of advance the margin halted. When the waste exceeded the advance the margin was melted back. Periodically there seem to have been great oscillations, so notable in their extent and in their effects as to be designated stages of the Pleistocene epoch. (See p. 6.) During stages of glaciation the ice advanced far to the south, driving the plants and animals before it, destroying and burying in the drift such as remained, and introducing a fauna and a flora better fitted to higher latitudes. During stages of deglaciation a reversal of these conditions took place; the climate became so much milder that the ice was melted and a new soil developed and plants and animals returned to their former habitats. This stage prevailed until the return of arctic conditions brought about a readvance of the ice and the deposition of a new sheet of drift, burying the soil and the organic remains.

KANSAN OR PRE-KANSAN STAGE.

Limits of the ice sheet.—The oldest glacial drift of the region is supposed to be of Kansan or possibly of pre-Kansan age. The approximate southern limit of the ice sheet that deposited this drift is shown on the areal geology map. Between the head of Hatch Run and the northern margin of the quadrangle this limit has been determined by the occurrence of scattered pebbles of quartzite with here and there a bowlder of granite that must have been deposited directly by the ice. Such were noted at a number of points on spurs and ridges at elevations ranging from 1900 to 2100 feet above the sea, showing that the ice reached at least that height. It seems most probable that tongues of ice ran up into the heads of the hollows, and that the ice sheet had an irregularly lobed border instead of the straight, smooth border drawn on the map. No evidence was collected along the hollows, however, so no attempt has been made to map the boundaries in detail. The main boundary probably followed the south bluffs of Allegheny River from the mouth of Glade Run westward, reaching up to 1500 feet above the sea, or higher. A tongue of ice also appears to have extended up the old Tionesta to Clarendon, where there is a large accumulation of gravel and other glacial detritus having the topographic features of a terminal moraine. The elevation of the top of the moraine is 1500 feet, and the depth of glacial filling is more than 250 feet. Probably this material is not all morainic, however, for a good deal of sand, silt, and clay must have been deposited in the valley while the ice was advancing to its southern limit.

Preglacial topography.—The preglacial topography of the Warren quadrangle differed from the present topography chiefly in the fact that the valleys were deeper by the amount of loose material now occupying them, as revealed in well drillings. Present-day streams flow on the surface of sand, gravel, clay, and other loose material, from 80 to 160 feet thick, which lie on solid rock. As the excavation of the stream valleys in solid rock was accomplished only by the streams themselves before the deposition of the loose material, it is evident that they once flowed on the rock floor upon which that material rests.

In sinking oil wells pipe is driven through the loose material to solid rock, and the depth to the rock floor and its elevation above the sea can thus be ascertained. The elevation of the rock floor along the valley from Sheffield to North Warren has been so determined at points enough to show the slope of the preglacial stream bed. The slope is shown in the following table, the elevations having been mainly determined by the writer, but a few of them taken from Carll.[a]

Elevation of bed rock in Tionesta, Allegheny, and Conewango valleys.

	Feet.
Sheffield	1215
Saybrook	1190
Tiona	1183
Weldbank	1163
Clarendon	1150
Trestle at crossing of Pennsylvania Railroad and Tionesta Valley Railroad, north of Clarendon	1102
Stoneham	1140
One-half mile north of Stoneham	1130
Mouth of Dutchman Run	1119
Irvine farm, three-fourths mile north of Glade Run	1088
Warren	1095
Clark farm, three-fourths mile north of Fifth Street Bridge, east side of Conewango Creek	1052
North Warren	1100
Russell	1108
Ackley	1024
State line	964

At the railroad crossing north of Clarendon and on the Clark farm, north of Warren, the rock floor is 40 to 50 feet lower than it is in immediately adjoining wells. The following explanations of these exceptional depths are suggested. First, the old valley may have been sharply V-shaped, or may have been nearly flat, with a narrow trench or gorge incised in its floor. In either case it may be assumed that only the two wells mentioned happened to be located over the deepest part of the valley, though from the large number of wells drilled in the valley it seems hardly probable that only two should have been so located. Second, there may be actual depressions of small extent below the general level of the old valley floor, due either to the scouring action of the glacial ice that occupied the valleys before they were filled by detritus, or to decomposition prior to the glacial filling of the rock floor of the old valley; and each of the wells mentioned may be over such a depression. Glacial scour seems the more probable explanation.

Aside from the exceptional depths just discussed, there is a regular descent of the rock floor from 1215 feet at Sheffield to 1095 feet at Warren. This is a fall of 120 feet in 12 miles, or 10 feet to the mile.

Preglacial drainage.—As was shown many years ago by Carll[b] and later by Chamberlin and Leverett,[c] the apparently anomalous course of Allegheny River is due to the fact that it was formed by the union of a number of independent streams, some of which originally flowed northward into Lake Erie.

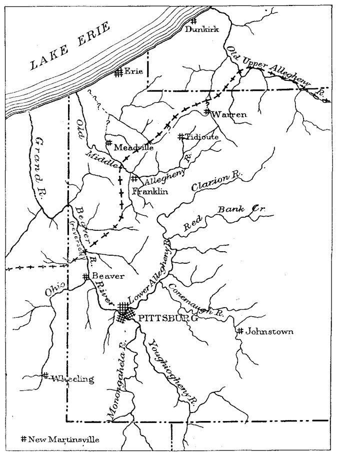

FIGURE 16.—Sketch map showing the probable preglacial drainage of western Pennsylvania. The terminal moraine is shown by a broken crossed line.

(After Leverett; with slight changes and addition of terminal moraine.)

As shown on the sketch map (fig. 16), the upper part found outlet to the northwest by Salamanca to Gowanda and thence down Cattaraugus Valley; the middle part, from a point as far south as Emlenton, followed a channel now utilized in part by French and Conneaut creeks, passed through Venango, Crawford, and Erie counties, and entered the Erie basin just east of the Ohio-Pennsylvania state boundary; and the waters of the Clarion and the lower Allegheny with its tributaries followed the present course of drainage to the mouth of Beaver River, where they apparently turned to the north and reached the Lake Erie basin along an old valley now occupied in part by Beaver and Grand rivers. These changes in drainage relations were brought about by the damming of the ancient channels by ice and gravel in Pleistocene time.

The Allegheny is also a much larger stream at present than in preglacial time, the present drainage basin down to and including Redbank Creek being about four times as large as the preglacial basin which drained through the lower Allegheny.

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[a] Second Geol. Survey Pennsylvania, Rept. III, 1880, p. 337.

[b] Idem, pp. 352–355.

[c] Am. Jour. Sci., 3d ser., vol. 47, 1894, pp. 247–283

Nor was Allegheny River the only stream in the quadrangle to be affected by glaciation. There is evidence that Tionesta Creek, instead of turning southward at Clarendon, as at present, continued northward along the valley of Dutchman Run to the Allegheny. There is also evidence that it was joined at Clarendon by a tributary flowing northward from the vicinity of Sheffield, and at the mouth of Dutchman Run by a small stream from the east following the present course of the Allegheny. The resulting stream probably flowed northward to Lake Erie, along the course of the Conewango, or westward along the Allegheny to Irvineton, whence it may either have continued westward along the present course of Brokenstraw Creek, or turned southward along the present course of Allegheny River.

The small stream following the course of the river and joining the old Tionesta at the mouth of Dutchman Run headed near Big Bend, where there was probably a col or divide separating it from another small stream flowing northward to join Kinzua Creek at Kinzua. This is indicated by the fact that bed rock is about 1170 feet above the sea at Big Bend, 1110 feet at the mouth of Hemlock Run, and, as shown already, 1095 feet at Warren. On the north side of the col the rock floor is 1150 feet above the sea at Kinzua. From Kinzua the rock floor of the valley of the preglacial Kinzua Creek is believed to slope northward to the vicinity of Steamburg, where there are good reasons for believing that it is about 1015 feet above the sea. That there was a divide south of Kinzua is further attested by the constriction of the valley between Kinzua and Glade Run to about a quarter of a mile, whereas it is a mile or so in width north of Kinzua and west of Warren.

That the preglacial drainage was from Sheffield, from the valley of the upper Tionesta above Clarendon, and from Big Bend to Warren is thus certainly established. Its course from Warren is a matter of doubt. There are three possible outlets, one northward by the Conewango Valley, one westward by the Allegheny to Irvineton and thence either westward by the Big Brokenstraw Valley or southward along the present course of the Allegheny.

With regard to the first possible outlet, it is to be noted that at no point between Warren and Ackley, except on the Clark farm, three-fourths of a mile north of Warren, is the rock floor of Conewango Valley known to be lower than it is at Warren; the lowest point, with the exception noted above, is 1100 feet at North Warren, which is 5 feet higher than the lowest elevation known at Warren. It is of course possible that lower points in the old valley floor exist at North Warren, but although many wells have been put down clear across the valley there, no lower points have been found and the probability is against there being any. On the other hand, there is clearly a rise in the preglacial valley floor from the state line southward as far as Russell and perhaps farther. These facts point to the existence of a low col between Russell and North Warren and are opposed to the supposition that the preglacial course of the Tionesta was along Conewango Valley.

Another point is worthy of consideration as bearing on the question whether the preglacial outlet of the Tionesta was along Conewango Valley. It is, with good reason, supposed by Leverett[a] that at the time of the earliest ice sheet a tongue of ice reached southward along Tionesta Valley to Clarendon. The main movement of the ice southward must have been along Conewango Valley, and if a preglacial col had existed between Russell and Warren it would have been worn down by the ice, perhaps nearly to the level of the river bed. Thus the present uncertainty regarding the slope of the rock floor and the direction of the preglacial drainage may have been brought about.

That the old Tionesta may have had an outlet westward via Allegheny River to a point near Irvineton is suggested by the fact that at Starbrick, about 3½ miles west of Warren, the rock floor, as shown by a well recently drilled, is only 1080 feet above the sea, 15 feet lower than its elevation at Warren. Unless there is a local depression of the floor at Starbrick this indicates a westward descent in the preglacial channel.

Beyond Irvineton the course of the water is doubtful; it may have gone west along the Big Brokenstraw or south along the Allegheny. The only determination known to the writer of the elevation of the rock floor in this vicinity is 1108 feet reported by Carll at Irvineton, at the mouth of Big Brokenstraw Creek.[b] This figure shows the rock floor at Irvineton to be higher than that at Warren and so far as it goes is opposed to the supposition of an outlet westward along Big Brokenstraw Creek. The evidence is not conclusive, however, for the river valley is over a mile wide at Irvineton and its deepest part might easily have been missed in the well at the mouth of the Big Brokenstraw, where the determination was made. On the other hand, it has been generally held that there was a preglacial col in the vicinity of Thompsons, a few miles southwest of the quadrangle. This col, if it existed, blocked all drainage southward along the Allegheny and compelled it to go northward, joining the old Tionesta at Irvineton or Warren, whence

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[a] Op. cit.

[b] Second Geol. Survey Pennsylvania, Rept. III, 1880, p. 337.

its only possible outlets were by the Conewango or the Big Brokenstraw.

The third outlet, that along the present Allegheny, was, of course, impracticable if the col at Thompsons station really existed. The argument for it is the narrowness of the Allegheny Valley for several miles in this part of its course. It is clearly much narrower than it is north and east of Thompsons station to Warren or south of it to Tidioute. The fact that the rocks constituting the Venango oil-sand group form the bottom and lower walls of the valley in this narrow part should be taken into consideration in interpreting the meaning of the constriction. This zone of rocks contains a number of sandstones and conglomerates that are more resistant than the rocks higher up the river or lower down, and the probable difference in their resistance to erosion may account for the difference in the width of the valley.

So far as known to the writer, no determinations of the elevation of the rock floor have been made in this part of the valley, so that the possibility that the preglacial drainage may have gone southward along the present river valley is not disproved by any positive evidence; and as the river valley in this part is no narrower than the Conewango Valley just north of Warren or the Big Brokenstraw Valley at Irvineton, if as narrow, it appears to the writer at least quite as probable that the preglacial drainage followed the present Allegheny Valley as that it followed either the Conewango or the Big Brokenstraw.

WISCONSIN STAGE.

After the first invasion described above the ice withdrew from the region for a long period, and then, toward the close of the Pleistocene epoch, it advanced again, the second sheet reaching south to Russell and depositing the terminal moraine at that place. Its limit appears to have been, in a general way, rudely parallel to but to the north of and within that of the older ice sheet. Its border, as approximately shown by the line on the areal geology map, was supposed by Lewis to mark the limit of glaciation, the scattering material between the Wisconsin ice border and the earlier ice border being spoken of by him as the "fringe."[a] Apparently Lewis did not recognize that there had been two periods of glaciation in the region.

This last advance is known as the Wisconsin stage. It marked the closing events of the Pleistocene epoch. The great amount of water from the melting ice transported much glacial detritus from the margin southward along the Conewango and spread it out as a layer over the earlier glacial filling.

RECENT EPOCH.

Since the retreat of the ice of the last glacial invasion there has been but little change in the surface of the quadrangle. The streams have entrenched themselves 40 feet or so below the surface of the Wisconsin drift and at times of overflow have deposited the silts that now constitute the alluvium of the valley flats.

ECONOMIC GEOLOGY.

The mineral products of the Warren quadrangle are petroleum, natural gas, coal, clay, building stone, sand, and gravel. Of these the petroleum and gas are the most important.

PETROLEUM AND GAS.

PETROLEUM.

Historical statement.—According to Carll[b] the first productive oil well in the Warren field was the Beatty well, drilled in East Warren in 1875. From that time to the present drilling has continued, though the greatest activity was in the twenty years following the opening of the field. It follows that most of the wells are more than fifteen years old and that their original stores of oil have been greatly depleted. Most of them produce less than one-half barrel a day, but newly drilled wells in previously undrilled locations in the midst of the field start off at 2 to 10 barrels a day, as do also wells drilled on the margin of the field.

The constantly diminishing yield of oil has compelled the adoption of the most economical methods of production. Practically all the properties have the wells pumped from one or more central stations, the pumps at the wells being connected to the power by iron rods or wire rope. As many as thirty or more wells are attached to the same power. Since the advent of the gas engine all the steam engines formerly used in pumping have been converted into gas engines by adapting a gas-engine cylinder to them. The oil wells themselves supply the necessary gas. In places where the number of wells is too small to justify the installation of a pumping plant the wells are bailed, commonly by horsepower, but a few by means of a rope connected with a central power, which bails a single well at a time, the rope being changed from well to well. Were it not for these means of raising the oil from the wells profitable production would be impossible.

Oil wells in the Warren quadrangle whose sections are given in figure 17.

	Name of well.	Owner.	Locality.
1	Asylum	Geo. Hazeltine	North Warren.
2	Do	do	Do.
3	Hackney No. 1	Hackney Oil Co.	Do.
4	Hackney farm	A. T. Hackney	Do.
5	Huffman No. 6	O. Nesmith	East Warren.
6	Irvine No. 19	John Bright	Glade Run.
7	Lacy farm	L. P. Rogers	Do.
8	No. 5	Parshall Oil Co.	Do.
9	No. 1	do	Do.
10	Book No. 4	John Bright	Do.
11	Book No. 5	do	Do.
12	Book No. 8	do	Do.
13	Book No. 21	do	Do.
14	Book No. 13	do	Do.
15	Book No. 12	do	Do.
16	Book No. 14	do	Do.
17	Rogers No. 2	V. A. Billstone	Do.
18	Rogers No. 3	do	Do.
19	Rogers No. 1	do	Do.
20	Hertzel No. 2	do	Do.
21	Hertzel No. 1	do	Do.
22	Hertzel No. 7	do	Do.
23	Hertzel No. 6	do	Do.
24	Columbia No. 36	Wm. McCray	Stoneham.
25	Lockwood No. 1	Lockwood	Do.
26	White No. 7	Smith & Co.	Do.
27	Ridelsperger No. 5	L. M. Ridelsperger	Do.

Oil-bearing sandstones.—The Starbrick well section (fig. 5) shows that the Warren oil sands are near the top of the lower third of the Chemung formation. Most of the oil is obtained from two sands, the Glade above and the Clarendon below. A few wells once produced from the Gartland sand below the Clarendon, and a few reported oil from beds above the Glade, but the production from such horizons was of brief duration.

It is of interest to note that the Bradford, the great oil-bearing sand of McKean County, can not be recognized with certainty in this quadrangle. Carll concludes, from such data as he could obtain, that the horizon of the Bradford sand is 400 to 450 feet below the Clarendon sand. The stratigraphic relations of the producing sands are shown in figure 17.

Oil above the Glade sand.—In a few wells there was a little oil above the Glade sand. In the Bishop well at North Warren oil occurred at 100 feet, 240 feet, and 340 feet, the Glade sand being at the depth of about 500 feet; the oil at 100 feet was in gravel. In a well on the Lessler farm, east of the Conewango at North Warren, and on about the same level as the Bishop well, oil was reported at 340 feet. In well No. 41 on the Columbia lease, near Stoneham, "slush" oil existed at depths of 400 and 440 feet, or about 350 feet above the horizon of the Glade sand; and in well No. 36 on the same lease "slush" oil was found 50 feet above the Glade sand. In well No. 25 of the Lockwood lease at Stoneham oil occurred at 150 feet, above the horizon of the Glade sand. These sporadic occurrences may indicate a general dissipation upward of oil from the sands below and an accumulation in beds locally favorable to its absorption and retention.

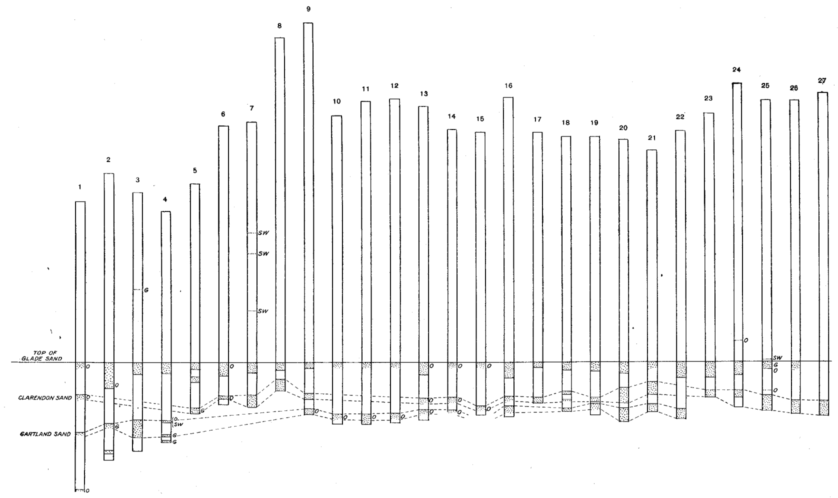

FIGURE 17.—Sections of oil wells from North Warren (on the left) to Stoneham (on the right), showing the Glade, Clarendon, and Gartland oil sands.
O, Oil; G, gas; SW, salt water. Scale, 1 inch=300 feet.
See table, this page, for owners and locations of wells.

Glade sand.—As drilling operations in the localities of the Glade sand have practically ceased, the writer had no opportunity to examine material from that bed, but in the D. W. Beatty well No. 1, as reported by Carll,[a] the Glade sand has the following section:

Section of Glade sand in D. W. Beatty well, East Warren, Pa.

	Feet.
Sandstone, hard, fine grained, fossiliferous	5
Sandstone, gray, soft, and friable	5
Sandstone, gray, soft, and friable, with some pebbles and slate (oil)	4
Sandstone, gray, soft, and friable, with some pebbles and slate (oil)	3
	17

The Glade sand is the productive stratum at North Warren and Warren and is the principal producer at Glade. It is not a producing sand south or east of the mouth of Dutchman Run, except that many of the wells of the South Penn Oil Company on the Mead farm, south of the river and 2 miles west of Big Bend, appear to produce both oil and gas from it. The Glade sand can be identified as far south as Stoneham, and the Clarendon sand can be recognized beneath the Glade as far north as Glade, being a producing sand in the Irvine No. 19 well, owned by John Bright. It is probable that the areal extent of the Glade sand is greater than is indicated by the well logs, as in the territory in which the Clarendon is the important producer no note of the Glade was made by the drillers. The approximate position of the Glade sand at any point with respect to sea level can be obtained by adding 100 feet to the nearest contour drawn upon the Clarendon sand (economic geology map), the distance between the tops of the two sands being roughly 100 feet. Salt water is not reported from this sand.

Clarendon sand.—The top of the Clarendon sand is regarded by the drillers and operators of the region as lying 100 feet below the top of the Glade sand. Actual measurements in wells, however, show that this distance varies from 50 feet in Book well No. 4 to 140 feet in the Lacy farm well (see fig. 17), if the measurements and identifications are correct. The distance between the sands may vary from place to place or the measurements may be inaccurate.

The Clarendon is a white or light-gray medium-grained siliceous sandstone and, according to reports, commonly has a hard pebbly layer a foot thick known as "the shell" at its top. The oil is said to be encountered just below this layer. The thickness of the sand may reach 50 feet or more, the top 10 feet generally being the productive part. The sand is universally reported to be free from salt water.

The productive area of the Clarendon sand is much larger than that of the Glade. It has been an important producer in a large part of Mead Township, in the western part of Kinzua Township, and in the southern part of Glade Township.

Gartland sand.—The top of the Gartland sand lies 40 to 50 feet below the top of the Clarendon sand. The Gartland is a coarse, pebbly white siliceous sand, in which oil was found in a few large wells in the vicinity of Glade. Its areal extent as a bed is not well defined, but its oil-bearing part is a narrow strip extending about 3 miles N. 45° E. from the vicinity of Glade; this part appears plainly to have been laid down as a sand bar along a shore line. It is the general belief among oil men that the Gartland is a persistent sand 100 feet below the top of the Clarendon, and that it is the same as the Cherry Grove or Garfield sand of the Cherry Grove oil field, in the township of that name just south of the quadrangle. The formula of the drillers is that the top of the Clarendon sand is 100 feet below the top of the Glade and that of the Gartland or Cherry Grove 100 feet below the top of the Clarendon. Although in some wells these intervals may be approximately as stated, they are

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[a] Second Geol. Survey Pennsylvania. Rept. Z, 1884, p. 45.

[b] Idem. Rept. I4, 1883, p. 211.

[a] Second Geol. Survey Pennsylvania, Rept. I4, 1883, p. 1.

widely different in others, so that the formula only roughly indicates the facts.

Oil below the Gartland sand.—At North Warren oil occurs locally 400 feet below the Glade sand. In Asylum well No. 1 (see fig. 17) the best production was at the depth of 900 feet, 400 feet below the Glade sand. Carll published the log of a well situated 500 feet northwest of the Dunkirk, Allegheny Valley and Pittsburg Railroad station at North Warren, in which oil occurred in shale at 938 feet. This well was about one-fourth of a mile southeast of Asylum well No. 1. Such occurrences as these are of no economic importance and are mentioned only to make the discussion of distribution complete.

Productive areas.—In the Glade sand there are two producing areas which seem to be disconnected, one at North Warren and the other extending from Warren to Glade and northward. These may be called the North Warren and Glade pools. A number of wells south of Allegheny River, 2 miles west of Big Bend, also appear to be in the Glade sand.

In the Clarendon sand the main producing area lies along Dutchman Run and upper Tionesta Creek; it extends eastward to Kinzua Township, southward for 2 or 3 miles beyond the edge of the quadrangle, and northward for a short distance beyond Allegheny River. There is also a small area along the upper course of Morrison Run. These areas may be called the Clarendon and Morrison Run pools.

The productive area of the Gartland sand has already been described.

Character of oil.—The oil from the Glade and Clarendon sands differs in character, the Glade oil being nearly opaque, dark green, and of 40° gravity, and the Clarendon oil transparent, amber colored, and of 47° gravity. The Clarendon oil has long been known as Tiona oil and was for years quoted in the market at a good premium over all other eastern oils.

NATURAL GAS.

A small quantity of gas is yielded by the oil wells of the region—enough to supply fuel for the gas engines used to pump the wells. Just south of the river on the east margin of the quadrangle is a small area that yields gas exclusively. The gas is supposed to come from the Clarendon and the wells are moderate producers.

The wells in the small area of the Glade sand just south of the river 2 miles west of Big Bend are said to be more important as gas than as oil producers. A few gas wells are also said to have been obtained on the island just above the mouth of Hemlock Run; the gas is piped to Warren.

RELATION OF OIL AND GAS TO STRUCTURE.

The approximate geologic structure of the oil sands is shown on the economic geology map by contours drawn at vertical intervals of 20 feet upon the top of the Clarendon sand, or at its horizon, where it is absent. The position of this horizon is calculated from that of the Glade sand (where this is present) by subtracting 100 feet from the elevations of the surface of the Glade, the top of the Clarendon being, in a general way, 100 feet below the top of the Glade. The positions of the tops of the sands were obtained from well borings and are subject to errors of measurement and identification. The positions as shown by the contours are probably correct within 20 feet. Where neither sand is present the position of the contours is inferred from the general structure as revealed with greater or less clearness by the rocks that outcrop. Their position is therefore more or less conjectural and the writer does not claim for them more than a rough approximation to the facts.

From these contours the positions of the other sands may be calculated; for the Glade sand 100 feet should be added to the elevations represented by the Clarendon contours, and for the Gartland 50 feet should be subtracted. For example, at all points on the Clarendon 400-foot contour the Glade sand should be about 500 feet and the Gartland sand about 350 feet above sea level. The depth to any sand at any point on the surface may be readily calculated from the elevation of the point as shown by the surface contours of the topographic map.

As shown by the contours, the dip is pretty regularly southward north of the river but is interrupted south of the river by the northwest end of the Kinzua-Emporium anticline and by what appears to be a low structural dome along the upper course of Morrison Run. The existence and form of the Kinzua-Emporium anticline are well established by well borings but the evidence for the Morrison Run swell is much less conclusive. There is only a narrow east-west belt of productive territory in that vicinity from which well logs are obtainable, so that the position of the sands in a north-south direction is not given. The well logs obtained show a comparatively sharp rise of the Clarendon sand from 300 feet above sea level at the line between Mead and Pleasant townships westward to 440 feet above the sea a little beyond the Booker Mill road, and then a gradual descent to a point about 1½ miles east of the Liberty School, where the most westerly well is located.

As shown by the map, the gas-producing area of the Clarendon sand lies on the summit of the Kinzua-Emporium anticline and the oil-producing area lies, at a lower level, around the point of the anticline parallel to the structure lines. This relation of the oil and gas is in harmony with the anticlinal theory that these substances are distributed vertically according to their densities, the gas lying higher than the oil because it is lighter. The distribution of the oil in the Glade sand does not indicate any particular structure and it may have been conditioned more by the character of the sand, the oil accumulating in the part of the stratum that was sufficiently porous to absorb and retain it.

COAL.

On the ridge southwest of Hodge Run, about 2 miles southeast of Scandia, is the Quaker Hill or Dinsmoor coal bed. The coal underlies the Olean conglomerate member, which here appears to be no more than 2 feet thick. It is probably the same as the Lower Marshburg coal bed of McKean County. The section of the bed is as follows:

Section of Dinsmoor coal bed.

	Feet.
Conglomerate.	
Shale	5
Coal	1½–2
Black shale	1
Sandy clay.	
Conglomerate? (Knapp?).	

The coal is very pure, as shown by the following analysis by McCreath:

Analysis of Dinsmoor coal.

Water	2.948
Volatile matter	35.217
Fixed carbon	58.096
Sulphur	.689
Ash	3.050
	100.000

The known area of workable coal, as shown on the map, probably does not exceed 50 acres, though the bed may extend in workable condition considerably farther to the southeast along the ridge.

Drifts have been driven from both the north and the south, and the bed has been found to dip in both directions, showing that it occupies a depression probably due to deformation since its deposition. The general dip toward the center of the basin is interrupted by reverse dips, so that the bed lies in rolls, the shale covering being thickest in the swales and the overlying conglomerate being nearly in contact with the coal on the rolls.

The coal bed was apparently laid down unconformably on the eroded surface of the Knapp formation in a partly inclosed lagoon as the waters in which the Olean conglomerate member was deposited gradually overspread the region. (See "Historical geology," p. 8.)

CLAY.

Deposits of clay of considerable extent occur on the river flats. These are utilized to some extent for brick by the Red Star Brick Company, at Starbrick, on the north side of the river, and by the Highhouse Brick Works on the south side of the river. The section of the clay at Starbrick is as follows:

Section of clay bed at pit of Red Star Brick Company, Starbrick.

	Feet.
Soil	1
Clay, blue and yellow mottled, sandy, micaceous	3
Clay, sand, and gravel	2
	6

The section at the Highhouse Company's pit is similar, but the thickness of the bed is variable and may reach 10 feet locally. Clay of similar character was noted in the town of Warren, and it is likely that deposits are extensive along the valley flats.

The clay is raised by plow and scraper. It is used in the proportions of one-third clay and sand from the lower bench and two-thirds clay and soil from the upper two benches.

At the Red Star Brick Company's works common bricks are made by the Hilton process. The clay is run through a crusher and pug mill to the press, which presses it wet into forms containing five molds, sanded before using. The wet bricks are dried in sheds for about five days, the time varying according to the weather, and are burned for about ten days in updraft rectangular kilns. The product is of good red color and does not warp nor crack. It is marketed mainly in Warren. The plant operates only in summer and has a capacity of 30,000 bricks daily.

At the Highhouse works dry-press bricks are made. The clay is run through a dry pan, kept dry by gas flame, thence to a revolving hexagonal inclined screen of about $\frac{1}{16}$-inch mesh, also kept dry by a gas flame. The clay passing the screen goes to a Boyd press, thence to the kiln. The bricks are of a fine red color and excellent quality and are suitable for any of the purposes for which a dry-press brick is desired.

BUILDING STONE.

Building stone of good quality is obtained from the Salamanca conglomerate member and to some extent from other formations, especially from loose blocks of the Olean conglomerate member. Many buildings in the region have been constructed of the Salamanca, the most notable being the State Asylum for the Insane at North Warren, the stone for which was obtained in part from surface blocks and bowlders found along the Conewango as far north as Ackley and in part from a quarry on the hillside a mile north of Warren. The stone from the quarry is said to have been taken from a layer about 2 feet thick. This stone is a medium-grained, more or less red or yellow banded or mottled siliceous sandstone, which apparently resists weathering well and on weathering assumes a pale-yellow or creamy tint of pleasing appearance.

Blue, thin-bedded, fine-grained argillaceous sandstone is obtained from the rocks immediately below the Salamanca conglomerate member. Such rock has been quarried on the point of the spur north of East Warren and at a quarry on Glade Run belonging to George Traub.

Stone from these quarries has been used to some extent for paving stones, facings for foundation walls, and steps. All the rock is more or less laminated, however, and is apt to crack and flake off parallel to the bedding planes, so that it can not be regarded as of good quality.

The Olean conglomerate and Connoquenessing sandstone members will yield plenty of stone suitable for foundation work and rough masonry. It is generally, however, on the high hills and is so far removed from transportation facilities that it can hardly have more than a local use. On the ridge north of the river, anywhere for 2 miles west of Big Bend, a large area of this rock could be made available by an incline to the Pennsylvania Railroad.

SAND AND GRAVEL.

Abundance of sand for cement and mortar and of gravel for concrete, rubble, and road metal can be obtained from the high-level glacial deposits in the vicinity of Warren. These deposits are largely drawn on for such materials at the pit owned by Weiler & Ruhlman and at the pit belonging to the asylum at North Warren. (See fig. 13.)

SOIL.

The quadrangle possesses soils of considerable variety. The northwest corner, including most of Farmington Township, is largely covered with glacial deposits of gravel and sand, which make the surface smooth and produce a warm and well-drained soil. Along the valleys are wide tracts of alluvial soil of excellent quality. On the higher ridges the soil is largely derived from the underlying conglomerates and is prevailingly sandy; on the lower ridges and hills it is derived from clay shales and argillaceous sandstones and is prevailingly clayey, with a rather impervious subsoil, which makes the surface soil rather wet and cold. The soils are all of a good degree of fertility, the alluvial soils notably so. Grass, corn, and oats are the principal crops. The region is best adapted to grazing and dairying, and these are the branches of farming most generally followed.

WATER.

Surface water.—The country is well watered. Allegheny River, Conewango and Tionesta creeks, and Morrison Run are living streams. From Morrison Run part of the water supply for the city of Warren is drawn. Measurements of flow made by the water-supply commission of Pennsylvania on August 15, 1908, from the suspension bridge over Allegheny River at Warren, showed a discharge of 882 second-feet, and from the Fifth Street Bridge over Conewango Creek at Warren a discharge of 226 second-feet. These measurements probably do not give the approximate minimum flow of these streams at Warren, for measurements on Allegheny River at Tionesta on August 25, 1908, gave 1030 second-feet, while a wading measurement at the same place on September 28, 1908, gave only 375 second-feet. The flow of the Allegheny at Tionesta diminished nearly two-thirds between the two dates, and presumably the same proportional diminution took place at Warren.

Underground water.—Springs abound on the hillsides, as they do throughout western New York and northwestern Pennsylvania where the rocks are thin-bedded sandstones and clay shales. The oil wells of the region show that the rocks are permeated with water to a maximum depth of 600 feet, the depth depending somewhat on the location of the well with reference to the relief. Pipe or casing to shut out the water in oil wells is rarely put down to depths greater than 600 feet, and generally less.

An abundant supply of water can almost invariably be obtained anywhere in the region by drilling to the depth of 100 feet, the rocks being permanently saturated at that depth, even beneath the hilltops. So far as known to the writer, no measurements have been made of the flow of springs or of the volume that would be yielded by wells.

The water is of a high degree of purity. Its principal impurity is carbonate of lime, which is present in sufficient quantity to make the water rather hard. The lime is derived from the fossil shells which abound in the rocks. No analysis of the underground waters is known to the writer.

December, 1909.

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Topography by Hoyt L. Johnston. Assistant, B.D. Stewart.
Control by E.L. McNair and Robt. D. Cummin.
Surveyed in 1905 and 1906.

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APPROXIMATE MEAN DECLINATION 1906.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.

Datum is mean sea level.

Edition of Oct. 1908, reprinted Aug. 1909.

LEGEND

RELIEF
printed in brown

2176
Figures
showing heights above mean sea level instrumentally determined

Contours
showing height above sea, horizontal form, and steepness of slope of the surface

Depression contours

DRAINAGE
printed in blue

Streams

Intermittent streams

Reservoirs and ponds

Springs

Marshes

CULTURE
printed in black

Roads and buildings

Churches, schoolhouses, and cemeteries

Private and secondary roads

Trails

Railroads

Electric railroads

Bridges

Ferries

Fords

Dams

Oil tanks

196
State line and monuments

Township lines

City, village and borough lines

△
Triangulation stations

BM × 2057
Bench marks

AREAL GEOLOGY

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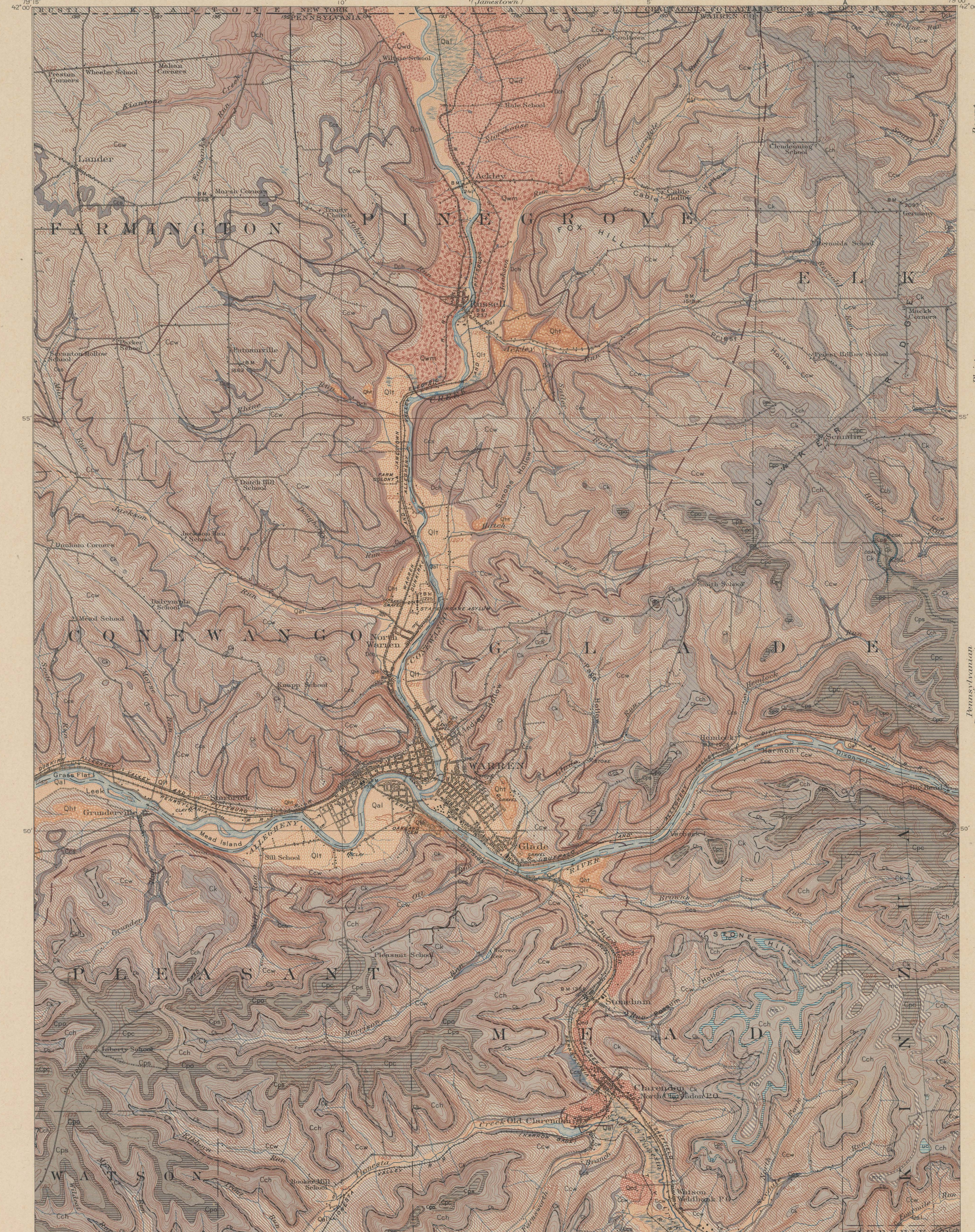

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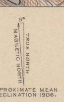

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LEGEND

SEDIMENTARY ROCKS

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

QUATERNARY

Recent

Qal Alluvium *(flood-plain deposits of present streams)*

Pleistocene

Qlt Lower terrace deposits *(partly stratified sand and gravel, outwash from Wisconsin terminal moraine)*

Qwm Wisconsin terminal moraine *(mainly unstratified sand and gravel)*

Qwd Unclassified drift of Wisconsin age

Approximate limit of Wisconsin ice sheet

Qht High terrace deposits *(sand and gravel, in places stratified and cross-bedded; outwash from terminal moraine of supposed Kansan age)*

Qed Earlier glacial deposits *(rudely-stratified sand and gravel, either terminal moraine of supposed Kansan age or outwash therefrom)*

Approximate limit of earlier ice sheet of supposed Kansan age

CARBONIFEROUS

Pennsylvanian — *Pottsville formation*

Cpc Connoquenessing sandstone member *(very coarse, white, quartz sand rock, containing some small quartz pebbles)*

Cps Sharon shale member *(black and gray clay and sandy shales, with thin coal streaks and limonite nodules)*

Cpo Olean conglomerate member *(coarse round quartz pebbles embedded in fine quartz sand; underlain locally by thin coal)*

UNCONFORMITY

Mississippian

Cch (uc, mc, lc) Cuyahoga formation *(greenish shale and thin-bedded fine-grained green and gray sandstone, with lentils of conglomerate of small flat quartz pebbles, lc, mc, uc)*

Cb Berea sandstone *(thin sandstone, commonly yellow, highly fossiliferous at top; probably Venango first oil sand)*

DEVONO-CARBONIFEROUS

Ck Knapp formation *(mainly flat-pebble conglomerate with shale parting in portion of area; upper part of Venango oil sand group)*

Ccw / **Ccs** Conewango formation and Salamanca conglomerate lentil *(green, gray, and red shales, thin-bedded, fine-grained sandstone, and thin conglomerate lentils; Salamanca flat-pebble conglomerate, probably Venango third oil sand, in middle)*

DEVONIAN

Dch Chemung formation *(gray, green, and purple shale and thin-bedded sandstone; includes "pink rock" of well drillers)*

Coal outcrop

⚒ *Quarries and mines*
x *Coal prospects*

ECONOMIC GEOLOGY

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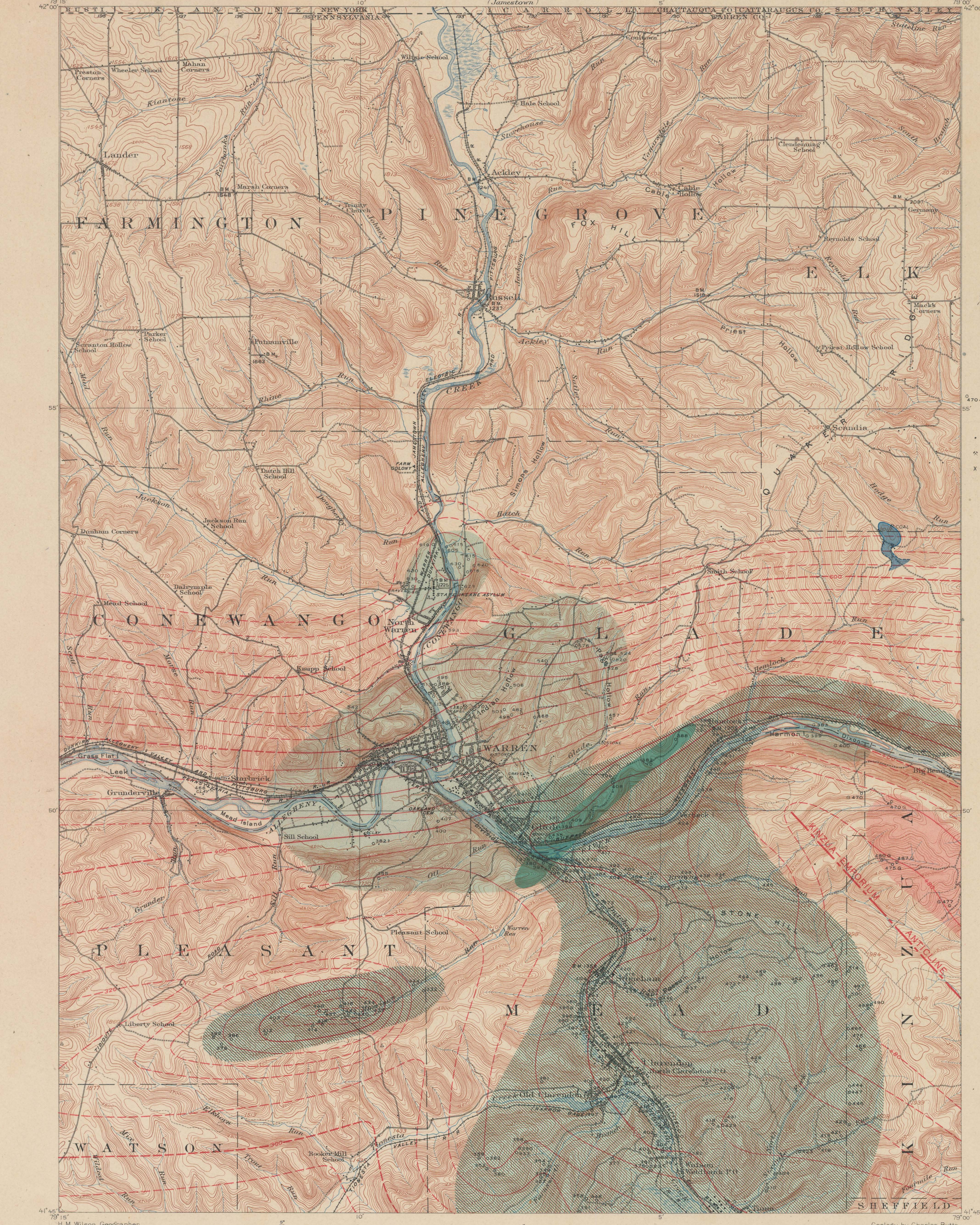

LEGEND

▨ Glade sand oil fields

🟥 Clarendon sand gas field

▨ Clarendon sand oil fields

🟩 Gartland sand oil field

Structure contours (showing elevation above sea of the top of the Clarendon sand; broken lines indicate approximate location; contour interval 20 feet)

Area underlain by workable coal

○470 *Selected oil and gas wells*
Numbers show elevation above sea of the top of the Clarendon sand, or its horizon calculated from the Glade sand; G *indicates gas.*

• *Oil tanks*

⚒ *Quarries and mines*
Coal, stone, clay, sand, and gravel

x *Coal prospects*

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§ These folios are also published in octavo form.

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