DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

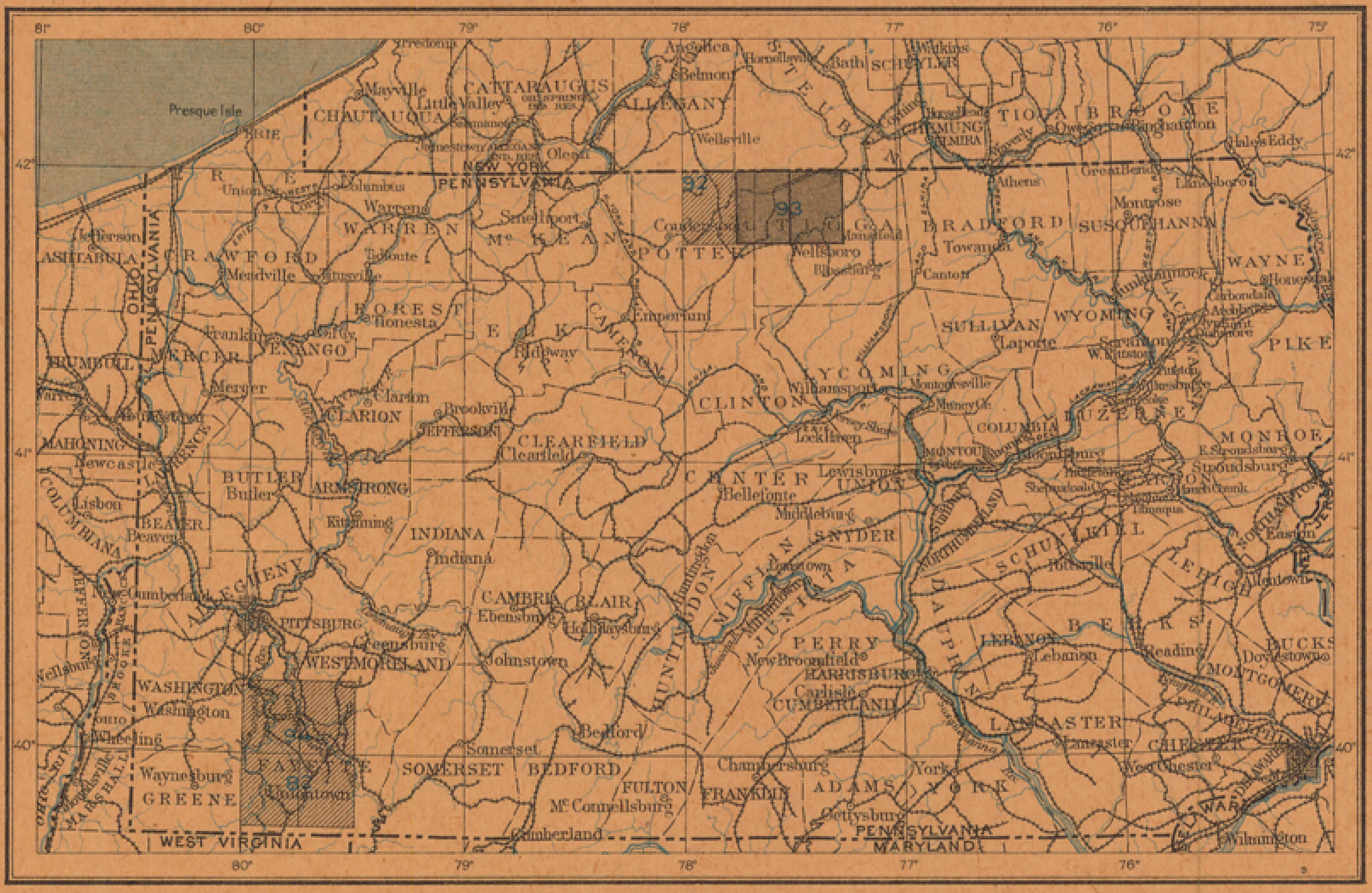
93

GEOLOGIC ATLAS OF THE UNITED STATES

ELKLAND-TIOGA FOLIO

PENNSYLVANIA

INDEX MAP



SCALE 40 MILES-1 INCH

AREA OF THE ELKLAND-TIOGA FOLIO

AREA OF OTHER PUBLISHED FOLIOS

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LIBRARY EDITION

ELKLAND-TIOGA FOLIO
NO. 93

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GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS   S. J. KUBEL, CHIEF ENGRAVER
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EXPLANATION.

The Geological Survey is making a geologic map of the United States, which necessitates the preparation of a topographic base map. The two are being issued together in the form of an atlas, the parts of which are called folios. Each folio consists of a topographic base map and geologic maps of a small area of country, together with explanatory and descriptive texts.

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 which are most important 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 horizontal outline, or contour, of all slopes, and to indicate their grade or degree of steepness. This is done by lines connecting points of equal elevation above mean sea level, the lines being drawn at regular vertical intervals. These lines are called *contours*, and the uniform vertical space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map:

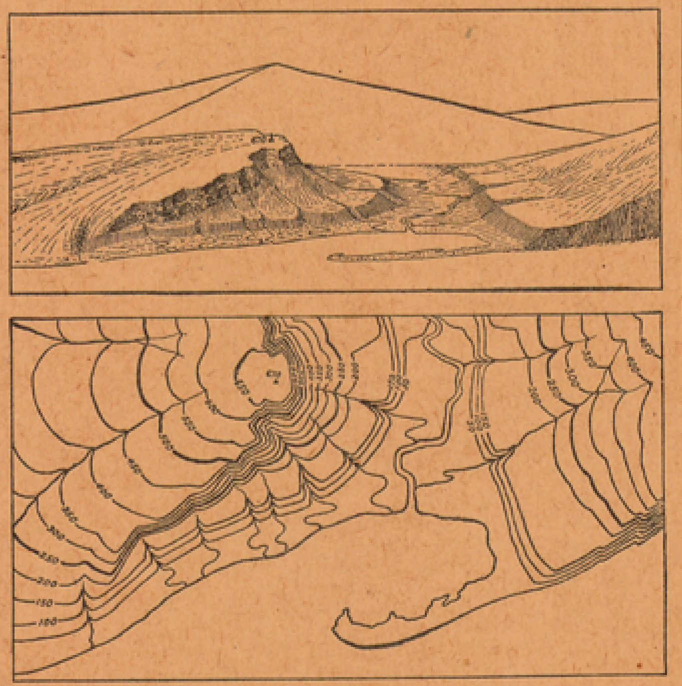

Fig. 1.—Ideal sketch and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand bar. On each side of the valley is a terrace. From the terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply in a precipice. Contrasted with this precipice is the gentle descent of the slope at the left. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade:

1. A contour indicates approximately a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, 200 feet, and so on, above sea level. Along the contour at 250 feet lie all points of the surface 250 feet above sea; and similarly with any other contour. In the space between any two contours are found all elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while 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 sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration nearly all the contours are numbered. Where this is not possible, certain contours—say every fifth one—are accentuated and numbered; the heights of others may then be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines conforming to the surface of the ground, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. The relations of contour curves and angles to forms of the landscape can be traced in the map and sketch.

3. Contours show the approximate grade of any slope. The vertical space between two contours is the same, whether they lie along a cliff or on a gentle slope; but to rise 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.

For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is used for regions like the Mississippi delta and the Dismal Swamp. In mapping great mountain masses, like those in Colorado, the interval may be 250 feet. For intermediate relief contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Water courses are indicated by blue lines. If the streams flow the year round the line is drawn unbroken, but if the channel is dry a part of the year the line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue, by appropriate conventional signs.

Culture.—The works of man, such as roads, railroads, and towns, together with boundaries of townships, counties, and States, and artificial details, are printed in black.

Scales.—The area of the United States (excluding Alaska) is about 3,025,000 square miles. On a map with the scale of 1 mile to the inch this would cover 3,025,000 square inches, and to accommodate it the paper dimensions would need to be about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the scale of the map. In this case it is "1 mile to an inch." 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 of "1 mile to an inch" is expressed by $\frac{1}{63,360}$. Both of these methods are used on the maps of the Geological Survey.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250,000}$, the intermediate $\frac{1}{125,000}$, and the largest $\frac{1}{62,500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62,500}$ a square inch of map surface represents and corresponds nearly to 1 square mile; on the scale $\frac{1}{125,500}$, to about 4 square miles; and on the scale $\frac{1}{250,000}$, to about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three different ways, one being a graduated line representing miles and parts of miles in English inches, another indicating distance in the metric system, and a third giving the fractional scale.

Atlas sheets and quadrangles.—The map is being published in atlas sheets of convenient size, which are bounded by parallels and meridians. The corresponding four-cornered portions of territory are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ contains one square degree, i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ contains one-quarter of a square degree; each sheet on a scale of $\frac{1}{62,500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, respectively.

The atlas sheets, being only parts of one map of the United States, are laid out without regard to the boundary lines of the States, counties, or townships. 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 the names of adjacent sheets, if published, are printed.

Uses of the topographic sheet.—Within the limits of scale the topographic sheet is an accurate and characteristic delineation of the relief, drainage, and culture of the district represented. Viewing the landscape, map in hand, every characteristic feature of sufficient magnitude should be recognizable. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property to be bought or sold; save the engineer preliminary surveys in locating roads, railways, and irrigation ditches; provide educational material for schools and homes; and serve many of the purposes of a map for local reference.

THE GEOLOGIC MAP.

The maps representing areal geology show by colors and conventional signs, on the topographic base map, the distribution of rock formations on the surface of the earth, and the structure-section map shows their underground relations, as far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. The original crust of the earth was probably composed of *igneous rocks*, and all other rocks have been derived from them in one way or another.

Atmospheric agencies gradually break up igneous rocks, forming superficial, or *surficial*, deposits of clay, sand, and gravel. Deposits of this class have been formed on land surfaces since the earliest geologic time. Through the transporting agencies of streams the surficial materials of all ages and origins are carried to the sea, where, along with material derived from the land by the action of the waves on the coast, they form *sedimentary rocks*. These are usually hardened into conglomerate, sandstone, shale, and limestone, but they may remain unconsolidated and still be called "rocks" by the geologist, though popularly known as gravel, sand, and clay.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried, consolidated, and raised again above the surface of the water. In these processes, through the agencies of pressure, movement, and chemical action, they are often greatly altered, and in this condition they are called *metamorphic rocks*.

Igneous rocks.—These are rocks which have cooled and consolidated from a liquid state. As has been explained, sedimentary rocks were deposited on the original igneous rocks. Through the igneous and sedimentary rocks of all ages molten material has from time to time been forced upward to or near the surface, and there consolidated. When the channels or vents into which this molten material is forced do not reach the surface, it may consolidate in cracks or fissures crossing the bedding planes, thus forming dikes, or spread out between the strata in large bodies, called sheets or laccoliths, or form large irregular cross-cutting masses, called stocks. Such rocks are called *intrusive*. Within their rock inclosures they cool slowly, and hence are generally of crystalline texture. When the channels reach the surface the lavas often flow out and build up volcanoes. These lavas cool rapidly in the air, acquiring a glassy or, more often, a partially crystalline condition. They are usually more or less porous. The igneous rocks thus formed upon the surface are called *extrusive*. Explosive action often accompanies volcanic eruptions, causing ejections of dust or ash and larger fragments. These materials when consolidated constitute breccias, agglomerates, and tuffs. The ash when carried into lakes or seas may become stratified, so as to have the structure of sedimentary rocks.

The age of an igneous rock is often difficult or impossible to determine. When it cuts across a sedimentary rock it is younger than that rock, and when a sedimentary rock is deposited over it the igneous rock is the older.

Under the influence of dynamic and chemical forces an igneous rock may be metamorphosed. The alteration may involve only a rearrangement of its minute particles or it may be accompanied by a change in chemical and mineralogic composition. Further, the structure of the rock may be changed by the development of planes of division, so that it splits in one direction more easily than in others. Thus a granite may pass into a gneiss, and from that into a mica-schist.

Sedimentary rocks.—These comprise all rocks which have been deposited under water, whether in sea, lake, or stream. They form a very large part of the dry land.

When the materials of which sedimentary rocks are composed are carried as solid particles by water and deposited as gravel, sand, or mud, the deposit is called a mechanical sediment. These may become hardened into conglomerate, sandstone, or shale. When the material is carried in solution by the water and is deposited without the aid of life, it is called a chemical sediment; if deposited with the aid of life, it is called an organic sediment. The more important rocks formed from chemical and organic deposits are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the above sedimentary deposits may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

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

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks over wide expanses, and as it rises or subsides the shore lines of the ocean are changed: areas of deposition may rise above the water and become land areas, and land areas may sink below the water and become areas of deposition. If North America were gradually to sink a thousand feet the sea would flow over the Atlantic coast and the Mississippi and Ohio valleys from the Gulf of Mexico to the Great Lakes; the Appalachian Mountains would become an archipelago, and the ocean's shore would traverse Wisconsin, Iowa, and Kansas, and extend thence to Texas. More extensive changes than this have repeatedly occurred in the past.

The character of the original sediments may be changed by chemical and dynamic action so as to produce metamorphic rocks. In the metamorphism of a sedimentary rock, just as in the metamorphism of an igneous rock, the substances of which it is composed may enter into new combinations, or new substances may be added. When these processes are complete the sedimentary rock becomes crystalline. Such changes transform sandstone to quartzite, limestone to marble, and modify other rocks according to their composition. A system of parallel division planes is often produced, which may cross the original beds or strata at any angle. Rocks divided by such planes are called slates or schists.

Rocks of any period of the earth's history may be more or less altered, but the younger formations have generally escaped marked metamorphism, and the oldest sediments known, though generally the most altered, in some localities remain essentially unchanged.

Surficial rocks.—These embrace the soils, clays, sands, gravels, and bowlders that cover the surface, whether derived from the breaking up or disintegration of the underlying rocks by atmospheric agencies or from glacial action. Surficial rocks that are due to disintegration are produced chiefly by the action of air, water, frost, animals, and plants. They consist mainly of the least soluble parts of the rocks, which remain after the more soluble parts have been leached out, and hence are known as residual products. Soils and subsoils are the most important. Residual accumulations are often washed or blown into valleys or other depressions, where they lodge and form deposits that grade into the sedimentary class. Surficial rocks that are due to glacial action are formed of the products of disintegration, together with bowlders and fragments of rock rubbed from the surface and ground together. These are spread irregularly over the territory occupied by the ice, and form a mixture of clay, pebbles, and bowlders which is known as till. It may occur as a sheet or be bunched into hills and ridges, forming moraines, drumlins, and other special forms. Much of this mixed material was washed away from the ice, assorted by water, and

DESCRIPTION OF THE ELKLAND AND TIOGA QUADRANGLES.

General Geology by Myron L. Fuller. Pleistocene Geology by William C. Alden and Myron L. Fuller.

GENERAL RELATIONS.

Location and area.—The area mapped and described in this folio includes the Elkland and Tioga quadrangles, and is situated in northern Pennsylvania, immediately south of the northern boundary of the State and about midway between its eastern and western limits. The Tioga quadrangle lies between longitude 77° on the east and 77° 15′ on the west, and the Elkland quadrangle between 77° 15′ on the east and 77° 30′ on the west. Both lie between latitude 41° 45′ on the south and 42° on the north, and each includes one-sixteenth of a square degree. The north-south length of each quadrangle is about 17.2 miles, the width about 13 miles, and the area 222.5 square miles, all of which lies within the limits of Tioga County. The Elkland quadrangle receives its name from the town of Elkland, in its northeastern part, on the Cowanesque River, while the Tioga quadrangle is named from the town of Tioga, near its center.

Relations to Appalachian province.—The Appalachian province, which extends from New York on the north to central Alabama on the south, and from the Atlantic Coastal Plain on the east to the lowlands of the Mississippi Basin on the west, has been subdivided into three grand divisions. The eastern division is marked by the more or less rounded, soil-covered ridges of igneous or altered sedimentary rocks which form the Appalachian Mountains proper; the central division by the long, straight or gently curved ridges, produced by the erosion of the strongly folded and faulted sedimentary rocks, comprising what is known as the Appalachian Valley; and the western division by the deeply trenched plateau-like uplands, existing over the region of gently folded rocks to the north and northwest of the previous division, known as the Allegheny Plateau. (See fig. 5, Illustration sheet.) It is to this region of gentle folds and plateau-like topography that the Elkland and Tioga quadrangles belong, the southwest corner of the former as measured across the strike of the folds to the south being about 40 miles from the Allegheny Front, which constitutes the western margin of the Appalachian Valley.

TOPOGRAPHY.

Drainage.—The area included in the Elkland and Tioga quadrangles, with the exception of a small area in the southern portion of the Elkland quadrangle which drains southward into Pine Creek, and another small area in the extreme northeast corner of the Tioga quadrangle which drains northeastward into the Chemung River in New York, is drained by the Tioga River and its tributaries.

The Tioga River has its source in the mountainous belt crossing Tioga County in a southwesterly direction from a point a little northeast of Blossburg to the southwest corner of the county. (See fig. 4, p. 8.) Near Blossburg, about 6 miles south of the limits of the quadrangles, the river turns to the north, and flows, with a direction a little west of north, across the Tioga quadrangle and into New York State, finally joining the Chemung River near Chemung. The Chemung carries the waters back to the southeast, adding them to those of the North Branch of the Susquehanna in the northern part of Bradford County, Pennsylvania, whence they flow in a somewhat devious course across the Appalachian ridges and eventually empty into Chesapeake Bay.

The two main tributaries of the Tioga River in the region under consideration are the Cowanesque River and Crooked Creek. The former enters the area in the northwestern portion of the Elkland quadrangle and flows in an easterly direction across the northern portions of the Elkland and Tioga quadrangles until it joins the Tioga River near Lawrenceville. Crooked Creek rises in the west-central portion of the Elkland quadrangle and flows with a similar easterly course until it empties into the Tioga River near Tioga.

Starting from Crooked Creek in the vicinity of Middlebury Center, in the eastern portion of the Elkland quadrangle, and extending southwestward to Ansonia at the southern border, is a broad, open valley with a flat and marshy bottom lying only a few feet higher than the streams at either end. Waters entering the valley from the hills on either side find their way out as sluggish, winding streams which empty in part into Crooked Creek on the north and in part into Pine Creek on the south. The present streams are doing no work of erosion and have evidently played no part in the production of the valley through which they flow. The valley is clearly the result of the erosive action of a large and powerful stream; and a study of the surrounding region shows that this stream, which occupied the valley until comparatively recent times, was a continuation of Pine Creek of Potter County. The diversion of the waters from the old channel into a new channel leading southward from Ansonia to the West Branch of the Susquehanna at Jersey Shore took place partly through ordinary processes of stream development and partly through the agency of the ice sheet which covered the region in early Pleistocene times. The nature of the diversion will be considered under the heading "Physiographic history," on pages 6 and 7.

In general the Elkland and Tioga quadrangles are well drained with the exception of the flat areas of limited extent occurring at the crests of the uplands, and marking, as will be seen later, the remnants of an old plateau, and of a few small areas whose natural drainage has been obstructed by glacial drift. The obstructions of drainage due to drift barriers are usually of slight importance, though in a few instances, as in the western portion of Chatham and the southern portion of Farmington Township in the Elkland quadrangle, and in the northeast portion of Charleston Township in the Tioga quadrangle, marshes from half a mile to nearly 2 miles in length occur. The only natural pond in the two quadrangles is a diminutive body, a few acres in area, in the center of Farmington Marsh.

Relief.—Briefly stated, the topography or relief of the Elkland and Tioga quadrangles is that of a dissected plateau, or, in other words, a plateau which has been cut into by the streams until the valley bottoms lie far below the general level of the uplands. The general level of the plateau is indicated by the mountainous belts of the area, the flat-topped crests of which are remnants of the old plateau surface.

Two of these belts occur within the area treated in this folio. The northernmost, the Cowanesque mountain belt, enters the northern portion of the Elkland quadrangle near the village of the same name. Though much broken by the Cowanesque River and its tributaries, it is represented by prominent hills at numerous points on each side of the valley. The second belt, which is the more prominent of the two, enters the eastern limits of the Tioga quadrangle at a point a little north of the center. From here, under the name of Tioga Mountain, it passes, with a course about S. 80° W., across the quadrangle and enters the Elkland quadrangle a little south of Crooked Creek. Continuing under the name of Crooked Creek Mountain, it crosses the Elkland quadrangle, eventually leaving the western border at a point about 3 miles north of the southwest corner. From this point its name again changes, the western continuation being known as Pine Creek Mountain.

The elevations of the crest lines of the mountain belts are very uniform, those of the much dissected Cowanesque belt varying from 2000 to 2200 feet above sea level, and those of the Crooked Creek–Tioga belt from 2150 to a little over 2300 feet.

Between the Cowanesque and the Crooked Creek–Tioga mountain belt, and also to the south of the latter, are broad belt-like areas of rounded hills, the higher of which appear to rise to a somewhat general level of from 200 to 400 feet below the level of the surface represented by the flat mountain crests. The slope of the surface of the supposed lower plateau before it was eroded was to the southeast. Its elevation, as recorded by the higher crests, appears to have been from 2000 to 2100 feet in the western portion of the Elkland quadrangle, about 1900 feet in the vicinity of the boundary between the Elkland and Tioga areas, about 1850 in the southwestern portion of the Tioga quadrangle, and from 1600 to 1700 in the southeastern portion. The difference of level between the upper and the lower plateau surface was due to the presence in the areas where the latter was developed of softer and more readily eroded rocks. The detailed history of the production of the plateau surfaces, however, will be considered under the heading "Physiographic history" (pp. 6–7).

While the hardness of the rocks has been important in determining the production of the broader topographic belts, the character of the streams has been the controlling factor in the production of the minor features. The large streams, and especially those which have been acting for long periods, have eroded wider and flatter-bottomed valleys than the smaller and younger streams. Thus the smaller streams, such as the minor tributaries of Tioga River, Crooked Creek, etc., flow in sharp V-shaped valleys, while the rivers and larger creeks flow wholly or partly in broad and relatively flat-bottomed valleys and are bordered by more or less well-defined flood plains. This flatness of the valley bottoms is, however, due in part to fillings of glacial drift, upon which the present streams flow and upon the surface of which the flood plains have been built. If this material should be removed, the wide rock bottoms of the valleys would probably show relatively narrow and sharp-cut channels sunk to a depth of 50 feet or more below the general level of the old bottoms. The erosion of these channels is supposed to have taken place at the beginning of the present geologic period (Pleistocene), and they are consequently still well preserved. The tributaries of the larger streams, especially those of the Tioga River, show evidences of similar sharp cutting in relatively recent geologic times, but streams removed from the main drainage lines, as about the headwaters of Crooked Creek, show little evidence of such action.

This comparatively recent cutting has had an important effect upon the topography in the region north of the Tioga mountain belt in the Tioga quadrangle. Nearly all the streams in this region flow through sharp, gorge-like valleys and are frequently bordered by perpendicular cliffs of considerable height. Elkhorn and Bear creeks in Tioga Township show these cliffs to the best advantage, but they are by no means uncommon in the other tributaries of the Tioga River north of the Tioga mountain belt. South of this belt the erosion was much less pronounced, evidently indicating that the period of strong erosive action was too short to completely reduce the barrier presented by the hard sandstones of the mountain belt, which thus served, in a way, to protect the region behind it from erosion.

By far the greater part of the valleys and channels of the region have been produced by the action of streams which now occupy them. A prominent exception has already been noted in the case of the wide valley between Middlebury Center and Ansonia. Other exceptions occur at the headwaters of Crooked Creek in Chatham Township and just south of Cobble Knoll in Charleston Township in the Elkland quadrangle, and at several points in Charleston, Tioga, and Sullivan townships in the Tioga quadrangle. All of these are due to the action of temporary streams during the ice invasion, or to streams diverted from their original channels by the ice or by the deposits laid down through its agency. These are known as glacial spillways and are shown on the Surficial Geology maps.

In general the glacial deposits have had relatively little influence upon the topography. Minor inequalities of the surface have been masked by a smooth till coating, and in many cases the valleys have been partially filled. The most marked deposits are the moraines, which, though of slight elevation as compared with the rock hills, are, nevertheless, often 100 feet or more thick and are conspicuous by reason of their kettle-pitted surfaces. The irregular terraces and fans of glacial materials represented on the Surficial Geology maps are interesting though not pronounced topographic features.

DESCRIPTIVE GEOLOGY.

Formations represented.—The rocks exposed at the surface in the Elkland and Tioga quadrangles are of two types. They include not only those firm, hard beds which everyone at once recognizes as rock, but also those loose, unconsolidated deposits of silt, sand, gravel, glacial till, etc., which are likewise considered by geologists as rock, and which occur as fillings in the valleys, as ridges or patches of loose materials, or as a thin mantle over the general surface.

The materials of the unconsolidated or surficial rocks are composed of fragments of varying size and composition which have been derived in one way or another from the consolidated rocks. The fragments range in size from the almost microscopic particles of the clays to large fragments and even bowlders. In the Elkland–Tioga area they have been derived almost wholly from the immediately underlying or from closely adjacent rocks. A small percentage, however, came from greater distances; some even from sources as distant as Canada. With the exception of a few recent stream deposits, practically all the materials comprising the surficial rocks have reached their present position, either directly or indirectly, through the agency of an ice sheet similar to that now covering the surface of Greenland. This ice sheet started in the far North during the early part of the present geologic period and spread out over nearly the whole northeastern portion of North America, including the area now under discussion. As the ice moved over the surface of the country large quantities of the loose materials, and even portions of the rocks themselves, were taken up and transported greater or less distances. By the melting of the ice and by other causes this material was later set free and was deposited either in direct association with the ice or by the streams flowing away from its margin. These glacial deposits do not reach any considerable thickness except in the valleys and in portions of the moraines.

The deposits laid down since the retreat of the ice are of even less geologic importance, being confined to thin coatings of silt forming the flood-plain surfaces along the larger streams, and a few fans and stream deposits of poorly assorted gravels.

The materials of which the consolidated sedimentary rocks are composed were originally derived, in the form of gravel, sand, and mud, from an old land mass, worn away under the action of streams or waves, the resulting waste being carried to the margin of the seas then existing, and thence distributed by waves and currents as stratified or sedimentary beds. As time has elapsed, these beds have been gradually consolidated by the chemical deposition of cementing materials about the grains of which the beds were composed.

In northern Pennsylvania and southern New York these sedimentary rocks reach a thickness of many thousand feet, and although only a small part of the whole can be seen at any point, or even in a single quadrangle, the deep cutting of the streams, taken in connection with the moderate tilting of the beds, has been sufficient to expose in the area under discussion a thickness of about 3500 feet of strata of Devonian and Carboniferous age. These exhibit many alternations of sandstone, shale, impure limestone, etc., but they may be grouped by their lithologic character in five formations, each marked by characteristic features. These lithologic divisions are, in ascending order, the Chemung, Cattaraugus, Oswayo, Mauch Chunk, and Pottsville formations. The first two are Devonian, the third is in part Devonian and in part Carboniferous, and the other two are Carboniferous in age. Their general characters and relative thicknesses are shown on the Columnar Section sheet at the end of the folio, and are described in detail in the following paragraphs.

DEVONIAN FORMATIONS.

Chemung formation.—The name Chemung is here applied to a lithologic division which includes the thick sequence of alternating shales, sandstones, and thin limestones, having as its basal limit (not exposed in either of the quadrangles) the underlying bluish shales of the Portage formation, and as its upper limit the overlying red shales or the red or green sandstones of the Cattaraugus formation. It is characterized by the typical marine fauna of the Chemung epoch, and as here defined excludes the overlying Cattaraugus and lower Oswayo red and green shales and sandstones, which are characterized by a fresh- or brackish-water fauna, and which have sometimes been referred to the Chemung epoch.

The Chemung is the lowest of the formations encountered at the surface of the quadrangles, and is made up largely of a series of calcareous and shaly sandstones, alternating with thick beds of soft shale and thin seams of impure limestone. Gray, greenish-gray, and buff are ordinarily the predominant colors of both the sandstones and the shales. The calcareous sandstone is of the type which has come to be considered as especially characteristic of the Chemung, namely, a somewhat coarse, friable sandstone, crowded with open cavities left by the solution of the fossil shells it originally contained. It grades on the one hand into typical gray and somewhat flaggy sandstone and on the other into more or less impure limestone. Where the Chemung is exposed at the surface the sandstones sometimes appear to be the predominant rock, but this is probably due in great part to the fact that they are more resistant to disintegration than the soft and finely laminated shales which the deep well records and the longer stream sections show to constitute the larger portion of the formation.

The limestones are commonly of a dark bluish-gray, sometimes almost black, argillaceous type. They are rich in brachiopod fossils, nearly the whole of the mass sometimes being made up of fragments of shells. The limestones are, in general, most abundant in the upper portion of the formation, the thickest beds apparently occurring in the upper 100 or 200 feet.

The shales are predominantly of an olive color, though gray and green beds are by no means uncommon. A single bed of bright-red shale, less than 2 feet in thickness, was noted, near the crest of the anticline in the southern portion of the Tioga quadrangle, in a position probably 300 feet or more below the top of the Chemung. This, with the thin lenses of iron ore occurring at approximately the same horizon, and the dull reddish-brown shales and sandstones occurring at somewhat lower horizons and exposed in the section along the Erie Railroad north of Tioga station, are probably the only representatives in the area of the lower red series (Oneonta formation?) which is so extensively developed at Le Roy, Franklindale, and other localities in the western half of Bradford County, a few miles southeast of the Tioga quadrangle.

The sandstones of the Chemung are extremely variable in color and texture, but the gray and buff types predominate throughout the larger part of the formation. The beds are rarely massive, but are generally marked by bedding planes which subdivide the rock into thin and rather irregular layers. In the upper part of the formation, at an interval of from 60 to 100 feet below the red beds which rest upon it, there is, in the southern half of the Tioga area, a prominent bed of green cross-bedded sandstone of the Cattaraugus type, having the same thin and perfect lamination planes. This sandstone, with other similar beds at approximately the same horizon, occurs above the upper of the impure Chemung limestones and is the first indication of the approach of Cattaraugus conditions of deposition.

Many of the sandstones of the Chemung afford fragments, the surfaces of which on exposure to the weather are bleached almost white. Such fragments are easily distinguished from the fragments of all other sandstones of the Chemung by their color and by the vertical borings with which they are frequently marked, but the individual beds appear to be of very limited extent, and belong to no particular horizon, though perhaps more common near the top of the formation.

Many of the shales and sandstones of the Chemung are characterized by concretions, some of which are several feet in diameter. (See fig. 9, Illustration sheet.) The concretions are composed mainly of sand, frequently in perfect concentric bands. They occur at all horizons, but, like most of the other distinctive beds, appear to be most abundant near the top of the formation. Ripple marks are present in some of the shales and sandstones, and an imperfect cross bedding characterizes many of the more sandy beds.

In a few localities in the Tioga quadrangle thin conglomerate lenses, of limited distribution, have been noted. These are generally composed almost entirely of pure quartz grains, which in some localities are somewhat stained by iron oxide. The conglomeratic layers appear to be most abundant near the upper limits of the Chemung, though a few pebbly layers and at least one strong bed of conglomerate occurs well down in the formation. Among the localities at which conglomerates have been noted are the hill west of Mansfield, over which runs the road leading south from Manns Creek, the hill immediately north of Mansfield and next to the river, the slopes just north of the road at the east edge of the Tioga quadrangle a mile southeast of Jackson Summit, and the south side of the valley leading eastward from the quadrangle 2 miles north of the same point. The bed at the last locality seems to be several feet in thickness and has furnished a large number of bowlders, up to 3 or 4 feet in diameter, which now cover the hillside. To the west the bed loses its conglomeratic character and becomes a grayish sandstone which on exposure bleaches almost white.

Of the different beds of the Chemung the iron ores are the most distinctive in character. They occur mainly along the anticline in the southern portion of the Tioga quadrangle, though a single outcrop has been noted on the south side of the anticline north of Crooked Creek. The beds are very thin, varying from a few inches to 3 feet in thickness, and are confined to two general geologic horizons. The upper horizon lies close to the top of the formation, and the second appears to be 300 feet or more below the first.

The upper horizon is probably represented by a single bed, usually known as the Mansfield ore bed. It has been opened up at several points and appears to be fairly persistent along the northern flank of the anticline, but it has not been definitely recognized on the south flank. In general it is a rather bright-red granular hematite, the lower portion of which is usually impure and filled with fossils. Its thickness varies from 1½ to 3 feet. It lies in close proximity to the lowest of the red beds of the Chemung-Cattaraugus transition, occurring a few feet below the red beds on the west side of the Tioga River and a few feet above the lowest of them on the east side.

The lower ore horizon is probably represented by a number of thin beds occurring in nearly the same geologic position but possibly overlapping in places. The locations of the various mines, prospects, and outcrops are shown on the geologic map. West of the Tioga River the ore is uniformly a highly fossiliferous red oolitic hematite and varies from 2 or 3 inches to 2 feet or more in thickness, the latter measurement being at the old mine on the hill about 1½ miles southwest of Mansfield. East of the river the ore, which is possibly at a slightly lower horizon, is much darker, more massive, and far less fossiliferous than the ore west of the river. Another bed of similar character is said to overlie the bed just described at an interval of 50 feet at one point, but it is probably a local lens.

With the exception of the upper 100 or 200 feet, which sometimes shows evidences of the approaching change to Cattaraugus conditions, the general character of the Chemung sediments appears to be fairly uniform throughout. Beds of sufficiently distinct lithologic character to admit of tracing if they were continuous over any considerable area, such as the iron ores and the more distinctive of the limestones, sandstones, and conglomerates, are known, but no beds which could be recognized with certainty at widely separated points have been seen. The absence of traceable beds has added greatly to the difficulty of working out the geologic structure of the region.

The general character of the Chemung formation, and the rapid alternations of sandstones and shales, are well brought out in the following section measured by Dr. E. M. Kindle along the railroad northward from Tioga station on the Erie Railroad. The top of the section is about 300 feet below the top of the formation:

Section of Chemung formation northward from Tioga station.

	Thickness in feet.	Depth in feet.
Gray thin-bedded sandstone	5	5
Covered	15	20
Dark thin-bedded sandstone, partly covered	16	36
Covered	48	84
Thin-bedded drab sandstone	28	112
Covered	32	144
Gray to reddish thin-bedded sandstone	25	169
Covered	12	181
Red ferruginous sandstone (with considerable iron)	2	183
Dull reddish to olive shale and sandstone	13	196
Bed of *Sp. disjunctus* shells	2	198
Olive-gray sandstone	5	203
Covered	5	208
Dull-reddish shale and thin-bedded sandstone	40	248
Thin-bedded gray sandstone	20	268
Olive-gray shale with thin bands of sandstone	30	298
Gray to salmon-brown thin-bedded sandstone with concretionary structure locally	25	323
Drab-gray shale and shaly sandstone	20	343
Covered	6	349
Dull reddish shale and sandstone	4	353
Covered	5	358
Dull-reddish to gray shale	18	376
Dark-reddish thin-bedded sandstone	15	391
Dull salmon-brown to olive shale	10	401
Olive-gray shale and shaly sandstone with similar bed of dull-reddish tint	30	431
Olive-gray and dull-reddish shale and thin-bedded sandstone	20	451
Covered	10	461
Olive-gray and dull-reddish thin-bedded sandstone with some concretionary structures	18	479
Covered	5	484
Thin-bedded sandstone	4	488
Gray to reddish shale	9	497
Calcareous bed of *Sp. disjunctus*, etc.	2	499
Gray sandstone	3	502
Calcareous sandstone full of *Sp. disjunctus*	3	505
Dull-reddish shaly sandstone	3	508
Concretionary sandstone and shale	4	512
Gray sandstone	4	516
Gray shale and sandstone	5	521
Soft gray clay shale	10	531
Covered	35	566
Thin-bedded drab sandstone	14	580
Covered	15	595
Brownish gray thin-bedded sandstone	20	615

The upper limit of the Chemung formation is ill defined, as the change from the Chemung to the Cattaraugus conditions is not abrupt. Beds of the typical Chemung type gradually give place to beds partaking more and more of the nature of the overlying Cattaraugus formation. Even after the appearance of beds of red shale or sandstone, layers of the same lithologic type and carrying the same fossils as the Chemung occur at intervals through a range of from 50 to 200 feet or more. In mapping, however, it has been necessary to select some horizon as marking the upper limit of the typical Chemung, and that of the bottom of the lowest red bed has been chosen. Between this horizon and that of the lowest of the heavy red beds the rocks partake of the nature of both the underlying and the overlying formations and are regarded and mapped as transitional beds.

The distribution of the Chemung sediments is shown by the geologic maps, and little needs to be said beyond the fact that they are brought to the surface by two well-marked anticlinal folds. The first of these enters the Tioga quadrangle from the northeast near its northeast corner and crosses it with a trend a little south of west. It enters the Elkland quadrangle in its northern half and leaves it at the middle of its western boundary. It is narrowest where it leaves the quadrangle, having at that point a width varying from 2½ miles on the uplands to about 7 miles measured between its extreme limits in the valleys. At the boundary between the quadrangles its width is from 8 to 9 miles. East of this point the Cattaraugus rocks are nowhere exposed on its northern flank, either in Pennsylvania or in New York.

The second belt enters the Tioga quadrangle a little northeast of Mansfield, passes southwestward to Canoe Camp, then westward and southwestward through East Charleston and Charleston, and across the southeast corner of the Elkland quadrangle. Its greatest width in the area is along the Tioga River, where it is exposed within the quadrangle for a distance of 7 miles. Its full width along the river, however, is probably 9 miles or more. It is relatively narrow on the uplands on each side of the Tioga River, its width varying from a little over 2 to 5 miles.

In both belts the greatest thickness exposed is along the Tioga River. In the northern belt it is probable that about 2000 feet of Chemung beds are brought to the surface, while in the southern belt about 800 feet of the beds are exposed.

DEVONO-CARBONIFEROUS FORMATIONS.

CATSKILL-POCONO GROUP.

Commencing with the beds of red shale which have been taken as marking the beginning of the formation succeeding the Chemung, and continuing upward to the Mauch Chunk formation, there is in the Elkland-Tioga region a great sequence of rapidly alternating shales and sandstones which were referred to in the reports of the Pennsylvania geological survey as the Catskill and Pocono formations. At their base they grade into the rocks of the Chemung formation, at a horizon some distance below that which marks the top of the same formation farther west, while at their top they are overlain by either the Mauch Chunk shales of the upper portion of the Mississippian or by the Sharon conglomerate of the lower part of the Pennsylvanian series of the Carboniferous. Notwithstanding this considerable difference in age between the lower and the upper portions of the sequence, no recognizable break in the paleontologic characteristics has been discovered, and the beds have, therefore, been referred to a transitional group known as the Catskill-Pocono.

Bright-red shales predominate in the lower portion and green or greenish-gray sandstones in the upper portion, but the two are not separated by any sharp break. The differences are so marked, however, that, notwithstanding the gradual transition, the series has been separated into two formations. The terms "Catskill" and "Pocono" as used in their typical localities are based on distinctions which do not hold in the region under consideration, and new names have therefore been applied. The names here adopted are Cattaraugus and Oswayo, the former embracing the lower or red-shale division and the latter the upper or greenish-gray sandstone division. The Cattaraugus formation is named from Cattaraugus County, N. Y., and the Oswayo formation from Oswayo Creek, which empties into the Allegheny River in the southeast corner of Cattaraugus County. The rocks of both divisions are well represented in the vicinity of Oswayo Creek and elsewhere in the southeastern portion of that county.

Cattaraugus formation.—The Cattaraugus formation is considered as beginning at the first considerable red bed above the Chemung. The point is also marked by a general change from an abundant marine fauna, consisting mainly of brachiopods, to a much less abundant fauna, mainly of fresh and brackish water, and consisting largely of fish remains, ferns, etc. Occasional layers of the formation, however, carry a few salt-water lamellibranchs.

The upper limit of the formation is placed at the top of the uppermost of the prominent and persistent red beds. The actual point at which this transition occurs is variable and does not admit of direct tracing. In general, however, it may be said that all the larger and more important red beds occur within a vertical range of 500 feet above the base of the first prominent red bed, while above this interval only occasional thin beds of relatively restricted area are found. On the map the top of the formation is drawn arbitrarily at the top of this interval of 500 feet.

The rocks of the Cattaraugus formation consist of a practically unfossiliferous succession of red shale and red and brown sandstone interspersed at intervals with gray and greenish shales and sandstones. If the formation is made to include the interval from the lowest to the highest of the persistent red beds, it is probable that the actual thickness of the red material will not exceed one-half of the whole thickness, the remainder being taken up by the green and gray shales and sandstones. The red beds, nevertheless, are the most characteristic and distinctive features of the formation.

Of the gray and green shales and sandstones, the green sandstone is the most conspicuous. This is largely because of its hard and siliceous composition, which causes it to resist erosion and stand out more conspicuously than the softer portions of the formation. When fresh it is of a distinctly greenish color on the exposed surface. It is almost universally cross bedded, the laminæ of both the sloping and the horizontal layers being unusually thin and perfect. Of the gray and green shales, the former predominate and form an important part of the formation. Some of the lighter beds carry ferns and other plant remains. Both shales and sandstones frequently exhibit ripple marks and other shore features.

The character of the Cattaraugus formation, especially the relative amounts of the red and gray or greenish-gray materials, etc., is well shown in the section at Seely Creek, a small tributary entering Lambs Creek from the north about a mile above its mouth, in the northern part of Richmond Township, in the Tioga quadrangle.

Seely Creek section.

(By Andrew Sherwood, Second Geol. Survey Pennsylvania, Rept. G, pp. 79-80.)

CATTARAUGUS FORMATION.

		Feet.
1.	Red shale, 10 feet or more exposed	10
2.	Red sandstone	20
3.	Red shale, somewhat mottled with green, and bands of calcareous rock. Contains fish remains, plants, and shells	4
4.	Red shale	12
5.	Red sandstone	8
6.	Red shale	34
7.	Greenish shale, containing a *Lingula*	4
8.	Concealed	4
9.	Gray sandstone	2
10.	Red shale	20
11.	Gray, calcareous band, containing ten or twelve species of well-known Chemung fossils	0½
12.	Gray sandstone	12
13.	Red shale	6
14.	Gray sandstone	2
15.	Red shale	5
16.	Greenish shale	4
17.	Red sandstone	15
18.	Red shale	5
19.	Red sandstone, 10 feet exposed	10
20.	Concealed, at the junction of red and gray rocks known as Chemung and Catskill; estimated thickness	100
21.	Gray Chemung shale, containing a bed of iron ore, 18 inches thick (bottom of section)	15
	Total	292½

The red shales of the Cattaraugus formation come in with the greatest suddenness and in strongest development in the southeastern portion of the area. Here single beds of red materials, consisting of alternating shales and sandstones, up to 100 feet or more in thickness, have been noted. To the west and northwest, however, the red beds are much thinner and are separated by more pronounced beds of other material.

The rocks of the Cattaraugus formation are most widely distributed in the northern half of the Elkland quadrangle, where they occupy the central portion of the syncline along the Cowanesque River. The next definite belt is along the south flank of the broad anticline covering the northern portions of both quadrangles. Starting about 1½ miles southeast of Jackson Summit, at the eastern edge of the Tioga quadrangle, the belt extends with a trend a few degrees south of west across both quadrangles, crossing the Tioga River a little above Tioga, passing through Hammond, Keeneyville, etc., and finally leaving the Elkland quadrangle near Azelta. On the south side of the Tioga–Crooked Creek mountain belt the Cattaraugus rocks extend in a belt nearly parallel with the preceding, starting near Mill Creek at the eastern edge of the Tioga quadrangle and passing a little north of Lambs Creek into the northern portion of Charleston Township. In the Elkland quadrangle they are well developed along Marsh and Crooked creeks and their tributaries. The southern belt connects with the preceding through the valley of Crooked Creek, in the Elkland quadrangle, and Hills Creek, Tioga River, and Mill Creek, in the Tioga quadrangle. Slight thicknesses of Cattaraugus rocks are exposed on the southern flank of the anticline in the higher of the hills along the southern edge of the Tioga quadrangle.

Oswayo formation.—The Oswayo formation includes the thick series of green and gray sandstones and shales with occasional thin beds or lenses of red shales lying above the uppermost of the stronger red beds and below the Mauch Chunk formation. The total thickness is not far from 1100 feet.

The green or greenish-gray sandstones predominate, and because of their siliceous character frequently stand out on the hill and mountain sides as distinct shelves and tables. On the exposed surface the sandstones are generally of a distinctly greenish-gray color. Internally, however, they are of a dirty-buff or brown color, distinctly argillaceous, and frequently specked with limonitic spots, probably due to the decomposition of minute crystals of pyrite. On continued exposure to the weather the sandstones seem to lose their greenish tinge and become light gray, presumably because of the washing away of the finer products of disintegration and decay, leaving only the insoluble quartz to show upon the surface. Like those of the Cattaraugus formation, the Oswayo sandstones are almost invariably cross bedded, and are characterized by minute mica plates along the lamination planes. In fact, the greenish sandstones of the two formations are so similar that it is impossible to distinguish them by lithologic characters. Ripple marks and other shore features are not uncommon.

The upper portion of the Oswayo formation grades insensibly into the Mauch Chunk where the latter is present, sandstones of the Oswayo type continuing to appear interbedded with red and green shales as far up as the Sharon conglomerate. On the map, however, the boundary of the Oswayo formation is placed just below the point at which decidedly red beds begin to reappear.

The rocks of the Oswayo formation are limited to the uplands along the Tioga–Crooked Creek mountain belt and to a few of the higher points of the mountain along the Cowanesque River in the western portion of the Elkland quadrangle.

CARBONIFEROUS FORMATIONS.

Mauch Chunk formation.—On the hills on both sides of the headwaters of Painter Run, near the eastern limits of the Tioga quadrangle, and directly below the Sharon conglomerate, there is a series of red and green shales and sandstones, including a bed of iron ore and at least one of fire clay. Although no fossils have been found in these beds, their strong physical resemblance to the Mauch Chunk and their occurrence in the proper position point strongly to the probability that they belong to this formation, and they have been so mapped. The thickness as measured from the lowest recognized red bed overlying the Oswayo appears to be a little over 100 feet.

The following section, which was determined by surface indications and one or two pits, shows something of the character of the upper portion of the formation. It starts at the top of the hill east of Painter Run, the upper bed being a few feet below the horizon of the Sharon conglomerate.

Section of Mauch Chunk formation near Painter Run.

	Feet.
Small residual blocks of Sharon conglomerate.	
Shaly sandstone, etc	10
Coarse, green, thin-bedded sandstone	10
Argillaceous iron ore (limonite)	2
Pure bog iron ore	4
Shaly sandstone, etc	10
Fire clay	?
Shaly sandstone, etc	10
Red shale	5
Shaly sandstone, etc.	

Red and green shale beds of the Mauch Chunk formation have been recognized in the crest west of Painter Run and on the crest between the Tioga River and Stephenhouse Run in the Tioga quadrangle. Beyond a slight show of red soil 80 feet below the Sharon conglomerate at the head of Baldwin Run, no indication which could be taken as pointing to the presence of Mauch Chunk beds was noted in the Elkland quadrangle. As there is strong probability of an unconformity at the base of the Sharon conglomerate which may cut out the Mauch Chunk at times, the latter formation has been mapped only where its presence is well established by characteristic outcrops.

Pottsville formation.—The Pottsville is the uppermost of the formations exposed in the Elkland and Tioga quadrangles. In this region it may be separated into two main divisions, the lower consisting of a well-defined conglomerate from 60 to 100 feet thick, known as the Sharon conglomerate, and the upper consisting of sandstones and shales resting upon the conglomerate and identified by plant remains, found by Mr. David White in a neighboring locality, as Pottsville in age.

The Sharon conglomerate is composed almost entirely of quartz and is frequently a coarse sandstone rather than a conglomerate. The pure white color of the grains and pebbles of quartz gives the rock a bright, almost white appearance, quite different from that of other rocks with which it is associated. Though sometimes thin bedded, it is commonly massive in character, and gives rise to somewhat conspicuous cliff-like outcrops. This cliff-forming character, however, is not nearly so prominent in the Elkland and Tioga quadrangles as at many other points in the State, and is apparently confined to certain of the more massive layers, which do not necessarily occur at exactly the same horizons in different localities.

The bed of conglomerate, though extremely resistant to the action of weathering and erosion, is much broken in places. This is probably due in large measure to the weathering out and removal of the softer and more easily eroded beds underlying the conglomerate, which is thus left unsupported. Large bowlders are frequently broken off and slide downward, burying the slopes with accumulations of débris.

The conglomerate caps several of the crests of the mountain belt west of Niles Valley in the southern portion of the Elkland quadrangle, but to the east does not occur until the crest west of the headwaters of Painter Run, near the eastern edge of the Tioga quadrangle, is reached. East of the run the conglomerate has disappeared as a bed, but is still represented by bowlders scattered over the top of the hill or occurring in the ravines on its sides.

The upper sandy division of the Pottsville is represented in the area by a few feet of sandstone and shale occurring just west of the head of Big Asaph Run, at the extreme western edge of the Elkland quadrangle.

PLEISTOCENE DEPOSITS.

The deposits of the Pleistocene period in the Elkland and Tioga quadrangles are of two classes: (1) those which were laid down either directly or indirectly through the agency of the great ice sheet which covered the region in the earlier portion of the period, and (2) those which have been deposited through the agency of ordinary stream or other water action since the final disappearance of the ice sheet. The former are known as glacial deposits and the latter as post-glacial or recent deposits.

GLACIAL DEPOSITS.

The glacial deposits consist of materials which were picked up by or dragged along in the bottom of the ice sheet as it moved southwestward across the region, or were transported by its associated streams. The material has all been moved from its original location and is known by the name of *drift*. This drift was deposited directly by the ice, being either set free by the melting of the portion into which it had been frozen, or simply left behind as a sheet beneath the ice as the friction between the drift in the bottom of the moving ice and the overridden surface became so great as to cause lagging and lodgment. The drift liberated by either of these methods usually consists of a heterogeneous mixture, including all grades of material from clay to large bowlders, and is known as *till*. Drift which is not deposited directly from the ice, but which has been taken up, transported, and finally deposited in a more or less distinctly stratified mass is known as *stratified* or *modified drift*. Each class is further subdivided into several types, depending upon minor features of origin.

Of the till deposits two types, the morainal and the till sheet or ground moraine, have been recognized in this area, while the stratified drift includes a part of the morainal deposits, esker and kame deposits, morainal and frontal terraces, and the older clays, sands, and gravels of the valley fillings.

Till sheet or ground moraine.—By far the most abundant of the deposits laid down by the direct action of the ice are those which belong to the class of till known as ground moraine, and which were deposited beneath the ice sheet, as we have seen, by the melting of the basal débris-laden layer or by the lodgment of the débris through the agency of friction.

The till thus deposited consists of a matrix of fine material, derived partly from the old soil and partly from the grinding and pulverizing of the rock fragments, in which are embedded angular and slightly worn fragments of rock varying from mere chips or pebbles to bowlders several feet in diameter. In places this fine material is more or less clayey, but since it is very largely derived from the underlying rocks, that of the Elkland and Tioga region is generally rather sandy. Not infrequently there occur rock fragments which show smoothing, polishing, and striations like those which have been noted on certain exposed rock surfaces and which have resulted from the grinding action of the rock material carried or dragged along at the bottom of the ice sheet. Such erosion phenomena are characteristic of glaciation as distinguished from water erosion or weathering.

One of the striking features of the till of this area, however, is the small amount of wear to which the greater part of the stony material has been subjected. The till is full of fragments of rock as fresh and angular as if but recently broken. Almost everywhere in the cultivated portions of the area one sees piles and fence walls of flat fragments of rock, of which only a small number give evidence of having been ground beneath the ice of the glacier. This angularity is undoubtedly very largely due to the brittle, thin-bedded character of most of the rock of this region, in consequence of which the bowlders, instead of becoming smooth and striated, as would a limestone of ordinary bedding and texture, split up into thin plates which are frequently broken to pieces. Certain layers of the Chemung and Portage formations are of an impure type of limestone which gives somewhat thicker bowlders, sometimes found beautifully polished and striated.

Sections permitting accurate measurements of the thickness of the drift are infrequent, and because of their slight depth are of little value except as indicating the minimum amounts of filling at local points. The frequent outcroppings of the underlying rock strata, however, indicate that the average depth must be very moderate. This is particularly true in the mountain belts, where rock ledges are often exposed. In other parts of the area the lack of these jutting ledges, together with the beautifully rounded contours typical of a well-glaciated region, give the impression that the drift mantle is of considerable thickness; yet even here road cuttings only a few feet in depth are likely to expose the soft shaly beds of the Chemung formation, showing that in reality the forms of the hills are due rather to erosion than to accumulations of drift upon their surfaces.

While it is often impossible to determine with any accuracy the thickness of the till at a given point, there are three distinct belts within the limits of each of which the thickness does not vary greatly from a certain average depth. The southern belt includes the region south of the Crooked Creek–Tioga mountain belt. In this region the till sheet is relatively thin, rock frequently showing through, and the soil over a large part of the area is essentially sedentary in character. The thickness of the till would perhaps average about 6 or 7 feet. Banked along the hillsides facing the Tioga River, however, especially on the west side, there are in places very thick accumulations of till, some of which show a considerable percentage of foreign material.

The second or middle belt includes the area of the Crooked Creek–Tioga mountain belt. The tops of the mountains are destitute of glacial deposits, with the exception of a few transported pebbles and bowlders and occasionally a very thin coating of till. The valleys, however, were in many cases deeply filled by drift deposits, which have subsequently suffered deep cutting and erosion.

In the third or northern belt, which includes the remainder of the Elkland–Tioga area, the till is much thicker than in either of the other two belts. Exposures of thick till are numerous and the surface almost everywhere shows by its topography that the till is relatively thick. Rock outcrops except in ravines are rare. As in the southern belt, the hillsides facing the rivers are often deeply banked with till, which possibly in places along the Cowanesque River reaches a thickness of 100 feet or more. The thickness on the general surface will probably average rather over 10 feet.

Not only is the drift banked up in thick deposits against the sides, but it also occurs as fillings of considerable depth in nearly all the valleys. In all but the broader of these the till constituent of the drift predominates, though important amounts of stratified drift deposited by waters derived from the melting ice sheet and concentrated in the valleys are usually present.

Where considerable deposits of drift occur in the valleys, especially in the deeper-cut valleys of the mountain belts, the slopes do not extend regularly from top to bottom, but part way up the declivities become less steep, forming somewhat indefinite sloping shelves, above which the slopes again rise steeply. The shelves probably represent in many instances the original levels of the drift fillings, into which the sharp, steep-sided channels of the lower portions of the valleys have been subsequently cut. In other cases the shelves may have resulted from irregularities of deposition. The sharp V-shaped valleys are especially characteristic of the tributaries of Pine and Marsh creeks.

In the lower parts of some of the other valleys, such as those of Troups and Jemason creeks in the Elkland quadrangle, the filling is so disposed as to give broad valley bottoms sloping gently to the streams. Both these creeks have been crowded close against the sides of their valleys, and have there cut their channels in drift and rock.

The amount of valley filling is not readily estimated. The streams frequently cut into or expose the underlying rock beds, but this usually occurs where the creek is crowded against one side of the valley. The sinking of water wells, however, shows that at many points the drift is 30, 50, or even 75 feet deep in the middle of the valleys. This filling, it should be remembered, is not all till, but consists in part of stratified drift, which in cases may even form a considerable portion of the deposit.

A feature which attracts the attention of anyone studying the drift of this area is the great preponderance of local material. Only a few scattering fragments have been derived from rocks other than those of the quadrangles or of contiguous regions. Some, however, have been derived from regions as remote as the Adirondacks or Canada. These occur distributed throughout both quadrangles, but are most abundant in the east, though even here only a few scattering fragments can usually be found at a single exposure. To one familiar with the glacial deposits of the Mississippi Valley this extremely local character of the rock fragments is a striking feature. In certain parts of the northern portion of the Mississippi Valley region as much as 10 to 20 per cent of the stony body of the drift was derived from the crystalline rocks of Canada, while sometimes as much as 95 per cent of the surface bowlders came from beyond the Great Lakes.

Retreatal moraines.—Besides the ground-moraine or till sheet which accumulated beneath the ice in the manner already explained, there is another class of drift deposited in direct connection with the ice, which, though perhaps of no more importance, is often more conspicuous. This is the class of deposits known as moraines, the materials of which have accumulated along the margin of the ice sheet at various periods of its history. The deposits occur as irregular patches which often form more or less well-developed belts. The materials consist of both unassorted drift or till and assorted or stratified drift, the former having been set free at the margin of the glacier by melting of the ice, and the latter having been deposited by streams and rivulets issuing from the margin. In the Elkland and Tioga quadrangles the morainal deposits were laid down during temporary halts or slight readvances which interrupted the general retreat of the ice from the region, and are therefore described as *retreatal moraines.*

The morainal deposits are most extensively developed in the Tioga quadrangle, especially along the Tioga and Cowanesque rivers. In places they probably reach a thickness of 100 or even 200 feet. They are generally marked by prominent knolls and hummocks and by irregular or bowl-like depressions known as kettles. Both till and stratified drift are well represented, not only in the moraines as a group but in the individual deposits. For this reason it has not been possible to separate the till from the stratified moraines. It may be said, however, that the stratified material predominates in the majority of the morainal deposits along the Tioga River.

The oldest of the morainal deposits in the Elkland and Tioga quadrangles are those which occur in the southern portions of the area. To the north and northeast they become progressively younger and younger until the limits of the area are reached. In their broader relations the deposits appear to fall into a number of groups, two of which constitute well-defined morainic belts.

The first or oldest group, so far as its deposits are concerned, is the least important, and is limited to a fair-sized area along Elk Run and a few other small patches in the southeastern portion of the Tioga quadrangle. These deposits probably mark relatively short halts in the glacial retreat.

The second group begins at the junction of Mill and Bailey creeks, at the eastern edge of the Tioga quadrangle, and extends westward without any important break to the mouth of Painter Run. From this point to the junction of Lambs Creek and the Tioga River there are thick drift deposits, which do not, however, possess a distinct morainal topography. Farther west the deposits again take on a typical morainic character and continue with a few interruptions as a well-defined belt to the edge of the quadrangle, in the northern portion of Charleston Township. The morainal deposits north of Wellsboro probably mark a continuation of the same group. To this belt, which constitutes the best defined series of morainal deposits in the region, the name Mill Creek moraine is here applied.

The moraine is parallel with the south edge of the Tioga mountain belt, a position which appears to have resulted from the influence of the highlands upon the position of the ice margin. Its deposits reach higher elevations on the uplands than any other similar deposits in the area, and have had a more important influence on the drainage, several of the streams having been forced to seek new and circuitous channels.

The third and youngest group of morainal deposits embraces all those lying behind or to the north of the Mill Creek moraine. Their deposition began with the first retreat of the ice from its position along this moraine; hence the earlier of them are continuous or at least intimately associated with its deposits, especially along Mill Creek and Tioga River. Included in the third group are two rather definite though interrupted bands of morainal deposits, one occurring along the Tioga River north of Tioga and the other along the Cowanesque River and its tributaries to the western limits of the quadrangle. The accumulations are far from continuous and there are grave doubts as to the contemporaneity of the individual deposits of either, since nothing has been seen which gives more than the most local indication of the position of the ice margin.

The morainal deposits near Crooked Creek on the northwest are very largely of till, but at the junction of this creek with Tioga River and along the east side of the latter the stratified materials predominate. The morainal deposits of the latter type appear in many instances to have formed after the ice had become essentially motionless, and frequently grade into flat-topped morainal terraces built up in the more or less open spaces between the ice and the valley walls. An important line of morainal deposits extends along Troups Creek and the Cowanesque River from the western edge of the Elkland quadrangle to the Tioga River, but is broken by a gap 8 miles in length between Knoxville and Elkland. The materials include both till and stratified drift, the former, though not predominating, being in rather larger amounts than in the majority of the morainal deposits of the area. The thickness is known to be as great as 130 feet in the deposits east of Phillips, and probably reaches similar depths southeast of Elkland, and possibly elsewhere. Morainic dams formerly existed across Troups Creek a mile northwest of Knoxville, across the Cowanesque River east of Phillips, at the eastern edge of the Elkland quadrangle, and possibly also at Tompkins and elsewhere.

Till deposits with drumloidal topography.—At several points in the northeastern portion of the Tioga area and also on Elkhorn Creek in the same quadrangle there are accumulations of till in the form of small hills or slopes of drumloidal outline. In general these accumulations occur on the sides or bottoms of valleys, and their longer axes are roughly parallel both with the valleys and with the probable direction of glacial movement. In all cases they are found in regions of thick drift and appear to be associated with typical morainal deposits, along which they occur in belts. Their smooth, rounded surfaces are, however, in marked contrast with the irregular surfaces of the moraines.

The close association of the accumulations in question with the moraines, and the apparent intimate relation between the two kinds of deposits, suggest that the small hills of drumloidal appearance are not the result of ordinary processes of drumloidal accumulation taking place beneath the ice sheet, but have very likely resulted from the rounding action of overriding ice upon morainal accumulations formed during some halt in the advance of the ice or during some earlier local or general recession of the ice sheet. It seems probable that some of the thick till deposits mentioned as occurring banked against the sides of the valleys of the Tioga and Cowanesque rivers may be, in part at least, the overridden remnants of earlier moraines of the same general invasion.

Esker and kame deposits.—The eskers observed in the Elkland–Tioga area are two in number. The first occurs in the extreme northeast corner of Lawrence Township, and is represented in the area covered by the map by a well-defined ridge about 25 feet in height and about half a mile in length. The second is a few miles east of Mansfield, in eastern Richmond Township and the northwest corner of Sullivan Township. At the east it begins as a well-defined ridge 15 or 20 feet in height, leading westward up a tributary of Elk Run. Just below the crest of the divide it becomes broken up into a series of kame deposits, which are interrupted at the crest, but soon begin again on the west side. A little farther down the westward-sloping valley the kame deposits narrow and are succeeded by a single ridge some 20 feet in height, which continues with minor interruptions for a distance of three-fourths of a mile. The eskers consist of fine to coarse gravels which were originally laid down by glacial streams flowing beneath or within or upon the surface of the ice sheet, on the melting of which they were left as the long, narrow ridges described.

Each esker merges at its lower end with a contemporaneous series of morainal terraces, the material of which was supplied by the stream which formed the esker. The deposition of the terraces evidently took place in open channels between the ice and the sides of the containing valleys at a stage of the ice sheet when all motion had ceased.

The manner of replacement of the eskers at their lower ends by the terraces apparently indicates that the esker streams, though flowing between ice walls, were resting upon the valley bottoms at these points, or at least very close to them. The conditions existing at other points in the esker streams, however, were not necessarily the same, and in the case of the esker stream east of Mansfield were certainly much more complex. In this instance the portion of the stream east of the divide probably flowed upon the surface of the stagnant ice; at the divide itself it appears to have flowed in an open channel and to have cut a slight notch in the rock at the crest; while west of the divide there was an open space from one-half to three-quarters of a mile in length, in which was deposited a flat-topped terrace. At the end of this space, at a distance of a little over a mile from the divide, the stream apparently reentered the ice, and continued in it, probably in a tunnel at the bottom of the ice or in an open channel, until it finally emerged at the head of the extensive terraces bordering the north side of Corry Creek.

The kame deposits of the Elkland–Tioga area include, besides the irregular gravel deposits described in connection with the eskers, only a few small deposits of confusedly stratified sands, gravels, etc., occurring in Chatham and Farmington townships in the Elkland quadrangle. They are believed to have been deposited in tunnels or other cavities beneath the ice or in channels near the margin into which flowed the waters derived from the basal portion of the ice sheet.

Morainal and frontal terraces.—By a frontal terrace is meant an approximately level-topped or gently sloping deposit of stratified drift which was laid down in direct contact with the ice margin and between it and the slopes of the adjacent valley walls or hills. Such terraces differ from moraines in that they have generally been deposited in standing water ponded between the ice and the adjacent slopes, or at least in prominent and well-defined streams flowing in similar positions along the margin of the ice. In consequence they are mainly of the nature of ordinary sedimentary beds, and in general exhibit morainal features only along the ice-contact slopes.

The morainic aspect of the topography of the marginal or ice-contact slopes, is, however, frequently a striking feature, and taken in connection with the presence of occasional masses of till and bowlders has given rise to the variety of frontal terraces known under the appropriate name of morainal terraces.

Terraces of this type occur in the sides of all the larger valleys, and are especially well developed along Marsh and Crooked creeks of the Elkland quadrangle, where the morainal character of the margins is unusually pronounced. In the Tioga area high flat-topped terraces occur south of the mouth of Elkhorn Creek and southeast of Tioga Junction. The former extends nearly across the full width of the valley of Crooked Creek.

Where terraces occur on both sides of a valley they rarely possess the same elevation, having apparently been deposited by independent streams flowing on opposite sides of the residual ice tongues. The slopes of the surfaces of the terraces usually correspond to the direction of the slopes of the bottoms of the containing valleys. An exception occurs in the case of the morainal terraces along those portions of Crooked Creek and Tioga River lying within the limits of the Tioga quadrangle. Terraces in these valleys rise in nearly every case to an elevation of about 1180 feet, and were evidently deposited in slack water, the level of which was determined by the height of the divide between Niles Valley and Stokesdale Junction in the Elkland quadrangle, over which the waters ponded in front of the ice sheet lying across the Tioga River to the north made their escape.

Glacial clays.—Clays of a buff or pinkish color and showing irregular contortions of the laminations have been noted in the beds or banks of several of the streams entering the Tioga River from the west in the southern portion of the Tioga quadrangle. They appear to have been deposited in waters ponded in front of the ice margin at a time when it lay across the Tioga River to the north. The contortions (see fig. 8 on Illustration sheet) are believed to be due to the settling and slipping of the water-saturated clays at a period subsequent to the disappearance of the ice.

Stratified valley drift.—In this class are included those deposits of sand and gravel which everywhere underlie the flood-plain silts of the larger streams. These gravels appear to reach an average thickness of perhaps 80 to 90 feet or more, and are believed to consist mainly of materials derived from the débris-laden basal portion of the ice sheet and brought together and deposited by the streams originating in the melting glacier and converging in the main valleys. Occasional wells sunk for water show that the deposits contain considerable amounts of unstratified drift, which at some points replaces the gravels. It also seems likely that in some localities, at least, considerable additions were made to the deposits after the disappearance of the ice sheet, though at present deposition appears to be confined to the building up of the flood plains.

POST-GLACIAL DEPOSITS.

Gravel fans and torrential stream deposits.—The torrential stream deposits consist of gravels composed of large, angular or very slightly rounded fragments, deposited with only rude traces of stratification, though occasionally showing rather distinct shingle structures (see fig. 8). They occur along the beds of streams of moderately steep grade, intermediate between the streams of high grade, the work of which is principally that of erosion, and the streams of very low grade, which are characterized by distinctly stratified deposits of well-rounded material of small size.

The gravel fans consist of similar materials which have been brought down by streams of all but the lowest grades and deposited in fan-shaped deltas at the points at which the velocity of the currents became checked on emerging upon the wide, flat bottoms of the river valleys.

The materials of both the stream and the fan deposits are much too coarse to be moved by the streams in their normal condition, and are transported or deposited only during unusual floods. They are still in active process of formation, a foot or more sometimes being added to some of the fans during a single flood. In most cases it seems probable that very little of the material of the fans was laid down as early as the close of the ice invasion, though the deposits at the mouths of some of the southward-leading valleys may be in part the result of deposition by glacial streams of which the valleys were the lines of discharge.

Marsh deposits.—The marsh deposits of the Elkland–Tioga area are of three types. The first is limited to the flood plains of the present rivers, the second to the broad, flat gravel or sand deposits of certain of the glacial streams. The marsh deposits occupying the abandoned channels of the Tioga and Cowanesque rivers, etc., though not represented on the map, are good examples of the former, while the extensive marshes at the headwaters of Crooked Creek, and probably also those south of Niles Valley and east of Marsh Creek in the Elkland quadrangle, are examples of the latter.

The third type of marsh deposits includes those occurring where the previously existing drainage has been obstructed by deposits of glacial drift. Marshes formed behind morainal or similar drift obstructions occur south of Elbridge in the Elkland quadrangle and in Charleston Township in the Tioga quadrangle, while small marshes formed in shallow basins in the till sheet are found at a considerable number of points, especially in the northeastern portion of the Tioga area.

Flood-plain silts.—The flood-plain silts consist of fine sediments, practically free from pebbles, which have been deposited as a mantle several feet in thickness over the top of the thick glacial and recent gravels which constitute the greater portion of the filling in the bottoms of the larger valleys. They are still in process of formation, receiving new though slight additions at every overflow of the streams.

GEOLOGIC STRUCTURE.

The Elkland and Tioga quadrangles belong to the moderately folded western division of the Appalachian province as described on page 1 under "General relations"—the part lying west and northwest of the Allegheny Front, the western margin of the Appalachian Valley. Westward from the Allegheny Front the folding gradually becomes less pronounced, and finally subsides into the very gently undulating or almost flat structure of southern New York and northwestern Pennsylvania.

The quadrangles under consideration are situated about 40 miles from the Allegheny Front, and are characterized by gentle though distinct folding. The dips throughout the greater part of the area are very gentle, being as a rule hardly appreciable to the eye in the ordinary small exposures. In larger exposures, however, the rocks are seen to possess gentle inclinations, usually from 2° to 4°; in a few instances dips as high as 15° or 20° were noted. These dips, slight as they are, are sufficient, nevertheless, to make a difference of about 2500 feet between the altitude at which beds occur at the bottoms of the deeper synclines and that at which they occur at the crest of the higher anticlines.

The area is crossed by two synclines and two anticlines, which, beginning at the north, may be designated the Cowanesque syncline, the Sabinsville anticline, the Pine Creek syncline, and the Wellsboro anticline. The structure of the folds and the relations they bear to one another are shown in fig. 1 by means of contour lines which give at 100-foot intervals the elevation of the upper surface of the Chemung formation in its relation to sea level. In the anticlinal areas where the top of the Chemung has been eroded the elevations when given are those which the surface would possess if no erosion had taken place. Occasional reference to the figure, in connection with the following descriptions, will give a clearer understanding of the points described. Fig. 4, on page 8, shows the extension of the folds in both directions and brings out more plainly the relations of the structure of the area to that of the adjacent portions of the Allegheny Plateau.

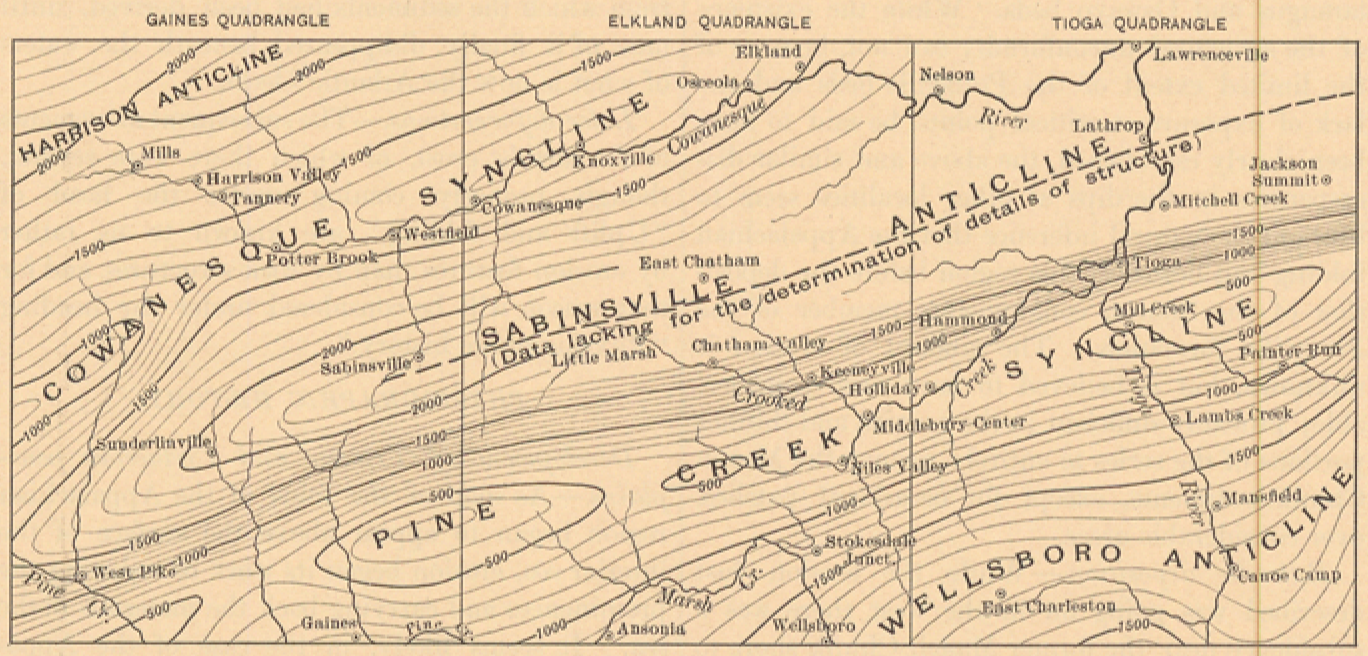

FIG. 1.—Sketch map of Gaines, Elkland, and Tioga quadrangles, showing by contours the structure of the upper surface of the Chemung formation.

Contour interval, 100 feet. Datum is mean sea level.

Cowanesque syncline.—The Cowanesque syncline takes its name from the Cowanesque River, which flows near its axis from the point where the syncline enters the Elkland quadrangle from the west to the point where it leaves the area a little northwest of the village of Elkland. The syncline is deepest near Knoxville, from which it shallows very gradually in both directions.

The rocks of the Chemung formation are exposed in the valleys along the axis of the syncline at all points except near the western edge of the quadrangle, and even here they appear in the side valleys within a distance of a mile or so from its axis. Higher up the hills are composed of rocks of the Cattaraugus formation, a few of the higher crests even showing slight thicknesses of the Oswayo beds.

The dips of the beds toward the axis of the syncline are gentle, amounting to about 200 feet per mile on the north side and from 150 to 300 feet per mile on the south side, the greater occurring near the western limits of the area.

Sabinsville anticline.—This anticline is named from the village of Sabinsville, in Clymer Township, about 1½ miles west of the western boundary of the Elkland quadrangle and near the summit of the anticline. The axis enters the quadrangle a little to the south of the north line of Clymer Township, passes north of Little Marsh and south of East Chatham, and leaves it at a point east and a little south of Elbridge. From this point it extends northeastward into the Tioga quadrangle, crossing the Tioga River near Rising, and leaving the quadrangle a little over 2 miles northeast of Jackson Summit.

The anticline is highest where it leaves the area at the east, though the greatest thickness exposed is probably along the deep cut of the Tioga River, where about 2000 feet or more of Chemung beds are brought to the surface by the anticline. To the west the axis pitches gradually downward at the rate of 50 feet or less per mile until it passes out of the area at the western edge of the Elkland quadrangle. Only 500 feet or so of rocks are here exposed.

In the Tioga quadrangle the Chemung sediments constitute the surface rocks over the entire area of the anticline, but in the Elkland quadrangle occasional patches of Cattaraugus beds cap the hills on the northern flank. The width of the Chemung belt on the uplands at the western limits of the Elkland quadrangle is only a little over 2 miles, but it rapidly increases until at the eastern edge of the area it has a width on the uplands of over 7 miles.

The dips on the north flank of the anticline vary from 150 to 350 feet per mile, and on the south flank they appear to vary from 700 to 900 feet, though considerably greater dips may occur locally.

Pine Creek syncline.—The Pine Creek syncline is named from Pine Creek, a prominent stream which flows for a considerable distance along the south flank of the syncline before it finally turns from its easterly course to a southerly one at a point just south of Ansonia and near the southern limits of the Elkland quadrangle. The axis enters the Elkland quadrangle near the head of Big Asaph Run, and extends across it with a course about N. 75° E. It passes from the Elkland to the Tioga quadrangle near the point where Crooked Creek enters the latter, and continues with a similar course to the eastern edge of the quadrangle at a point about 2¼ miles southeast of Jackson Summit. It crosses Tioga River a little south of the mouth of Mill Creek.

The syncline reaches its greatest depth at the western edge of the Elkland quadrangle, where a few feet of the sandstones above the conglomerate occur. To the east the conglomerate caps the crests for a distance of about 7½ miles. Between this point and the Tioga River the syncline is shallower and the conglomerate is absent. East of the river, however, it deepens again and the conglomerate caps the crest west of Painter Run.

The rise of the beds to the north, as has been seen from the description of the Sabinsville anticline, ordinarily varies from 700 to 900 feet per mile. To the south the rise is much more gentle, varying from 150 to 300 feet per mile.

Wellsboro anticline.—This anticline takes its name from the town of Wellsboro, the county seat of Tioga County, which is located on the north flank of the fold. The axis crosses the Elkland quadrangle at its extreme southeast corner and enters the Tioga quadrangle a little south of Charleston. At this point it has a bearing about N. 35° E., but it gradually swings to the east and south until near the Tioga River it bears a little south of east. East of Canoe Camp, however, it bends sharply to the north, and it passes out of the quadrangle with a course approximately N. 45° E., at a point 4 miles east and between 1½ and 2 miles north of Mansfield.

The steepest of the northerly dips, amounting to about 300 feet per mile, appear to occur near the boundary between the Elkland and the Tioga quadrangle, and near the eastern edge of the latter in the vicinity of the junction of Elk Run and Mill Creek. The gentlest of the northerly dips occur near the Tioga River, where the beds slope at a rate of about 150 feet per mile. The southerly dips are more gentle, being on an average from 100 to 150 feet per mile. The steepest occur at the broad, flat swell of the anticline in the vicinity of Canoe Camp and Canoe Camp Creek.

Structure sections.—The sections on the Structure Section sheet supplement the above description by showing in a graphic manner the probable underground extensions of the beds recognized at the surface. They show the relative positions of the beds and the folds into which they have been compressed, as they would be exhibited if cut transversely by a deep valley or trench along the line at the upper edge of the blank space above the section on the map. The horizontal and vertical scales are the same; hence the hills, the thickness and dips of the beds, the breadth and character of the folds, are shown in the proportions in which they actually occur. In the absence of deep wells, or other underground sources of information, the structure beneath the ground has been inferred from what it was possible to observe on the surface.

GEOLOGIC HISTORY.

ACCUMULATION OF THE LOCAL SEDIMENTS.

DEVONIAN DEPOSITS.

Chemung deposition.—The earliest deposits which appear at the surface in the Elkland and Tioga quadrangles are the fossiliferous sandstones, shales, and thin limestones of the Chemung formation. At the time these beds were deposited, namely, near the close of the Devonian period, nearly the whole of the southern half of the interior portion of what is now the North American continent was covered by the waters of a great interior sea, which, however, maintained a connection with the open ocean in the far north and also at times with the present Gulf of Mexico. It was in a great bay of this sea which extended across western and central Pennsylvania and southern New York that the deposits of the Chemung were laid down. The land from which the sediments were derived was situated to the east of the present Appalachian Mountains, the highest points in the northern portion of the province being probably not far from the present coast line of the Atlantic. To the south the Devonian land is known to have been low and flat, and it seems likely that in the north the relief was likewise rather moderate.

The waters of the bay in which the deposition took place were comparatively shallow, as is attested by the somewhat sandy character of the sediments and by the presence of ripple marks and cross bedding resulting from the action of currents of some strength. That the water in the Pennsylvania and New York region was clear and salt, and not fresh or brackish, or charged with silt, as was the case during the same period farther south, and also in the north during the deposition of a considerable portion of the overlying Cattaraugus and Oswayo formations, is attested by the presence of an especially abundant marine fauna.

A characteristic feature of the Chemung formation is the great number of alternations of material which it exhibits. It is true there are no indications of marked or extensive changes of condition; but the rapid alternations of the thin beds of shales and sandstones, with occasional thin limestones, are indicative of fluctuations great enough to affect deposition, though probably the changes were mainly of a local nature. These rapid changes in the northern areas were again at variance with the conditions existing farther south, which were fairly constant during the corresponding period of time

DEVONIAN-CARBONIFEROUS TRANSITIONAL DEPOSITS.

CATSKILL-POCONO GROUP.

Cattaraugus and Oswayo deposition.—The deposition of the Cattaraugus beds was preceded or accompanied by a somewhat marked change of physical conditions. The salt-water deposits of the Chemung gave place, as attested by ferns, fresh-water fishes, etc., to the fresh- or brackish-water deposits of the Cattaraugus formation. The waters at the same time doubtless became much shallower, as indicated by the greatly increased frequency of cross bedding, ripple marks, rain prints, and other shore features, apparently indicating a more or less complete separation of the embayment from the open interior sea.

Whether this change was brought about by a cessation or a temporary reversal of the movement of subsidence which had been going on during the deposition of the Chemung and earlier sediments, or by the rapid accumulation of the sediments themselves, resulting from an increased rate of erosion due to an increase in the elevation of the land area, is not fully understood. It is known, however, that the deposition which marks the advent of what are usually known as Catskill conditions did not take place at the same time throughout the areal extent of the formation, but was earliest in the eastern portion of the embayment and became progressively later as the distance from the eastern margin increased. In eastern New York the deposition of the peculiar deposits is believed to have begun just after the close of the Hamilton, and as time elapsed and the conditions became favorable the Cattaraugus beds were deposited farther and farther west. It was probably not until near or possibly after the close of the Devonian, however, that conditions favorable to the deposition of red beds came into existence in western New York. In the Elkland-Tioga region the Catskill conditions were inaugurated after 2000 feet or more of Chemung sediments had been deposited, and continued at least to the close of the Devonian, and probably well into the Carboniferous period.

Fluctuations of the conditions of deposition were probably less frequent during the deposition of the Catskill-Pocono group than in the Chemung. This is indicated by the less frequent changes in lithologic character in the former group, and the greater thickness of the component strata. The greater thickness, however, may have resulted entirely from greater rapidity of deposition in the Catskill-Pocono group, due to the fact that the accumulation took place close to the shores of the lands from which the materials were derived. The supply of material was also probably greater because of acceleration of land erosion due to the slight uplift which appears to have accompanied the inauguration of Catskill conditions.

The red Cattaraugus shales, which are the earliest of the deposits accompanying the introduction of the Catskill conditions, gradually disappear, the sandstones at the same time rapidly increasing in importance and constituting the sandy formation known as the Oswayo. The change from one to another, however, takes place without recognizable break, indicating the absence of any abrupt change of conditions at the opening of the Carboniferous period.

CARBONIFEROUS DEPOSITS.

Mauch Chunk deposition.—Following the deposition of the Oswayo sandstones, which carry relatively little shale, there appears to have been a return to conditions similar to those existing during the accumulation of the deposits of the Catskill type. As in the case of the Catskill deposits, the sediments were thickest in the east, and decreased gradually from a maximum of about 3000 feet in the region of the anthracite fields of Pennsylvania to nothing in the northwestern part of the State. To the east the sediments were evidently deposited not far from shore, and though prevailingly of red and green shale, also include considerable thicknesses of gray, greenish, buff, and even carboniferous sandstones. To the west the series is less sandy and the shales become distinctly calacareous and include thin beds of impure limestone, apparently indicating deeper-water conditions. In the region about Gaines the red and green shales corresponding in position to the Mauch Chunk are not over 40 feet in thickness at the most, and may be considerably less.

Pre-Pottsville deformation and erosion.—The deposition of the Mauch Chunk shales appears to have been followed by a period in which deposition ceased and the clays just laid down were more or less extensively eroded. In the Elkland-Tioga region the Mauch Chunk beds have been recognized only in occasional patches, and the entire lower and middle portions of the Pottsville formation are missing, the Sharon conglomerate, constituting the lowermost member of the upper division of the Pottsville, resting either on the Mauch Chunk shales or on the Oswayo sandstones.

Two hypotheses have been advanced to account for the absence of the lower and middle Pottsville deposits and the erosion of the Mauch Chunk shales. The first postulates strong currents sweeping around the borders of the embayment from the southwest and receiving and partially distributing sediments from the land on the southeast and east. No sediments are supposed to have been received from the north, the action of the currents on the north side of the embayment being almost entirely one of scour. The second hypothesis postulates a bodily uplift of the region, bringing all but the southern and eastern portions of the floor of the former embayment above the level of the waters, where it was subjected to erosion by streams or waves.

The uplift, which is here considered as the more probable cause of the Mauch Chunk-Pottsville unconformity, is generally supposed to have taken place without noticeable folding. In the Gaines quadrangle, bordering the Elkland on the west, however, there are phenomena which appear to indicate that this suggestion is not correct. Thus, in the region about Gaines and Gurnee, in the southeastern portion of the Gaines quadrangle, it was found that the dips of the Pottsville conglomerate were only from a third to half as great as the calculated dips of the Chemung and the conformable Cattaraugus and Oswayo beds. While the existence of the structural unconformity can not, because of the limited extent of the Pottsville beds and the lack of exposure at critical points, be said to have been clearly established, the above and similar discrepancies in the dips at other localities seem to bear out the natural inference that the Appalachian folding had begun in this region before the deposition of the Sharon conglomerate member of the Pottsville formation. The amount of erosion is unknown, but is believed to have been considerable; probably sufficient in the western and thinner portions of the series to entirely remove the Mauch Chunk sediments, except for occasional patches, over considerable areas.

Pottsville deposition.—While the erosion just described was going on in the west, there was a subsidence near the former Mauch Chunk shore to the east, and the lowest of the Pottsville beds, consisting of materials derived from the adjoining Archean lands, were laid down. It was considerably later when the subsidence, which once more carried the eroded surface of the Mauch Chunk beds below the level of the sea, extended to the western portion of the State. The Sharon conglomerate, constituting in the Gaines region the lowest of the Pottsville beds, and known from the paleobotanical evidence of the associated sandstones to belong to the upper division of the Pottsville, did not begin to be deposited until after many hundred feet of Pottsville sediments had been laid down in eastern Pennsylvania.

After the deposition of the Sharon conglomerate the conditions during the deposition of the remainder of the Pottsville sediments were somewhat unsettled. Periods of submergence, marked by the deposition of sandstones, alternated with periods of slight uplift, during which considerable areas were cut off from the sea, and fresh-water vegetation, now marked by the black shale and coal beds, flourished upon their surfaces. These alternating conditions continued throughout the Pottsville, and in fact throughout the remainder of the Carboniferous period, during which many hundred feet of sandstones, shales, limestones, etc., were laid down.

UPLIFT AND FOLDING.

Appalachian revolution.—The deposition of the thick sediments of the Carboniferous was accompanied by a gradual subsidence of the sea bottom; a process which is essential to the accumulation of great thicknesses of strata, since otherwise the sea basin would soon be filled and deposition would practically cease.

The depression thus inaugurated constituted a zone of weakness, and under the application of lateral pressure its beds were compressed into broad and often steep folds and broken by the great fractures or faults which are so characteristic of the Appalachian province. The beginning of the folding, if the interpretation of the conditions of unconformity near Gaines is correct, began as early as the close of the deposition of the Mauch Chunk beds, but it did not attain its maximum until near the close of the Carboniferous period.

The extent and complexity of the folding and faulting are greatest in the east, or near the coast line of the interior sea. It was here, in close proximity to the shore, that the sediments accumulated in greatest thickness, that the subsidence and weakening of the crust were greatest, and that, consequently, the effect of lateral or tangential pressure met the least resistance. In this portion of the Appalachian province the difference in elevation between the crests and troughs of the folds is often several thousand feet, and the faults are of great length and magnitude. To the west and north the folding gradually becomes less severe and complex. Sharp folds give place to the open folds and gentle undulations of the western portion of the province; faulting becomes less frequent, and finally ceases almost entirely. It is in this gently folded region that the Elkland and Tioga areas lie.

Accompanying the development of the folds of the Appalachian region, constituting what is known as the Appalachian revolution, there was a general bodily uplift of the whole interior of the continent, the result of which was to lift its surface above the water and to bring to a close the history of this great interior sea. At the same time it is believed that there was a sinking of the eastern land mass from which the sediments had been derived, until most of it finally disappeared beneath the waters of what is now the Atlantic Ocean.

Later deformations.—The subsequent movements of the earth's crust, of which there were several, though properly coming under the head of "Uplift and folding," are known to us rather by erosion features than by rock structures, and for that reason will be considered under the heading "Physiographic history."

PHYSIOGRAPHIC HISTORY.

Development of Triassic and Cretaceous peneplains.—As soon as the folds of the Appalachian region began to appear above the surface of the interior sea, erosion began its work of reducing the prominences and carrying back the materials to the sea. It seems likely, in the case of the Appalachian Mountains, that erosion did not keep pace with the uplifting of the folds, but that more or less pronounced elevations soon began to appear and to increase in prominence as long as the folding continued. After the cessation of the folding the land is believed to have remained fairly constant in elevation during the remainder of the Carboniferous and early Triassic times. In this interval erosion progressed rapidly, though to exactly what extent is not established. It is known, however, that the Newark beds of later Triassic times, which occur at intervals along the Atlantic border, rest upon rocks reduced by erosion to a flat or gently rolling surface, known to geologists as a peneplain.

The uplift, accompanied by the tilting and faulting of the Newark beds in late Triassic or early Jurassic times, partly destroyed the effect of previous erosion. Erosion in the new cycle proceeded vigorously, with the result that the continental border had been so reduced in late Jurassic or early Cretaceous times that a slight subsidence allowed the sea to advance and cover with deposits of Cretaceous age the wide, flat or undulating lowlands reaching to the base of the highlands then existing near the present limits of the coastal plain. Erosion, however, continued its attack on the remaining highlands with undiminished energy until in late Cretaceous times they had been reduced to a peneplain—the Cretaceous peneplain—on which the folds of the Appalachian region were represented, if at all, only by broad, low, flat hills, the component strata, both hard and soft, and of all ages, being alike cut down to the peneplain level. The highest point of this peneplain, in the north at least, is supposed, on the ground of drainage indications, to have been in northern Pennsylvania or southern New York, from which region the land probably sloped away in all directions. An idea of the nature of the peneplain surface may still be obtained from the top of one of the flat-topped mountain crests. Viewed from such a standpoint, the crests of the mountain belts everywhere appear to reach the same general level, and the irregularities, which when seen close at hand sometimes seem to be important, appear in their true nature when viewed from a distance—as simply slight undulations in the upland surface. All except the nearest of the valleys, though perhaps a thousand feet deep, disappear from view, and one apparently looks out over a very gently undulating, almost featureless plain covered with forests. This apparent plain is probably a close reproduction of the appearance of the original plain before the erosive action of the stream had begun to cut into it, and to wear it away until only the flat-topped ridges and mountains remain to show the position of the old land surface.

Early Tertiary peneplain.—In the description of the topography of the Elkland-Tioga region it was shown that there are evidences of the existence of old surfaces at two distinct elevations, the higher one marked by the flat-topped crests of the mountain belts and the lower by the higher of the hills of the broad belts of soft Chemung rocks. There are two explanations by which these features may be accounted for. The first assumes both the higher and the lower of the apparent surfaces to have been contemporaneous in development, and to represent the limits of variation of a single surface, while the second explanation assumes that only the upper level, marked by the mountain crests, is to be correlated with the Cretaceous peneplain, the lower level being referred to an early Tertiary, possibly Eocene, period of local peneplanation.

The objection to referring the two apparent levels to a single surface lies in the fact that the range of elevation, amounting to from 200 to 400 feet, indicates an incomplete peneplanation not in harmony with the extremely uniform level exhibited by the remnants of the old surface presented in the flat-topped mountain crests. Another strong objection which has been urged against the Cretaceous age of the general surface of the region is its comparatively youthful aspect. Notwithstanding the very moderate resistance of the rocks of the region to erosion, considerable remnants of the old peneplain surface are preserved practically without modification, while, except in the areas of the softer Chemung shales, the valleys are still sharp and V-shaped.

The topography of the area, as shown in the discussion of the relief, appears to point to a southeastward slope of the supposed lower peneplain level at a rate of about 200 feet in the length of the quadrangle. No accurate maps exist covering an area equivalent to four quadrangles lying to the southeast, but in the vicinity of Sunbury, at the forks of the Susquehanna, there are evidences of a former rather well-defined surface developed on the softer rocks at a level of about 900 feet. This elevation accords well with the assumed southeastern slope of the supposed early Tertiary peneplain. In the next two quadrangles to the south the slope continues, with increased grade, until in the neighborhood of Harrisburg it has a level of about 500 feet.

The evidence, therefore, so far as it goes, points to the probable existence in the Elkland-Tioga region of remnants of two peneplains, an upper peneplain of Cretaceous age and a lower peneplain apparently to be correlated with the peneplain developed on the softer belts on each side of the Susquehanna in early Tertiary time.

The vertical interval between the upper and the lower peneplains varies from about 400 feet in the Elkland-Tioga area to 1100 feet in the vicinity of Harrisburg, and probably about 1200 feet in the southwestern portion of the State. This would indicate that previous to the last prominent uplift the remnants of the Cretaceous peneplain stood at an altitude of about 1100 feet above the later plain in southeastern Pennsylvania, but not more than 400 feet above it in the Elkland-Tioga region. What the altitude may have been relative to sea level can not be told, but it is probable that it was not much in excess of the figures indicated. The uplift following the development of the Tertiary peneplain, as indicated by the present altitude of its remnants, reached its maximum in the north, instead of in the south, as was the case of the early uplift, and resulted in a partial, or, as in certain regions in central Pennsylvania, nearly complete restoration of the Cretaceous peneplain to a horizontal position.

Development of drainage in the Elkland-Tioga area.—The slopes bordering the streams in the synclinal areas of the relatively resistant rocks rise abruptly and without break nearly to the level of the plateau-like remnants of the Cretaceous peneplain. A moderate broadening may apparently be detected, however, about 100 feet below the highest level of the older peneplain, and is probably to be regarded as marking the position of the valleys during the period of development of the later peneplain. This feature is confined to the vicinity of the present valleys, indicating that the major drainage lines of the present time agree essentially with those of the Cretaceous and Tertiary peneplains.

It is thought that the agreement of the present with the early drainage is probably a general feature throughout this portion of northern Pennsylvania. If so it would indicate that in the development of the Cretaceous peneplain the larger streams, though exhibiting a general tendency to follow strike lines, did not occupy either the synclinal troughs, as the original consequent streams of the newly folded regions must have done, or the soft and easily eroded anticlinal areas of Chemung rocks, as a completely adjusted system would have done, but usually took an intermediate position at one side of the hard rocks occupying the center of the syncline. In some instances, however, such as those of the Cowanesque River and the stream draining the Blossburg syncline (see fig. 4), the drainage was consequent, the streams flowing for some distance along the very center of the synclines. To what extent the courses of the transverse streams have been influenced by the outcrops of the folded beds is not apparent, though it seems probable that in the Elkland-Tioga region the influence has been very slight. In fact, although in its broader relations the development of the present drainage appears to have been dependent to a considerable extent upon the geologic structure, its minor features show very little relation to it.

The present drainage lines, coinciding as they do with those which existed on the surface of the older peneplain, may be said to have been inherited from that surface. Further back than that, little is known beyond the existence of the general relationship of the drainage to structure.

Uplifting and erosion of later peneplain.—After the development of the lower and younger of the peneplains, the completion of which is assigned provisionally to early Tertiary times, possibly Eocene, there occurred an uplift, accompanied by tilting and slight warping, which elevated the surface to a position not far from that which its uneroded remnants still occupy. The result was an increased activity of the streams, which began the cutting of deep and canyon-like gorges, first in their lower courses and later nearer their headwaters. This erosion, though affected by a number of oscillations of level in late Tertiary or Pleistocene times, has continued until the present, and has produced the topography which now exists.

The uplift which inaugurated this period of erosion appears to have culminated at a point some distance northwest of the Elkland-Tioga area. Within this area the slope was to the southeast and averaged between 11 and 12 feet per mile. The tilting appears to have been sufficient to change the general slope of the peneplain from a north-eastward direction, as indicated by its drainage lines, to a southeastward direction, but the uplift was not rapid enough to reverse the drainage. In fact, the effect of the southward slope is shown chiefly in the greater activity of the southward-flowing streams, as recorded by their greater length and their greater erosive effects. This relationship of length to direction of flow is well brought out at several points in the surrounding region (see fig. 4), but is not conspicuous in the Elkland-Tioga area itself.

Later Tertiary events.—It has been frequently urged among geologists that the advent of the earliest Pleistocene ice sheet was preceded by a general uplift of the northern half of the continent, affecting the surface throughout the northern portion of the United States. In western Pennsylvania, however, the presence of Pleistocene river gravels on rock terraces several hundred feet above the bottom of the present gorge of the Upper Allegheny River indicates that the last stage of active erosion did not begin there until after the first ice invasion, though the uplift and the inauguration of the erosion in the lower reaches of the river may have been somewhat earlier. The uplift recorded by the rock terraces immediately adjacent to the Susquehanna in the eastern portion of the State is of questionable date, but would appear to be of late Tertiary or early Pleistocene age.

In the Elkland-Tioga region there appears to be a slight notching in the bottom of the old valley of Pine Creek and some of its tributaries, but it is believed that this was not produced until after the southward deflection of the lower portion of the creek through the gorge south of Ansonia. This diversion, as will be described more fully in the discussion of the earliest glacial stage, was probably due in great measure to the accumulation and overflow of waters ponded in front of the advancing ice sheet, and the consequent reduction of the divides and the cutting of a new channel in which the stream persisted even after the ice had disappeared. The notching of the bottom of Pine Valley and its branches was a result of the diversion through the new and lower channel, and affords, therefore, no evidence of uplift.

GLACIAL HISTORY.

From the phenomena of erosion, transportation, and deposition, of a character known to be associated with glacial action, it has been established that most of the northern half of North America was covered in comparatively recent (Pleistocene) geologic times by great ice sheets similar to the sheet now covering the greater part of Greenland.

The phenomena associated with the ice invasion consist of certain peculiar superficial deposits of clay, sand, gravel, and bowlders, known as *drift*, and certain scourings and groovings of the surface of the underlying rocks, evidently due to some agent like a glacier furnished with rock fragments which were pushed or dragged along over the surface upon which it rested. The examination of these deposits over the vast area covered by the ice leaves no reasonable doubt that this was their general mode of origin, though parts of the material, it is equally clear, were deposited through the agency of glacial waters. The two types unite to form a nearly continuous mantle, indiscriminately overlying rock formations of all characters and ages.

Glacial stages.—While the fact is not usually apparent from a superficial study of the drift, a detailed examination of its structure and of its general distribution and associations shows that instead of a single sheet formed by one ice advance there are in reality several distinct drift sheets, each of which represents a separate ice advance.

The intervals of deglaciation or disappearance of ice between these ice advances are made apparent by the presence of soils and beds of peat and marl and other effects of life, and also by the weathering of certain zones now buried in the midst of drift deposits; while the sheets themselves differ markedly in extent and often in color, composition, and other physical properties. These differences, together with the morainal ridges marking the various positions of the ice margins, form a basis for the subdivision of the Glacial epoch in North America into nine divisions, as follows:

Outline of Glacial stages.

1. Pre-Kansan or sub-Aftonian glaciation.
2. Aftonian deglaciation.
3. Kansan glaciation.
4. Yarmouth deglaciation.
5. Illinoian glaciation.
6. Sangamon deglaciation.
7. Iowan glaciation.
8. Peorian deglaciation.
9. Wisconsin glaciation (latest stage).

Of the drift sheets of the various stages described, only two have been recognized in Pennsylvania, and of these only one can be assigned with certainty to a definite stage. This is the main drift sheet covering the northern part of the State and including the Elkland and Tioga quadrangles. It is assigned to the Wisconsin stage. The other recognized drift consists of scattered fragments or a thin sheet deposited by ice and its associated drainage beyond the moraine marking the southern limits of the Wisconsin drift. From its weathered character it is believed to belong to the Kansan or pre-Kansan stage. The distribution of both drifts is shown in fig. 2.

KANSAN OR PRE-KANSAN INVASION.

Advance of the ice.—The cause of the accumulation of the glacial ice and its spread over so large a part of the northern portion of the continent is not as yet determined. It is known, however, that an ice sheet came into existence in the northern portion of the continent and spread southward, as has been seen, into the latitude of northern Pennsylvania (see fig. 2).

Obstruction and deflection of drainage.—When the ice margin advancing from the northeast reached the lower portion of the Tioga River near Corning, N. Y., the natural outlet for the waters of that river and its tributaries, draining the Elkland-Tioga area and the whole of the northern and eastern portions of Tioga County, was obstructed, and a series of long, narrow lakes similar to the Finger Lakes of New York, but more crooked, came into existence in the valleys of the Tioga and its larger tributaries. The water in these branching lakes must have continued to rise until it finally overflowed at the lowest divide and passed off to the south into the Susquehanna. The lowest divide appears to have been about 2 miles south of Ansonia. Its elevation can not now be determined, but it had probably undergone a great reduction by the backward cutting of the headwaters of the southward-leading stream in consequence of the uplift and tilting of the Tertiary peneplain.

When on the continued advance of the ice the margin reached the lower portion of the Cowanesque River, the arm of the early lake occupying its valley became a separate lake, which continued to rise until it found a divide at the head of Jemason Creek, 3 or 4 miles east of the western limits of the Elkland quadrangle. The elevation appears to have been originally 1600 or 1700 feet, but it was gradually reduced as the waters continued to pour over its crest. On the closing of this outlet by the advancing ice a new one was opened at an elevation of probably 1800 feet or more over the divide between Mill Creek and Long Run in central Clymer Township, about 3 miles west of the limits of the Elkland quadrangle. This in turn continued to suffer reduction by the escaping waters until the advancing ice covered the region and brought the first chapter of the history of the lakes to an end.

Drift deposits.—So thin is the early drift sheet in this part of Pennsylvania that it is only rarely that any direct glacial deposits of the early stage, even a few feet thick, are to be observed, and over a large area an occasional ice-transported fragment from the north is all that there is to indicate the former presence of the ice. It seems likely, from the attenuated nature of this drift, that the ice of the first invasion remained but a short time in the region, since otherwise much more material would have been brought from the north and deposited by the ice; though the alternative view that the deposits were originally of considerable thickness and have since been materially reduced by erosion is maintained by some.

The thinness of this drift has also made it very difficult to determine the exact limits of the first ice invasion, though it seems probable that it reached considerably beyond the southern limits of the Elkland-Tioga area. North of the southern limits of the Wisconsin advance, the effects are still more obscured because of the deposits of that invasion, and so far as can be seen at the surface the glacial phenomena appear to have been the work solely of the latter invasion.

INTERVAL OF DEGLACIATION.

With the cessation of the conditions favorable to the existence of the ice sheet the latter drew back to the north and possibly quite disappeared from the continent. During this retreat it is probable that series of events took place similar to those which occurred during the advance, but in reversed sequence. It is not improbable that the lakes were of shorter duration than the earlier ones, and that the divides over which the waters escaped suffered relatively little reduction at that time. The character of the topography of the divide south of Ansonia is such that it appears probable that its origin antedates the Wisconsin stage, and it seems likely that the reduction had proceeded so far at the close of the Kansan stage that the pass afforded even then the easiest outlet for the waters of upper Pine Creek.

Upon the disappearance of the ice sheet, streams and the atmosphere began their work on the glacial deposits, and in some parts of Pennsylvania even on the underlying rocks, with the result that extensive channels were eroded in places and such drift as remained was deeply weathered and leached of its calcareous constituents. This weathering is especially noticeable in the almost completely disintegrated crystalline fragments, and is in marked contrast with that of similar fragments in the Wisconsin drift, which show almost no evidence of decay. The disintegrated and decayed state of the materials of this early drift indicates a long exposure to the weather, and taken in connection with the extensive erosion which is known to have occurred in many places since their deposition, has led most geologists to believe that the time interval between their deposition and that of the Wisconsin drift is many times as long as that which has elapsed since the latter drift was laid down. The long intervening time was marked, farther north at least, by stages of glaciation, when the ice readvanced over the soils, vegetation, and older drift deposits, and by intervals of deglaciation, when the ice retreated far to the north, or even completely disappeared. None of these advances are known to have reached beyond the limits of the Wisconsin drift in the Pennsylvania region.

WISCONSIN INVASION.

Advance of the ice.—The recurring conditions favorable to glaciation at length produced an ice sheet during the Wisconsin stage which, starting in the north, spread southward and reached well into Pennsylvania. The limits of this invasion are shown on the sketch map of Pennsylvania (fig. 2).

Direction of ice movement.—As in the earlier invasion, the general movement of the ice was from the northeast toward the southwest (fig. 2). The local movement, however, was probably more or less dependent upon the configuration of the surface over which the ice passed, and varied from S. 10° W. to due west. The location and direction of observed striæ are shown on the Surficial Geology maps. Across the flat uplands, as west of the head of Baldwin Run in the Elkland quadrangle, the direction of movement was only about 10° from due south; but at other points the ice was deflected through the influence of the east-west stream valleys until in some cases the ice movement was nearly due west. Such valleys had a maximum influence on the ice motion during the opening and closing stages of the invasion, when the sheet was relatively thin, and a minimum influence when the ice was at its maximum development. The diverging striæ are probably also to be explained, in some cases at least, by the irregular movements of

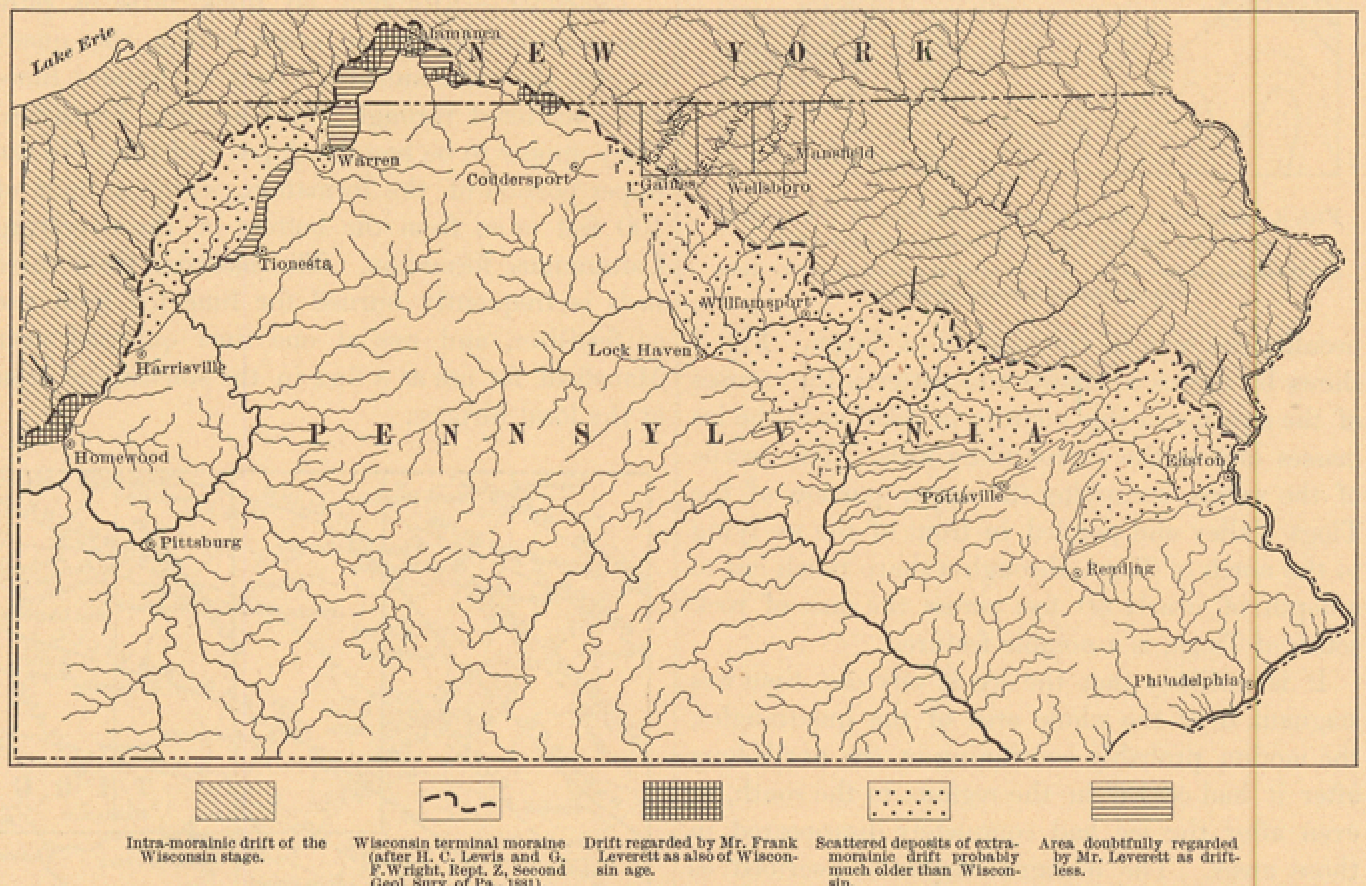

FIG. 2.—Sketch map showing the distribution of the glacial deposits of Pennsylvania and adjoining portion of New York. Compiled by Wm. C. Alden, 1901.

Arrows indicate direction of glacial striæ.

The limit of the extra-morainic deposits west of Coudersport is by Mr. Leverett; that east of Coudersport is by Prof. Edward H. Williams, jr., who regards this drift as of comparatively recent age (Am. Jour. Sci., vol. 149, 1895, pp. 174-185, and personal communication).

loose materials set free beneath the ice sheet by basal melting during the closing stages of glacial activity.

Deflection of drainage.—When the ice margin advancing from the northeast obstructed the lower portion of the Tioga River near Corning, N. Y., the drainage of the Elkland-Tioga area was again gathered into long, narrow lakes which found an outlet, as in the earlier invasion, just south of Ansonia. As the ice continued to advance and obstructed the course of the Cowanesque River the drainage of this stream was likewise forced to seek a new outlet, in this case across the divide between the headwaters of Jemason and Crooked creeks in Chatham Township. Still later Jemason Creek was itself obstructed by the ice, the waters of the upper portion of the Cowanesque finding an outlet southwest of Sabinsville, about 2 miles to the west of the limits of the Elkland quadrangle.

No very prominent deflections of drainage occurred within the Tioga quadrangle, though the headwaters of Hills Creek, in Charleston Township, were turned to the southwest and, after cutting sharp channels through two divides (designated glacial spillways on the Surficial Geology maps), eventually emptied into the headwaters of the Catlin Hollow stream near Charleston.

Work of the glacier.—The work of the glacier consisted in the erosion of the surface of the rock over which it moved, the transportation of the débris thus obtained to greater or less distances from the places of derivation, and the deposition of this débris, both directly by the melting ice and indirectly by the waters flowing beneath the glacier or issuing from its front. The amount and character of the work accomplished by the ice in a given locality depended largely upon its thickness and rapidity of movement, upon the amount of abrasive materials which it held, and upon the character of the rock over which it moved.

In the Elkland-Tioga area all the broader topographic features are clearly the work of streams, though the ice was possibly an important factor in producing the beautifully flowing contours of the broad areas of Chemung rocks. That the action of erosion was not a powerful one, however, is apparent on passing into the areas of the harder Cattaraugus and Oswayo formations, where the slopes are steep, the crests imperfectly rounded and nearly free from glacial deposits, and projecting ledges abundant. An examination of the rounded Chemung hills shows that a very slight cutting usually serves to expose the underlying rock, indicating that relatively little of the rounding is due to coatings of glacial materials. In fact, the general topography is everywhere manifestly the result of stream erosion. Although in general the glacial action was not such as would produce an important modification of the topography, there were local conditions, especially in certain of the valleys, which favored the accumulation of considerable amounts of glacial drift. Entering into the deep, narrow valleys transverse to the direction of glacial movement, the heavily drift-laden basal layers of the ice sheet became lodged, or at least greatly retarded, and, on melting, deposited, either directly or through the agency of the glacial waters which were concentrated in the valleys, the considerable quantities of drift found in such positions.

The most conspicuous deposits of the glacier, however, are those which accumulated in the manner previously described at the immediate margin of the ice and which are known as the moraines. Such moraines probably formed during every important halt in the advance and the retreat of the ice. Those formed under the former conditions would usually be removed or at least undergo important modifications by the ice during its maximum development. The hills of drumloidal appearance in the northeastern portion of the Tioga area have been qualifiedly referred to such early morainal deposits which were later overriden and rounded by the ice, and it seems possible that the thicker of the till deposits banked against the sides of the Tioga and Cowanesque valleys may have had a similar origin.

The outermost or terminal moraine, though nowhere touching these quadrangles, is of special interest as marking, in this region at least, the farthest advance of the ice of the Wisconsin invasion. Its general extent in Pennsylvania is shown in fig. 2, while fig. 4 shows its position in more detail for the Elkland-Tioga region and vicinity. The moraines formed during halts in the recession of the ice are shown on the Surficial Geology maps.

Retreat of the ice.—The peculiar climatic conditions which led to the inauguration, development, and maintenance of the ice sheet, finally gave way to a more temperate climate, and the ice sheet gradually contracted and finally disappeared. It seems probable that the ice in the Elkland-Tioga region did not respond quickly to this climatic change, with the result that, instead of a gradual retreat of the ice front, the whole marginal portion of the sheet for some miles from its edge became essentially stagnant. Whether the cessation of motion took place while the uplands were still covered by the ice is not established, but from the nature of the morainal terraces along the valleys it seems likely that it had ceased in some cases while still at or near the level of the highest hills of the Chemung areas, though in some of the southward-leading valleys it doubtless continued until a somewhat later period. In the final stages the ice was confined to long, narrow masses occupying the valleys and ravines and was clearly motionless. At this stage the drainage usually followed along one or both sides of the ice masses and found outlets by routes often circuitous and complex into the streams or long lakelets emptying into Pine Creek at Ansonia. The most interesting of these drainage

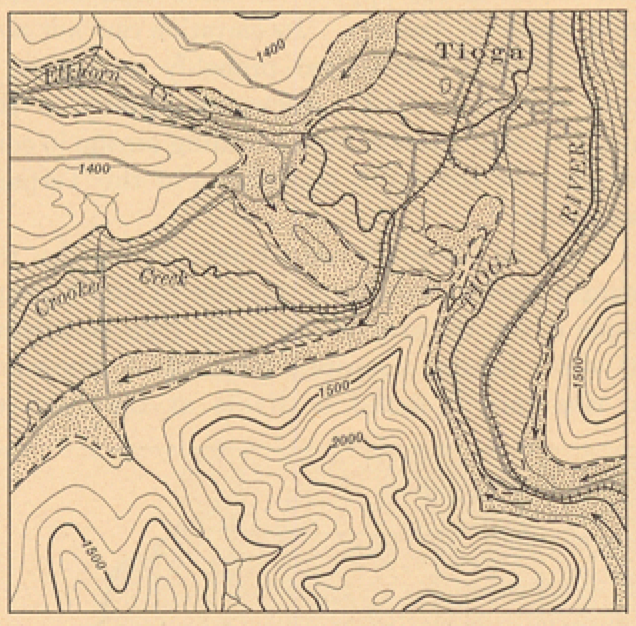

FIG. 3.—Map showing drainage conditions in the vicinity of Tioga during the final retreat of the ice.
Ruled portions covered by ice; stippled portions covered by water. Direction of drainage indicated by arrows.

peculiarities was in the vicinity of Tioga. Fig. 3 shows by means of arrows and patterns the courses of the streams in this vicinity in relation to the ice masses and to the surrounding hills. The escape of the waters occupying the upper portion of the Tioga Valley and ponded in front of the ice lying to the north of Tioga, through a sharp notch cut to a depth of nearly 50 feet across the nose of rock south of Tioga, is a notable feature.

It is unlikely that the ice at any one time was stagnant over the whole area of the quadrangles, the motion probably continuing in the north long after it had ceased in the regions to the south, or even after the ice had completely disappeared in those areas. The morainal deposits described as occurring at many points in the two quadrangles mark halts in the retreat, or possibly readvances of the ice, during which the movement again became active to the very front.

With the retreat of the ice to the north a final series of long, narrow glacial lakes came into existence in the valleys of the Tioga and Cowanesque rivers, Crooked Creek, etc. Into these poured the glacial waters loaded with sediments, parts of which are represented by the valley fillings and clays previously described. The waters, as in the Kansan or pre-Kansan invasion and at the time of the Wisconsin advance, rose until they passed into the stream leading southward from Ansonia. With the final disappearance of the ice, however, the streams returned to their probable interglacial courses, which they still occupy.

POST-GLACIAL HISTORY.

As the valleys were successively opened up by the retreat of the ice the streams of the steeper ones entered actively upon the work of removing the glacial deposits of their bottoms and reducing them to their former condition. The deposits thus removed from the smaller and steeper valleys have been carried to the broad, open valleys of gentle slope, where they have been incorporated in the general filling upon which the present flood plain deposits rests, or left in the form of broad, low gravel fans at the mouths of the streams. The valley fillings are probably composed mainly of glacial materials, but the filling of the inequalities and the building of the upper portion of the deposits is doubtless to be assigned to post-Glacial deposition of the nature mentioned.

The only other deposits which are assigned to post-Glacial time are the poorly assorted gravels of certain of the torrential streams, the marsh deposits occurring in poorly drained portions of the flood plains and in drift-obstructed valleys or in drift depressions, and the thin coating of flood-plain silts along the rivers.

The small amount of erosion and the correspondingly limited deposition, together with the slight leaching and oxidation of the drift, seem to indicate a post-Glacial time which in length is but a small fraction of that which elapsed between the earliest and the latest invasion of the ice in this region.

ECONOMIC GEOLOGY.

Flagstone.—Quarries have been opened in the green or reddish flags of the Cattaraugus formation, and more rarely in the Chemung, at a considerable number of points in the Elkland-Tioga area. Some of the quarries have been operated intermittently for many years and considerable quantities of a very fair quality of flags have been produced.

The largest of the flagstone quarries, and the only one actively worked at present, is located near the base of the Cattaraugus formation at the extreme eastern edge of the Tioga quadrangle between the forks of Cory Creek, east of Mansfield (see fig. 6). This quarry has had a large output of a good quality of flags, some of which are said to have measured as much as 20 feet in diameter. The product is mainly used in the adjacent regions in northern Pennsylvania and southern New York.

Limestone.—Although no thick beds of pure limestone are known to occur within the quadrangles, there are numerous beds of impure limestone scattered through the Chemung formation. They appear to be best developed and purest in the upper portion of the formation, within a limit of 100 feet or so from the bottom of the overlying Cattaraugus formation. The material from these beds is frequently burned for lime for local use as fertilizer, and was at one time quarried near Mansfield for use as a flux in the smelting of iron at the local furnace.

Fire clay.—A bed of fire clay has been exposed in a small pit on the high crest just east of the headwaters of Painter Run, in Rutland Township in the Tioga quadrangle. Its thickness and extent are so slight and its position is so inaccessible that it is not likely to prove of economic value.

Brick clay.—Buff and pinkish clays showing strongly contorted laminations have been noted in the beds or banks of several of the streams entering the Tioga River from the west in the southern portion of the Tioga quadrangle. The material belongs to the class of glacial clays described on a previous page, and like other clays of the same class would doubtless be found, on testing, to fulfill the requirements of a good brick clay.

Similar clays possibly occur at many other points in the Elkland and Tioga quadrangles, but if present are effectually concealed by later deposits of sand and gravel.

Gravels.—Gravels occur in abundance at many points, especially along the larger streams and in the morainal and glacial terrace deposits shown on the Surficial Geology sheet. The glacial gravel and sand deposits are especially prominent at the junction of Crooked Creek with Tioga River, and also along the east side of the valley of the latter from Tioga to Lawrenceville. The principal use of the gravel is as road metal on the roads built upon the soft loamy top of the flood plain along the rivers. The sand is used to some extent in mortar and plaster.

Petroleum.—No petroleum has yet been found in the Elkland-Tioga area, although numerous wells have been sunk in search of it. The Gaines oil field, however, is only 4 miles from the southwest corner of the Elkland quadrangle, and it is by no means improbable that profitable pools may at some future time be discovered in the area itself.

The oil of the Gaines field is obtained from two horizons, the upper, known as the Atwell sand, being about 700 feet below the top of the Chemung formation, and the lower, known as the Blossburg formation, occurring about 200 feet higher. The geologic features which may be of significance in relation to the occurrence of oil in the Gaines pools are as follows: The location of the pool midway between the axes of the Pine Creek syncline and the Wellsboro anticline (fig. 4); a shallowing of that portion of the syncline opposite the field; a simultaneous change in the direction of the synclinal axis; and the occurrence of the oil at a point marked by a flattening of the dips.

It is probable that there are points in the Elkland-Tioga area where the conditions for the occurrence of oil are as favorable as at Gaines, but the question as to its actual occurrence can be settled only by the drill. The condition at Gaines is in harmony with the general mode of occurrence of oil in other regions, and in locating new wells similar geologic conditions should probably be sought for. Fig. 4 shows the approximate locations of the anticlinal and synclinal axes in the Elkland and Tioga quadrangles, and their extensions in the surrounding regions, as determined by the Second Geological Survey of Pennsylvania. By its aid localities corresponding to the position of the Gaines field can be approximately determined.

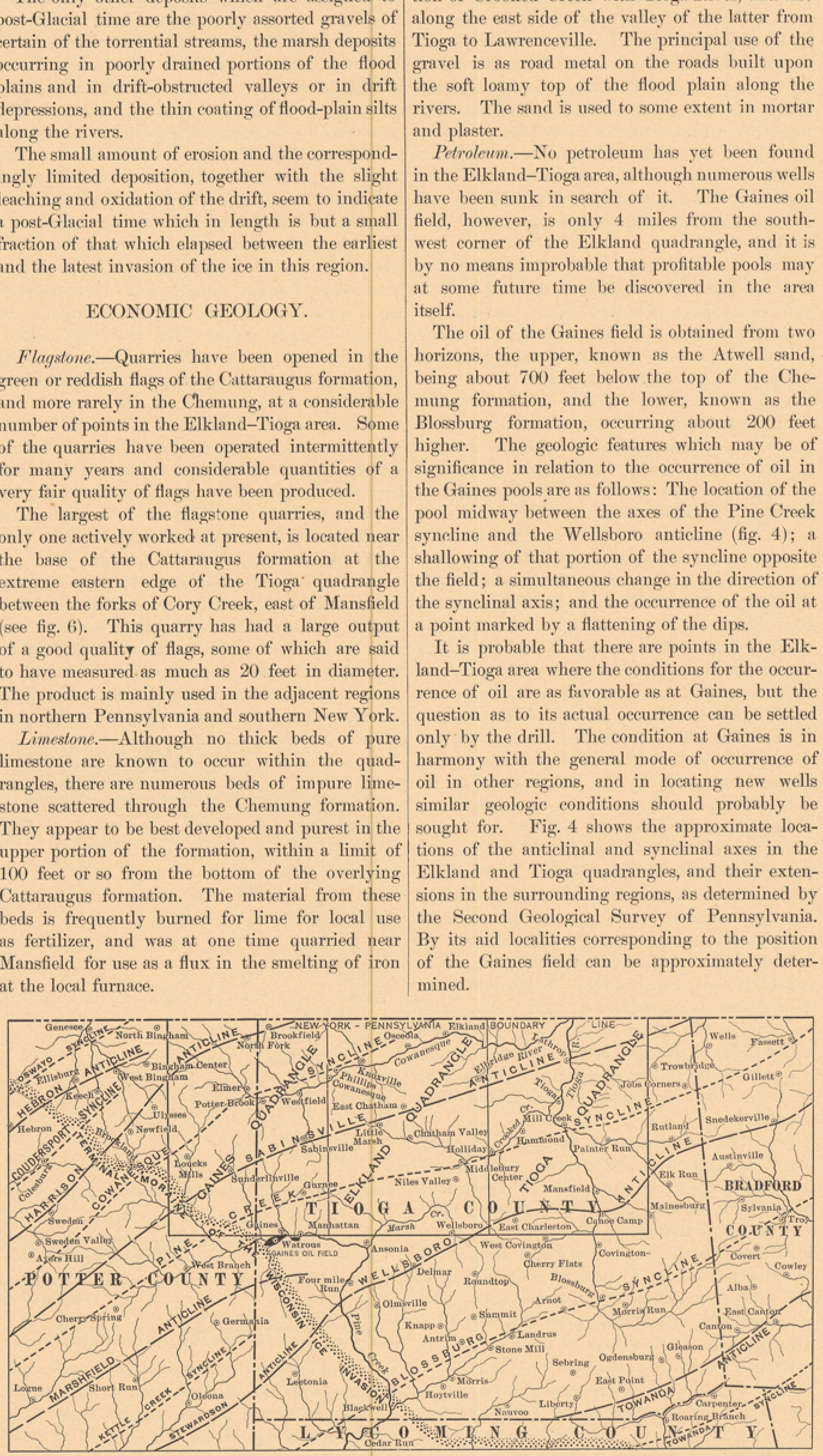

FIG. 4.—Sketch map of Gaines, Elkland, and Tioga quadrangles and adjacent portion of Pennsylvania.
Showing position of the terminal moraine and approximate location of anticlinal and synclinal axes. The Gaines oil field is shown at the southern border of the Gaines quadrangle.

In drilling for oil in the region it should be borne in mind that the Gaines field probably occurs in rock as strongly folded, or more strongly folded, than those of any other oil field in Pennsylvania, and that, while it can not be said that oil will not be found in more strongly folded rocks, the chances for finding it in paying quantities appear to be better in regions of gentle dip. Fig. 1, on page 5, shows, by means of contour lines at 100-foot intervals, the elevation and conformation of the upper surface of the Chemung formation in its relation to sea level, and affords a basis for determining the location of areas of steep or slight dip in the field.

Natural gas.—Gas has been found in a number of the "wild cat" wells in the Elkland-Tioga area, but beyond slight amounts burned in the immediate vicinity of the wells, no use is made of it. It is probably somewhat more widely distributed than the oil, and wells drilled in search for it are more likely to meet with success. The most likely position for its occurrence is probably along the crests of the anticlines, the positions of which may be seen from figs. 1 and 4.

Iron ores.—Twenty-five or more years ago hematite iron ores were mined to a moderate extent at several points in the vicinity of Mansfield, and were smelted at the furnace at that place. In consequence of the development of large mines elsewhere in the country, especially in the Lake Superior region, the mines about Mansfield were abandoned and will probably never be reopened.

The position and general characters of the ores have been described in the discussion of the Chemung formation. The composition is shown in the table given below, compiled from the report of the Second Geological Survey of Pennsylvania on Bradford and Tioga counties.

Partial analysis of iron ores of the Tioga quadrangle.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Iron.......	31.800	38.900	32.400	42.800	43.100	35.300
Lime.......	......	13.100	9.170	......	1.800	4.740
Magnesia..	......	2.140	2.918	......	.922	......
Phosphor's	.253	.603	.585	.903	.657	.215
Sulphur...	.034	.063	.065	.018	.018	.026
Insoluble residue..	35.120	11.565	23.890	21.670	20.910	28.845

No. 1 is a highly fossiliferous oolitic hematite from an outcrop on the highway about three-fourths of a mile east of the southwest corner of the quadrangle. It was known to the Second Pennsylvania Survey as the Lower or Second ore bed, and is situated several hundred feet below the top of the Chemung formation. Thickness of bed, 15 inches.

No. 2 is a fossiliferous hematite from the Upper or First ore bed, which lies just below the Chemung-Catskill transition. It was taken from the mine on the crest of the hill just south of the head of Manns Creek. Thickness of bed, 2 to 3 feet.

No. 3 is from the Upper bed, and was taken from an exposure on Lambs Creek. Thickness of bed, 18 inches.

No. 4 is from the Upper bed, and was taken from the vicinity of the Pickle Hill mine, northeast of Mansfield. Thickness of bed, 1 to 3 feet.

No. 5 is from a Lower bed at the same horizon as No. 1, or a little below it, and was taken from an exposure in the bed of the Tioga River about a mile north of Mansfield. The thickness of the bed is unknown.

No. 6 is from the Lower horizon and was taken from the west side of Bixbys Hill, a little over a mile southeast of Mansfield. Thickness of bed, probably 1 to 2 feet.

Many of the openings which were accessible at the time the analyses were made (about 1875) are not now to be seen. The locations of such of these as are known, together with a number of new outcrops encountered in the field work, are indicated on the Areal Geology map. Hematite ore has been reported as occurring beneath a portion of Wellsboro, and on one of the high hills near the crest of the anticline at a point about 8 miles southeast of Knoxville; but the reports are not substantiated. The limonite bed described in connection with the Mauch Chunk formation as occurring east of the head of Painter Run, though thicker than the hematite beds about Mansfield, is not likely to prove of any value.

Soils.—The soils of the Elkland and Tioga quadrangles are of two types, glacial and alluvial. True sedentary soils, or those formed in the exact spot where found and composed of the insoluble sandy and clayey products of decay of the immediately underlying rock, do not occur anywhere within the quadrangles.

The glacial soils of the region, however, are fundamentally of sedentary derivation, the glacier having, on its advance, simply taken up the soil that covered the surface, transported it a short distance, and then, as the ice melted, deposited it. The soils thus formed consist of heterogeneous aggregates of materials of all sizes from clay to large fragments, the finer portions of which are thoroughly decayed. Most of the soils of this type, like the true sedentary soils, agree in composition with the underlying rock; hence the geologic map showing the distribution of the rocks will also show, in a general way, the distribution of the soils. The region least affected by glacial action, and the one in which the soils most nearly resemble the true sedentary soils, is the broad Chemung area south of the Crooked Creek–Tioga mountain belt. To the north of this belt the glacial deposits are thicker and more of the material is of foreign derivation, and though the soils still correspond in a general way to the character of the underlying rock, the agreement is less close than in the area to the south. The best farming land appears to be in those locations where the soil most nearly approaches the character of the true sedentary soil.

Of the formations represented upon the maps the Chemung has the most regular and gentle slopes, and gives soils most nearly resembling those of sedentary origin. It underlies the broad belt of low hills lying between the Cowanesque and Tioga–Crooked Creek mountain belts and also the low belt to the south of the latter. It includes all the valuable farming land except that along the alluvial flood plains of the larger streams, and gives excellent crops of wheat, oats, corn, etc.

Next to the Chemung the Cattaraugus formation affords the most valuable soil, but because of the presence of heavy beds of flaggy sandstones and its association with the relatively massive Oswayo formation, the areas are usually steep and rough and are not well adapted to cultivation. Buckwheat is the principal crop.

The Oswayo formation gives extremely steep slopes, and soils composed almost entirely of a mass of sandstone fragments. Its areas are mostly forested and have in the past yielded quantities of timber and of hemlock tan-bark. Occasional small clearings have been made and small amounts of buckwheat, etc., are raised.

The Mauch Chunk formation occurs only in a few small areas at or near the very tops of the higher mountain crests of the Tioga quadrangle, and although it is said to afford a fair soil, its extent is so limited and its position so inaccessible that it is of little importance.

The outcrops of the Sharon conglomerate are of still more limited extent and the resulting soils are so slight as to be negligible.

The alluvial soils are partly the result of deposition by glacial streams and partly the result of the deposition of fine sediments upon the flood plains of the larger streams in recent times. The glacial alluvium is irregular in its distribution, covers but a small area, and is unimportant as a soil. The flood-plain alluvium, however, furnishes the richest soil of the region and gives fine crops of a superior tobacco.

June, 1902.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

STATE OF PENNSYLVANIA
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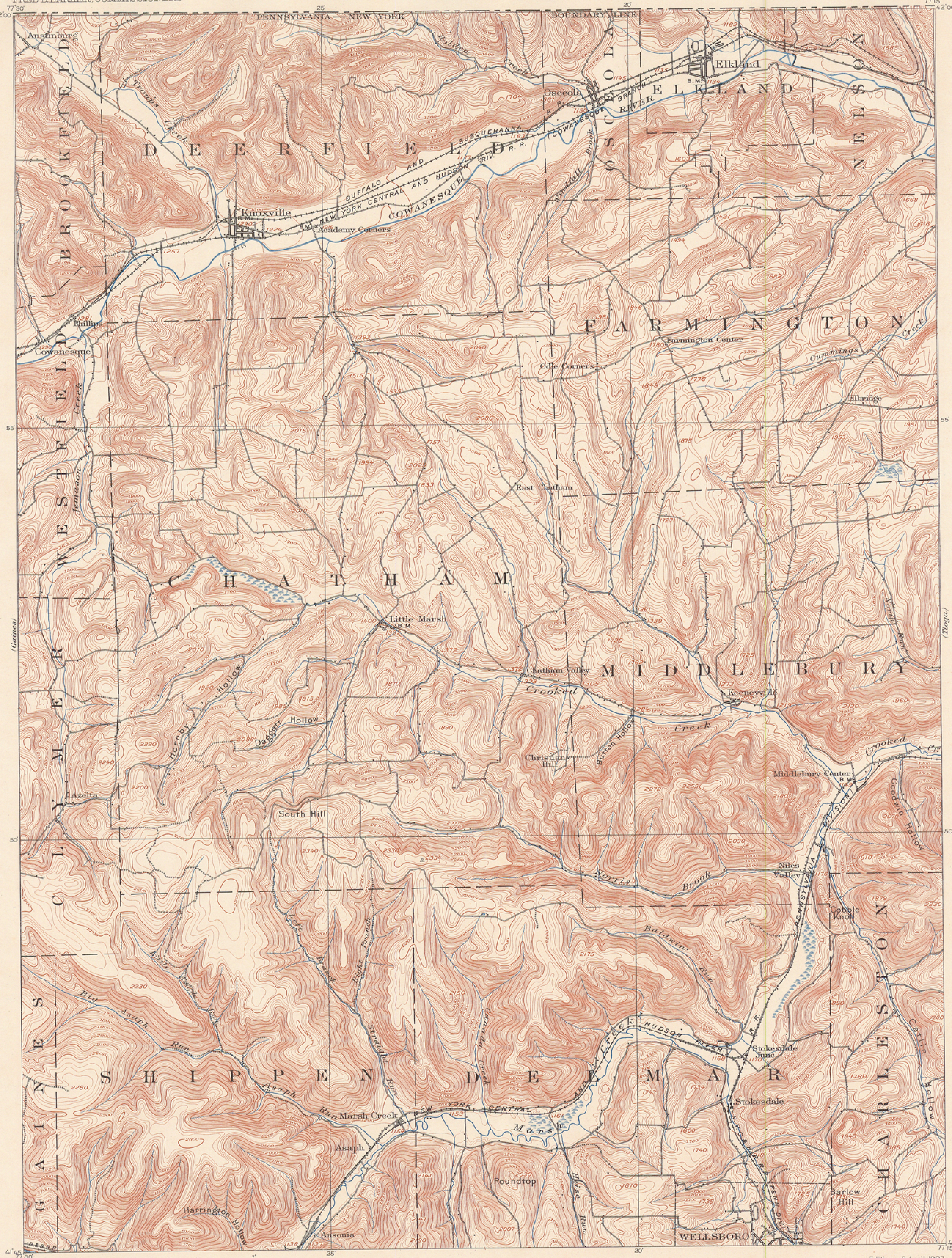
TOPOGRAPHY

PENNSYLVANIA
(TIOGA COUNTY)
ELKLAND QUADRANGLE



LEGEND

RELIEF
(printed in brown)

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

Lakes and ponds

Marshes

CULTURE
(printed in black)

Roads and buildings

Private and secondary roads

Railroads

State lines

Township lines

Village lines

Triangulation stations

Bench marks

H. M. Wilson, Geographer in charge.
Control by S. S. Gannett, Oscar Jones, and J. W. Thom.
Topography by J. H. Jennings and J. W. Thom.
Surveyed in 1899 in cooperation with the State of Pennsylvania.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{62500}$

Contour interval 20 feet.
Datum is mean sea level.

Edition of April 1903.

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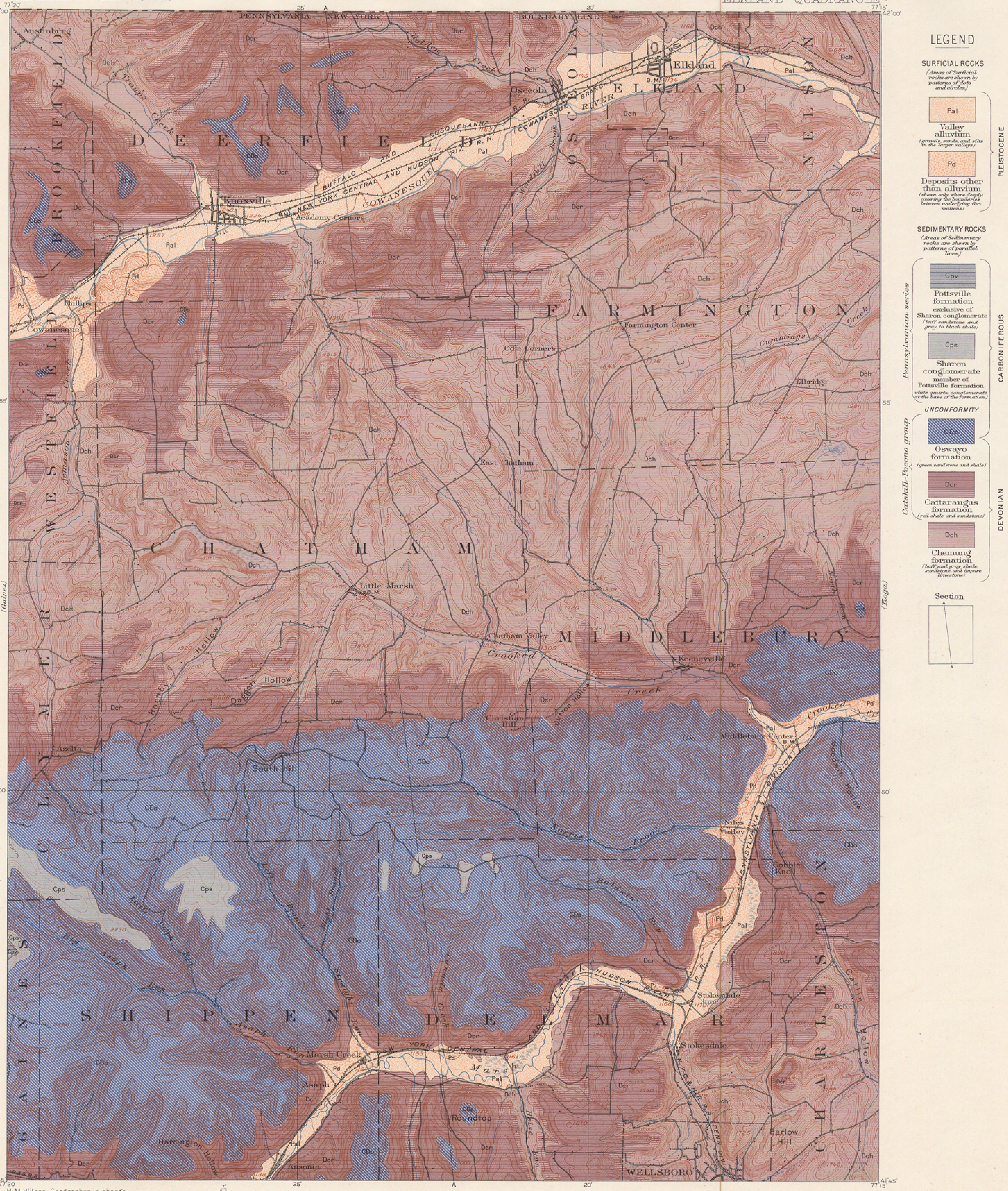
AREAL GEOLOGY

PENNSYLVANIA
(TIOGA COUNTY)
ELKLAND QUADRANGLE



H. M. Wilson, Geographer in charge.
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Scale $\frac{1}{62500}$

Contour interval 20 feet.
Datum is mean sea level.
Edition of May 1903.

M. R. Campbell, Geologist in charge.
Geology by M. L. Fuller, J. D. Irving, and Charles Butts.
Surveyed in 1900.

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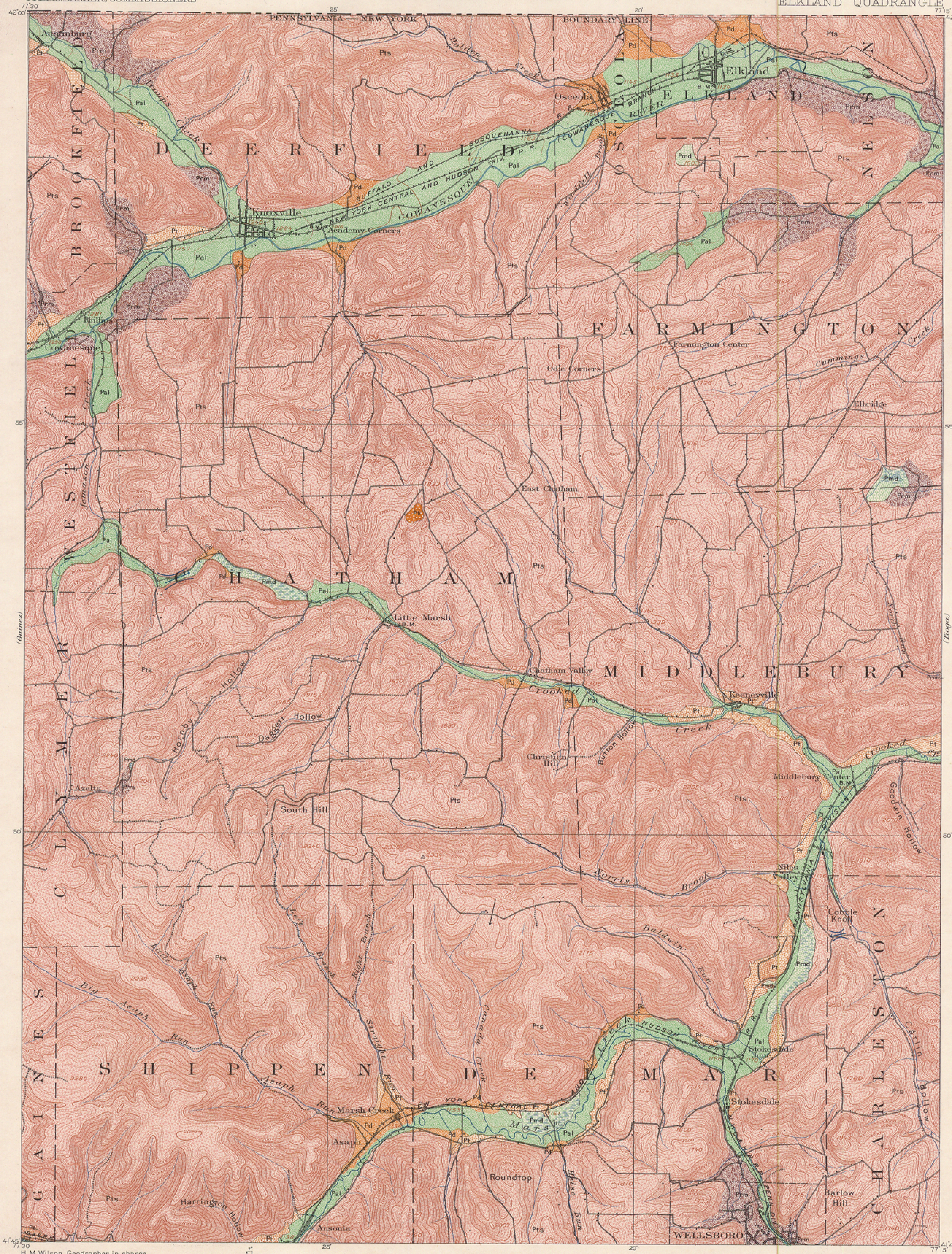
SURFICIAL GEOLOGY

PENNSYLVANIA
(TIOGA COUNTY)
ELKLAND QUADRANGLE



LEGEND

SURFICIAL ROCKS

(Areas of Surficial rocks are shown by patterns of dots and circles)

PLEISTOCENE

Post-Glacial

- Pal — Alluvium *(flood plain silts underlain by stratified drift)*
- Pmd — Marsh deposits *(peat and muck)*

Wisconsin Glacial Invasion

- Pd — Gravel fans or deltas
- Pt — Morainal and frontal terraces
- Pk — Kames *(including isolated gravel deposits)*
- Prm — Retreatal moraines
- Pts — Till sheet

Glacial spillways *(direction of current indicated by arrow)*

Glacial striae

H. M. Wilson, Geographer in charge.
Control by S. S. Gannett, Oscar Jones, and J. W. Thom.
Topography by J. H. Jennings and J. W. Thom.
Surveyed in 1899 in cooperation with the State of Pennsylvania.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

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 April 1903.

T. C. Chamberlin, Geologist in charge.
Geology by William C. Alden.
Surveyed in 1900.

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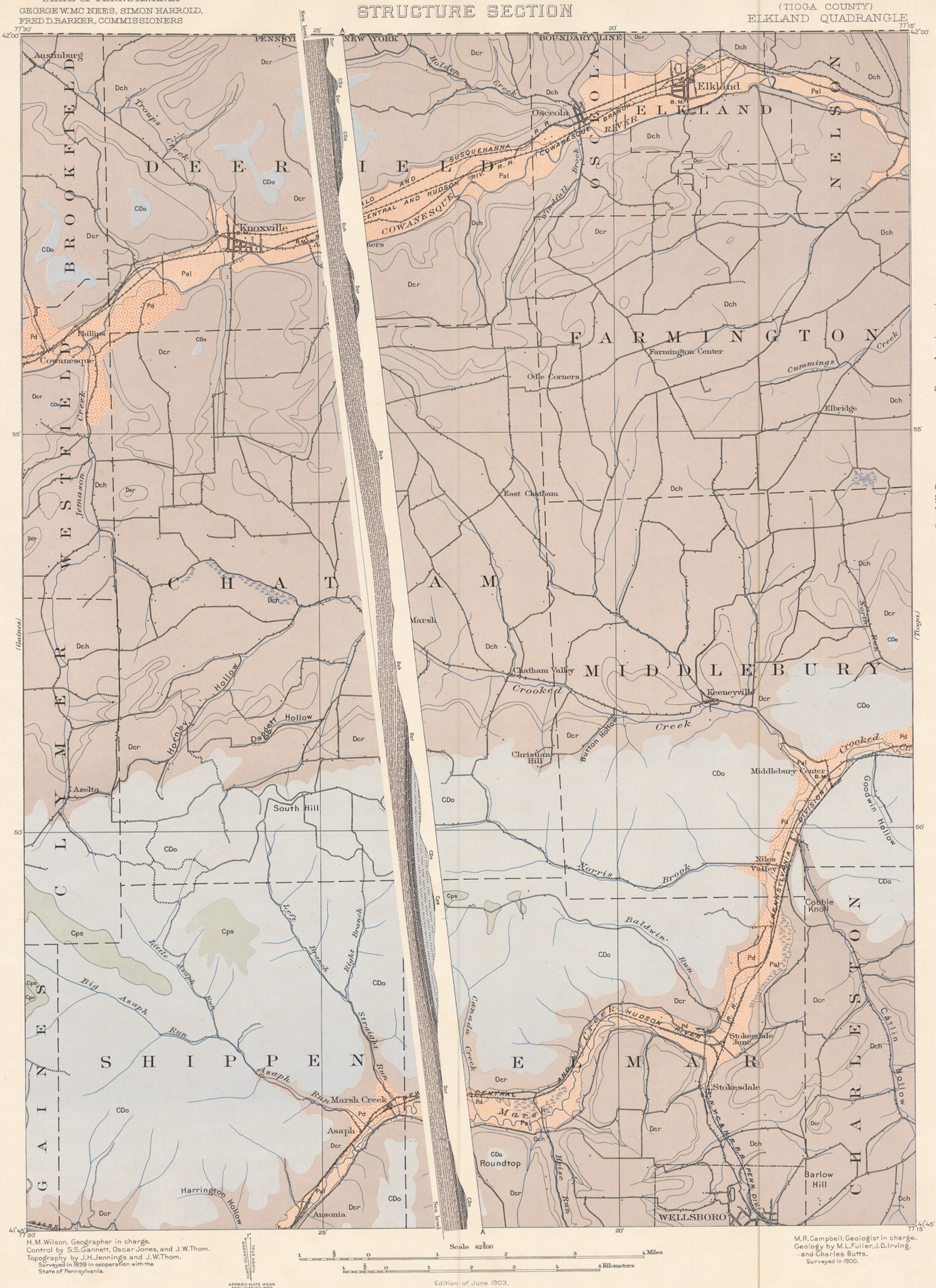
STRUCTURE SECTION

PENNSYLVANIA
(TIOGA COUNTY)
ELKLAND QUADRANGLE



LEGEND

SURFICIAL ROCKS

SHEET SYMBOL

PLEISTOCENE

- Pal — Valley alluvium (gravels, sands, and silts in the larger valleys)
- Pd — Deposits other than alluvium (shown only where deeply covering the boundaries between underlying formations)

SEDIMENTARY ROCKS

SHEET SYMBOL / SECTION SYMBOL

CARBONIFEROUS — Pennsylvanian series

- Cpv — Pottsville formation exclusive of Sharon conglomerate (buff sandstone and gray to black shale)
- Cps / Cps — Sharon conglomerate member of Pottsville formation (white quartz conglomerate at the base of the formation)

UNCONFORMITY

Catskill-Pocono group

- CDo / CDo — Oswayo formation (green sandstone and shale)

DEVONIAN

- Dcr / Dcr — Cattaraugus formation (red shale and sandstone)
- Dch / Dch — Chemung formation (buff and gray shale, sandstone, and impure limestone)

H. M. Wilson, Geographer in charge.
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Topography by J. H. Jennings and J. W. Thom.
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Edition of June 1903.

M. R. Campbell, Geologist in charge.
Geology by M. L. Fuller, J. D. Irving, and Charles Butts.
Surveyed in 1900.

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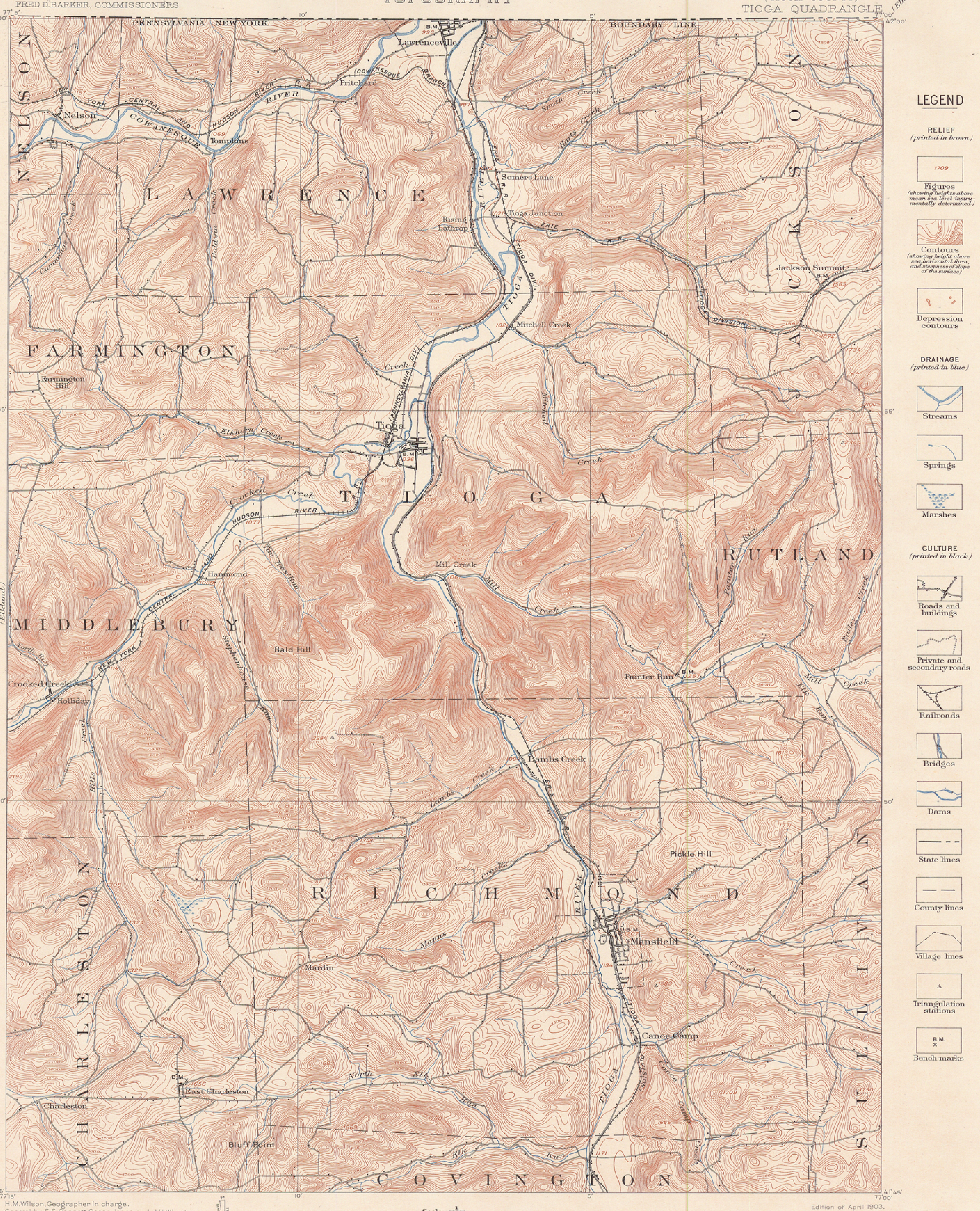
PENNSYLVANIA
(TIOGA COUNTY)
TIOGA QUADRANGLE



H.M. Wilson, Geographer in charge.
Control by S.S. Gannett, Oscar Jones, and J.H. Wheat.
Topography A.M. Walker.
Surveyed in 1899 and 1900 in cooperation with the State of Pennsylvania.

APPROXIMATE MEAN DECLINATION 1903.

Scale $\frac{1}{62500}$

Contour interval 20 feet.
Datum is mean sea level.

Edition of April 1903.

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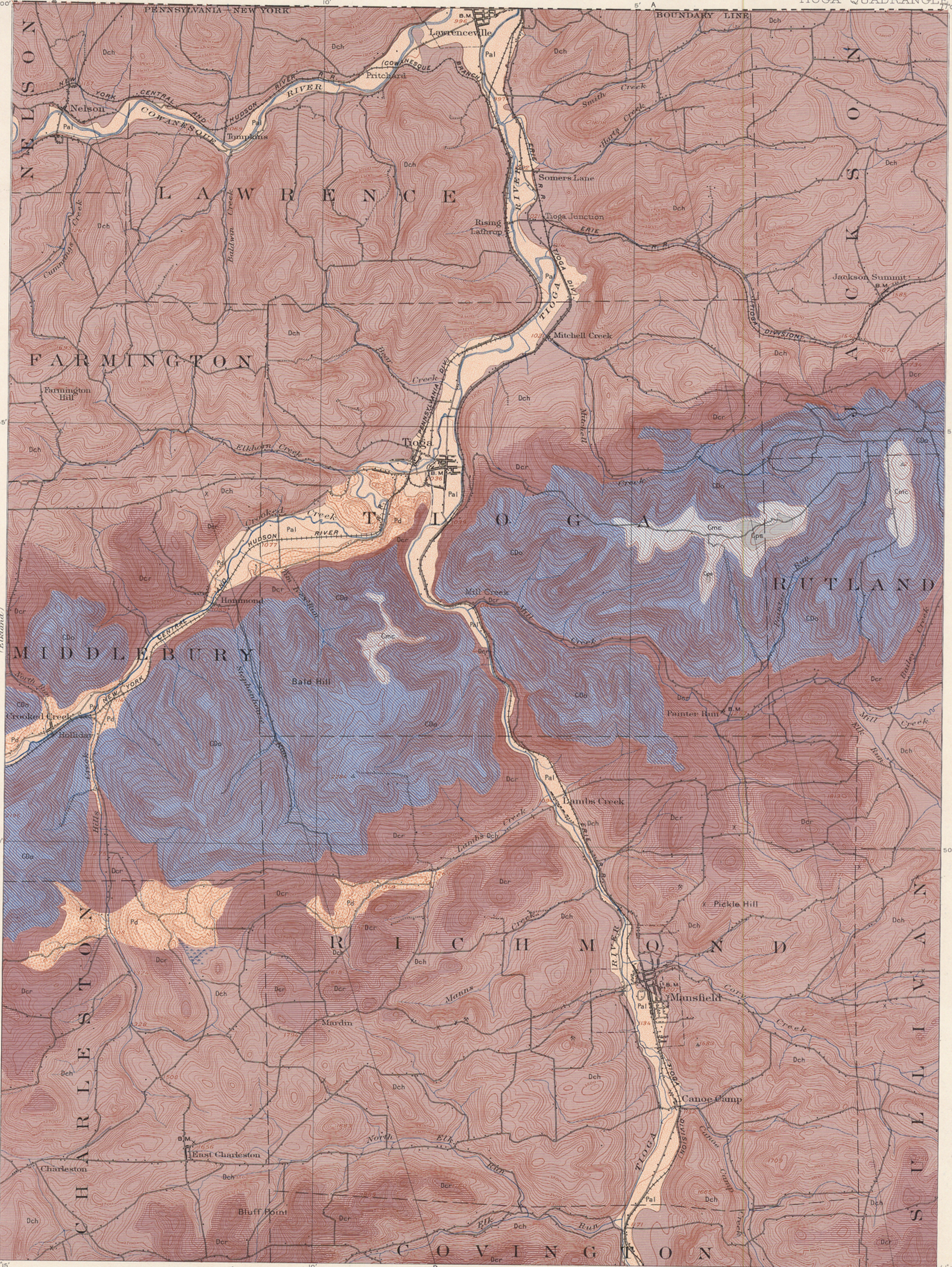
AREAL GEOLOGY

PENNSYLVANIA
(TIOGA COUNTY)
TIOGA QUADRANGLE



LEGEND

SURFICIAL ROCKS

(Areas of Surficial rocks are shown by patterns of dots and circles)

PLEISTOCENE

- Pal — Valley alluvium (gravels, sands, and silts in the larger valleys)
- Pd — Deposits other than alluvium (shown only where deeply covering the boundaries between underlying formations)

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines)

CARBONIFEROUS

Pennsylvanian series

- Cps — Sharon conglomerate member of Pottsville formation (white quartz conglomerate at the base of the formation)

UNCONFORMITY

Mississippian series

- Cmc — Mauch Chunk formation (red shale, green and buff shale and sandstone, and fire clay)

Catskill-Pocono group

- CDo — Oswayo formation (green sandstone and shale)

DEVONIAN

- Dcr — Cattaraugus formation (red shale and sandstone)
- Dch — Chemung formation (buff and gray shale, sandstone, and impure limestone)

⚒ *Abandoned iron mines*
× *Iron prospects and outcrops*

Sections

H. M. Wilson, Geographer in charge.
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Topography A. M. Walker.
Surveyed in 1899 and 1900 in cooperation with the State of Pennsylvania.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

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 May 1903.

M. R. Campbell, Geologist in charge.
Geology by Myron L. Fuller.
Surveyed in 1901.

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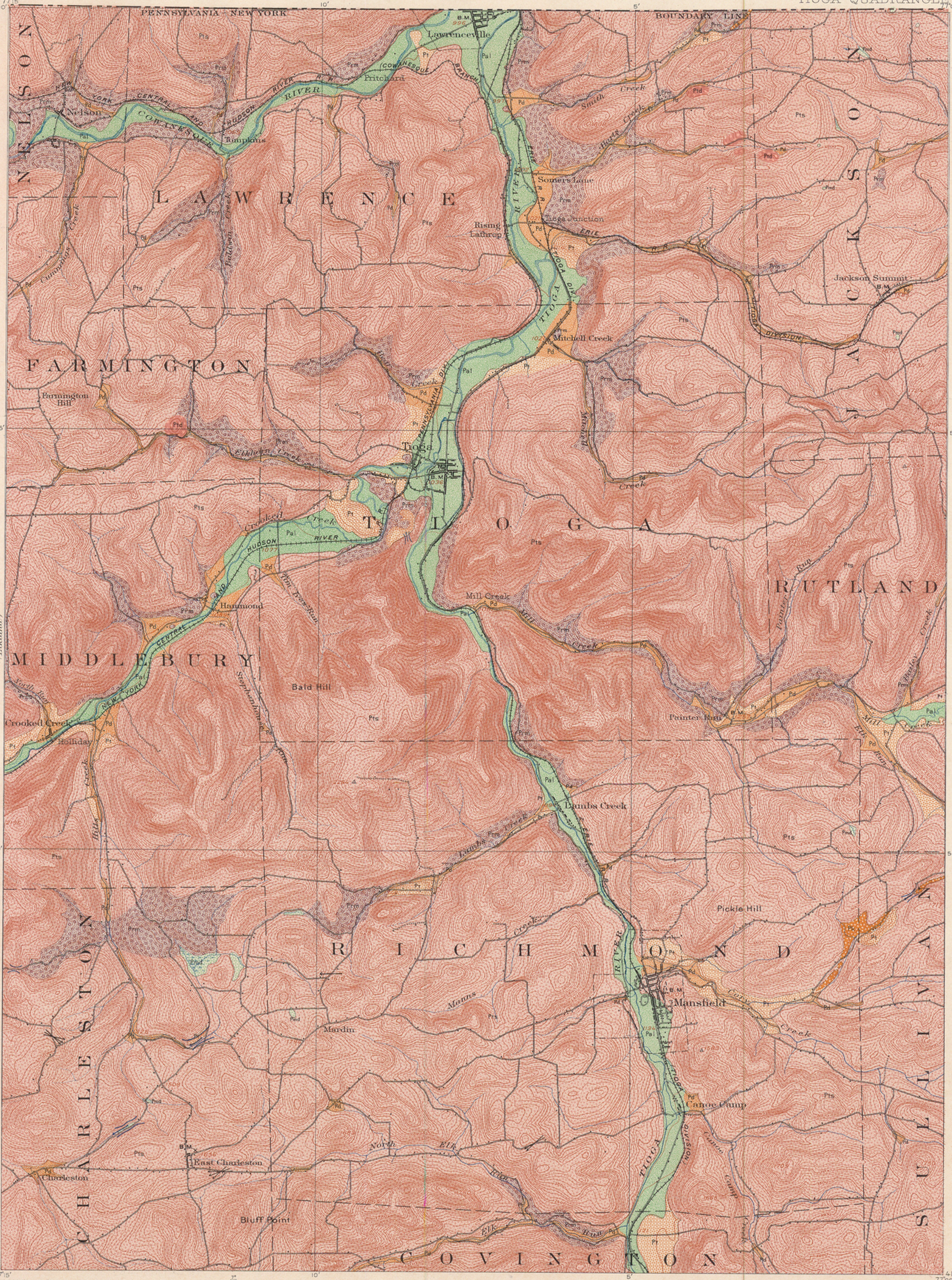
SURFICIAL GEOLOGY

PENNSYLVANIA
(TIOGA COUNTY)
TIOGA QUADRANGLE



LEGEND

SURFICIAL ROCKS
(Areas of Surficial rocks are shown by patterns of dots and circles.)

PLEISTOCENE

Post-Glacial

- Pal — Alluvium *(flood plain silts underlain by stratified drift)*
- Pmd — Marsh deposits *(peat and muck)*

Wisconsin Glacial Invasion

- Pd — Gravel fans or deltas *(including torrential stream deposits)*
- Pt — Morainal and frontal terraces
- Pk — Eskers and kames
- Prm — Retreatal moraines
- Ptd — Till deposits with drumloidal topography
- Pts — Till sheet

Glacial spillways *(direction of current indicated by arrow)*

Glacial striae

H. M. Wilson, Geographer in charge.
Control by S. S. Gannett, Oscar Jones, and J. H. Wheat.
Topography A. M. Walker.
Surveyed in 1899 and 1900 in cooperation with the State of Pennsylvania.

TRUE NORTH
MAGNETIC NORTH
7°
APPROXIMATE MEAN DECLINATION 1902.

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 April 1903.

Geology by Myron L. Fuller.
Surveyed in 1901.

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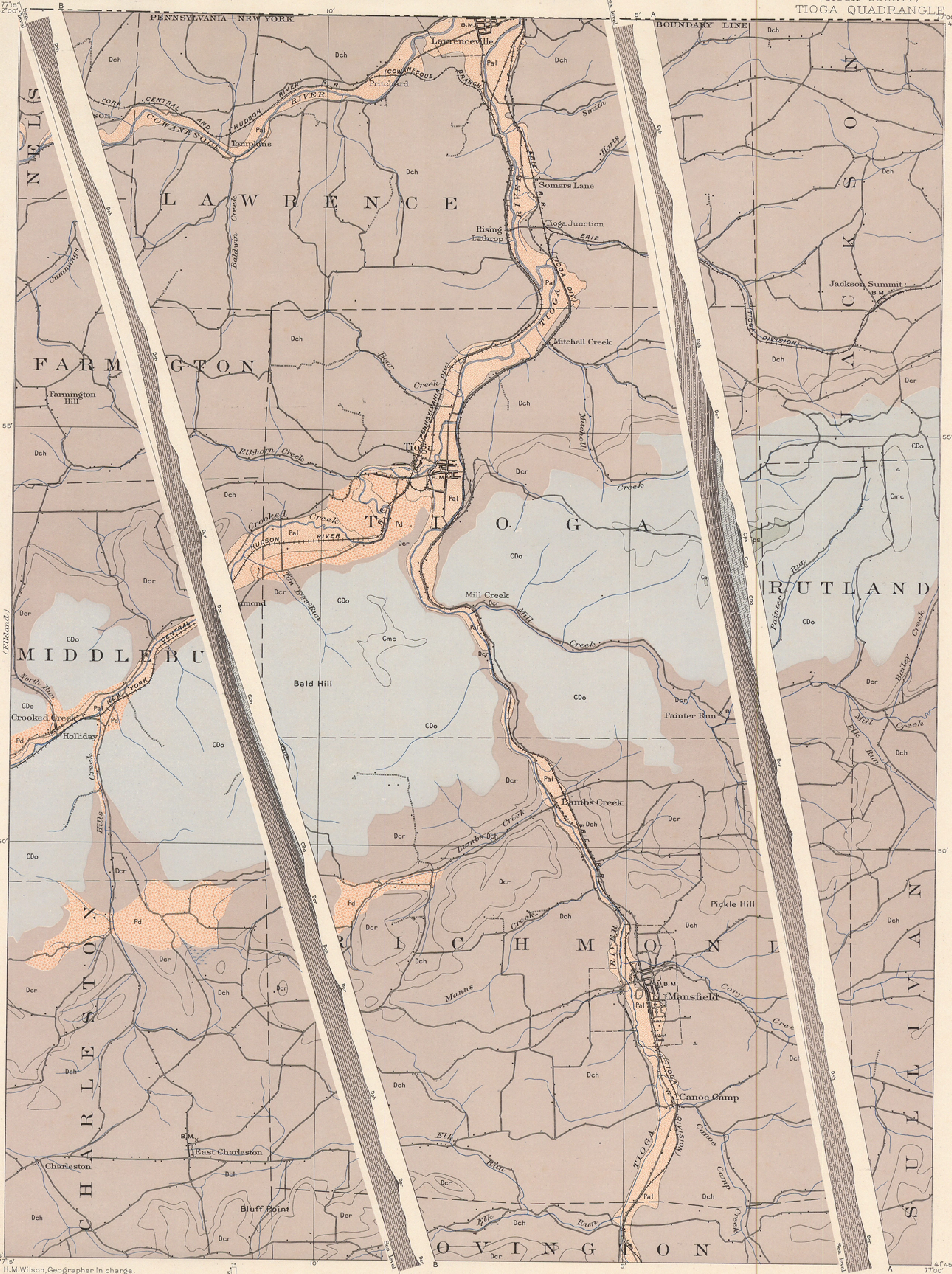
STRUCTURE SECTIONS

PENNSYLVANIA
(TIOGA COUNTY)
TIOGA QUADRANGLE



LEGEND

SURFICIAL ROCKS

SHEET SYMBOL

PLEISTOCENE

- Pal — Valley alluvium *(gravels, sands, and silts in the larger valleys)*
- Pd — Deposits other than alluvium *(shown only where deeply covering the boundaries between underlying formations)*

SEDIMENTARY ROCKS

SHEET SYMBOL | SECTION SYMBOL

CARBONIFEROUS

Pennsylvanian series

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UNCONFORMITY

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- Cmc | Cmc — Mauch Chunk formation *(red shale, green and buff shale and sandstone, and fire clay)*

Catskill-Pocono group

- CDo | CDo — Oswayo formation *(green sandstone and shale)*

DEVONIAN

- Dcr | Dcr — Cattaraugus formation *(red shale and sandstone)*
- Dch | Dch — Chemung formation *(buff and gray shale, sandstone, and impure limestone)*

H.M.Wilson, Geographer in charge.
Control by S.S.Gannett, Oscar Jones, and J.H.Wheat.
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TRUE NORTH
MAGNETIC NORTH
7°
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Edition of June 1903.

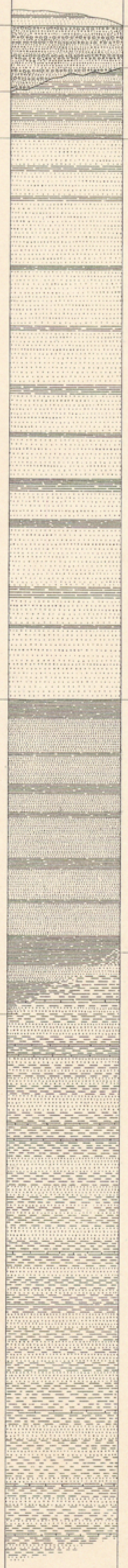
M.R.Campbell, Geologist in charge.
Geology by Myron L.Fuller.
Surveyed in 1901.

COLUMNAR SECTION

GENERALIZED SECTION OF THE SEDIMENTARY ROCKS OF THE ELKLAND AND TIOGA QUADRANGLES.

SCALE: 1 INCH=200 FEET.

System.		Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.	Character of Topography and Soils.
CARBONIFEROUS	PENNSYLVANIAN	Pottsville formation.	Cpv		30	Greenish argillaceous sandstone with a thin streak of black shale and coal.	Caps plateau remnant at western edge of Elkland quadrangle. Soil sandy and rather barren.
		Sharon conglomerate member.	Cps		60 – 100	White quartz conglomerate and sandstone.	Caps the higher plateau remnants and frequently forms cliffs. Soil highly siliceous, generally with bowlders, and of very limited distribution.
		UNCONFORMITY.					
		Mauch Chunk formation.	Cmc		0 – 100	Red and green shales and green and buff sandstones, with a thin bed of fire clay and a three-foot bed of limonite.	Gently undulating cappings to some of the plateau remnants in the Tioga quadrangle. Soil variable, frequently clayey, and generally rather poor.
CARBONIFEROUS ? DEVONIAN	MISSISSIPPIAN	Oswayo formation.	CDo		1000±	Heavy beds of green and gray flaggy sandstones with some green and gray shales and local beds of red shale.	Steep hillsides with frequent projecting ledges. Slopes generally covered with talus of sandstone plates. Soil stony and barren.
DEVONIAN		Cattaraugus formation.	Dcr		500±	Persistent red shale alternating with red brown, and green sandstones and gray and green shales.	The lower moderately steep slopes of hillsides, frequently covered with talus of sandstone from its own beds or from the overlying Oswayo formation. Soil generally sandy or stony. Poorly situated for farming.
		Chemung formation.	Dch		2000+	Relatively thin beds of gray or greenish fossiliferous shales and sandstones in rapid alternation with occasional streaks or thin beds of more or less impure limestone.	The lowest slopes of steep hillsides and well-rounded hills of moderate slope and height, free from talus. Soil yellowish and of good quality. Contains many platy fragments of shale and shaly limestone.



MYRON L. FULLER,
Geologist.

ILLUSTRATION SHEET

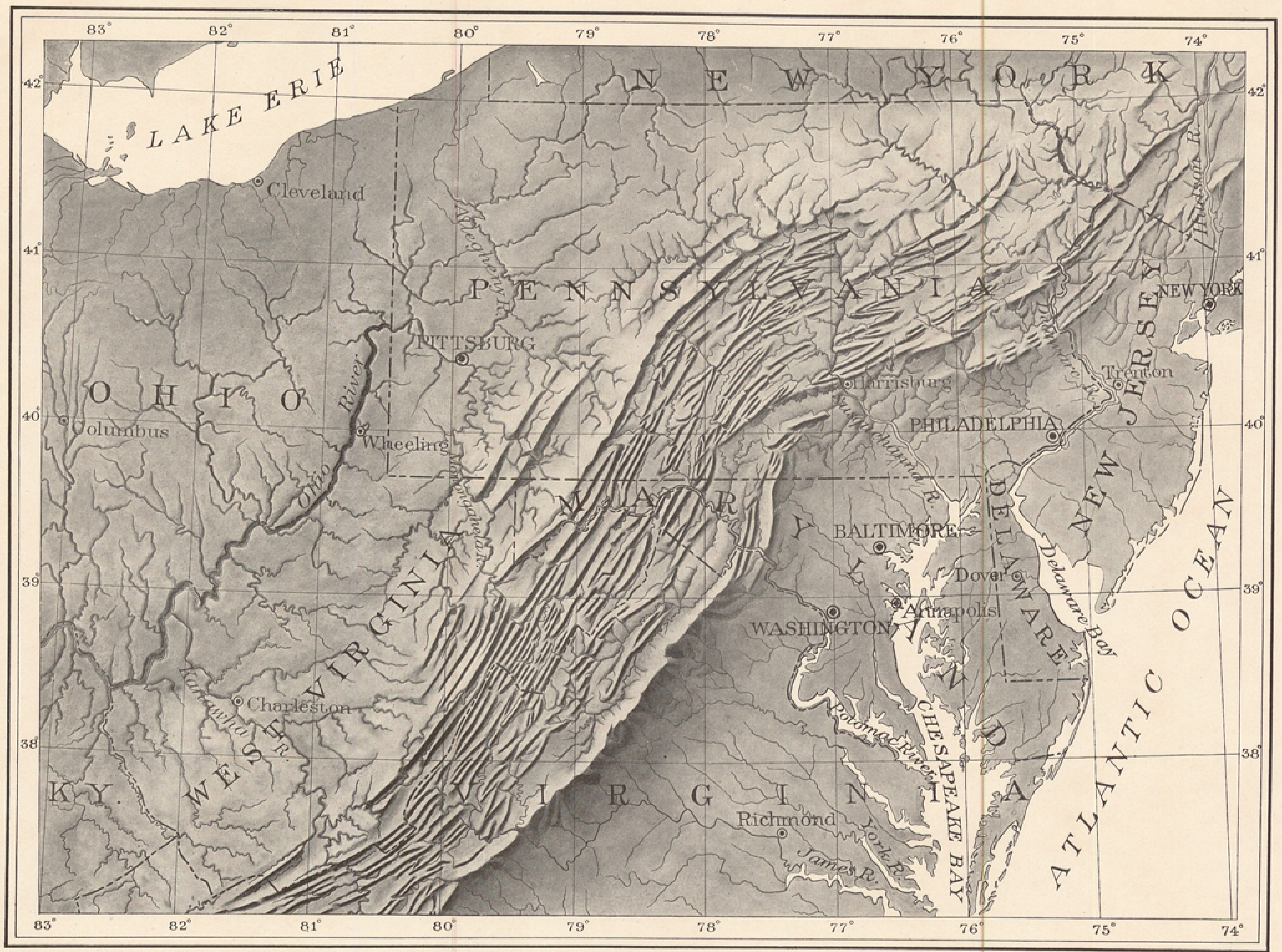


FIG. 5.—RELIEF MAP OF THE NORTHERN APPALACHIAN MOUNTAINS.

The Elkland and Tioga quadrangles are situated on the plateau lying north of the belt of ridges, in the north-central portion of Pennsylvania

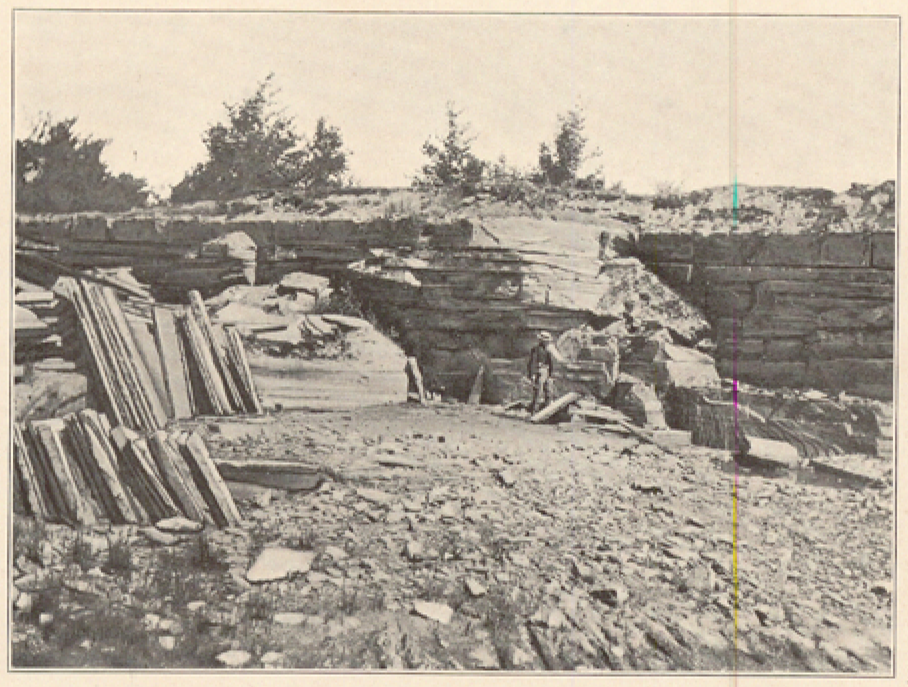


FIG. 6.—FLAGSTONE QUARRY AT HEAD OF CORY CREEK, EAST OF MANSFIELD.

Showing character of rocks near base of Cattaraugus formation. (From photograph by Dr. E. M. Kindle.)

FIG. 7.—ROUNDED HILL OF CHEMUNG FORMATION.

Showing characteristic rounded outline of the hills of this formation and landslide scars. (From photograph by Dr. E. M. Kindle.)

FIG. 8.—TORRENT GRAVEL IN BED OF STREAM AND SECTION OF GLACIAL CLAY SHOWING CONTORTIONS DUE TO CREEP.

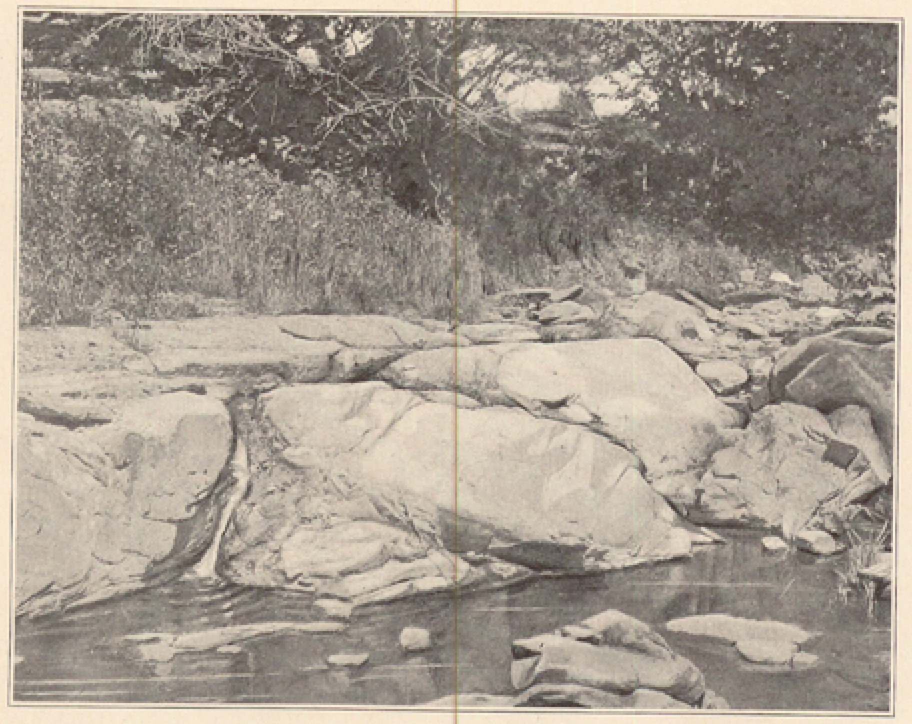


FIG. 9.—CONCRETIONARY MASSES IN THE CHEMUNG FORMATION A FEW MILES NORTHEAST OF THE TIOGA QUADRANGLE.

(From photograph by C. A. Hartnagel.)

redeposited as beds or trains of sand and clay, thus forming another gradation into sedimentary deposits. Some of this glacial wash was deposited in tunnels and channels in the ice, and forms characteristic ridges and mounds of sand and gravel, known as osars, or eskers, and kames. The material deposited by the ice is called glacial drift; that washed from the ice onto the adjacent land is called modified drift. It is usual also to class as surficial rocks the deposits of the sea and of lakes and rivers that were made at the same time as the ice deposit.

AGES OF ROCKS.

Rocks are further distinguished according to their relative ages, for they were not formed all at one time, but from age to age in the earth's history. Classification by age is independent of origin; igneous, sedimentary, and surficial rocks may be of the same age.

When the predominant material of a rock mass is essentially the same, and it is bounded by rocks of different materials, it is convenient to call the mass throughout its extent a *formation*, and such a formation is the unit of geologic mapping.

Several formations considered together are designated a *system*. The time taken for the deposition of a formation is called an *epoch*, and the time taken for that of a system, or some larger fraction of a system, a *period*. The rocks are mapped by formations, and the formations are classified into systems. The rocks composing a system and the time taken for its deposition are given the same name, as, for instance, Cambrian system, Cambrian period.

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be discovered by observing their relative positions. This relationship holds except in regions of intense disturbance; sometimes in such regions the disturbance of the beds has been so great that their position is reversed, and it is often difficult to determine the relative ages of the beds from their positions; then *fossils*, or the remains of plants and animals, are guides to show which of two or more formations is the oldest.

Strata often contain the remains of plants and animals which lived in the sea or were washed from the land into lakes or seas or were buried in surficial deposits on the land. Rocks that contain the remains of life are called fossiliferous. By studying these remains, or fossils, it has been found that the species of each period of the earth's history have to a great extent differed from those 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.

When two formations are remote one from the 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 found in the rocks of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

Colors and patterns.—To show the relative ages of strata, the history of the sedimentary rocks is divided into periods. The names of the periods in proper order (from new to old), with the colors and symbol assigned to each, are given in the table in the next column. The names of certain subdivisions and groups of the periods, frequently used in geologic writings, are bracketed against the appropriate period names.

To distinguish the sedimentary formations of any one period from those of another the patterns for the formations of each period are printed in the appropriate period-color, with the exception of the one at the top of the column (Pleistocene) and the one at the bottom (Archean). The sedimentary formations of any one period, excepting the Pleistocene and the Archean, are distinguished from one another by different patterns, made of parallel straight lines. Two tints of the period-color are used: a pale tint is printed evenly over the whole surface representing the period; a dark tint brings out the different patterns representing formations. Each formation is furthermore given

Period.		Symbol.	Color.
Cenozoic	Pleistocene	P	Any colors.
	Neocene (Pliocene, Miocene)	N	Buffs.
	Eocene, including Oligocene	E	Olive-browns.
Mesozoic	Cretaceous	K	Olive-greens.
	Juratrias (Jurassic, Triassic)	J	Blue-greens.
Paleozoic	Carboniferous, including Permian	C	Blues.
	Devonian	D	Blue-purples.
	Silurian, including Ordovician	S	Red-purples.
	Cambrian	Є	Pinks.
	Algonkian	A	Orange-browns.
	Archean	Æ	Any colors.

a letter-symbol composed of the period letter combined with small letters standing for the formation name. In the case of a sedimentary formation of uncertain age the pattern is printed on white ground in the color of the period to which the formation is supposed to belong, the letter-symbol of the period being omitted.

The number and extent of surficial formations, chiefly Pleistocene, render them so important that, to distinguish them from those of other periods and from the igneous rocks, patterns of dots and circles, printed in any colors, are used.

The origin of the Archean rocks is not fully settled. Many of them are certainly igneous. Whether sedimentary rocks are also included is not determined. The Archean rocks, and all metamorphic rocks of unknown origin, of whatever age, are represented on the maps by patterns consisting of short dashes irregularly placed. These are printed in any color, and may be darker or lighter than the background. If the rock is a schist the dashes or hachures may be arranged in wavy parallel lines. If the metamorphic rock is known to be of sedimentary origin the hachure patterns may be combined with the parallel-line patterns of sedimentary formations. If the rock is recognized as having been originally igneous, the hachures may be combined with the igneous pattern.

Known igneous formations are represented by patterns of triangles or rhombs printed in any brilliant color. If the formation is of known age the letter-symbol of the formation is preceded by the capital letter-symbol of the proper period. If the age of the formation is unknown the letter-symbol consists of small letters which suggest the name of the rocks.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology sheet.—This sheet shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any particular colored pattern and its letter-symbol on the map 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 given formation, its name should be sought in the legend and its color and pattern noted, when 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 symbols and names are arranged, in columnar form, according to the origin of the formations—surficial, sedimentary, and igneous—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology sheet.—This sheet represents the distribution of useful minerals, the occurrence of artesian water, or other facts of economic interest, showing their relations to the features of topography and to the geologic formations. All the formations which appear on the historical geology sheet are shown on this sheet by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A symbol for mines is introduced at each occurrence, accompanied by the name of the principal mineral mined or of the stone quarried.

Structure-section sheet.—This sheet exhibits the relations of the formations beneath the surface.

In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which exhibits those relations is called a *section*, and the same name 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 the natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of the formation of rocks, and having traced out the relations among beds on the surface, he can infer their relative positions after they pass beneath the surface, draw sections which represent the structure of the earth to a considerable depth, and construct a diagram exhibiting what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

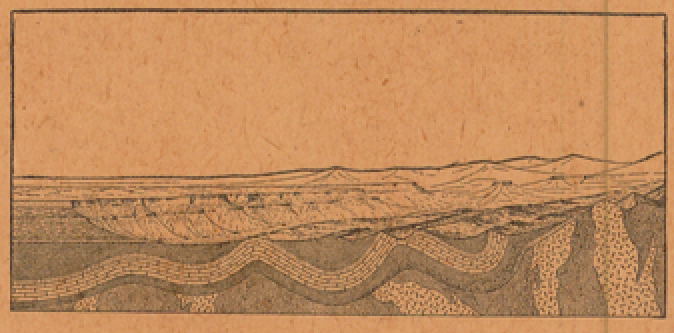


Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground by a vertical plane, so as to show the underground relations of the rocks.

The kinds of rock are indicated in the section by appropriate symbols of lines, dots, and dashes. These symbols admit of much variation, but the following are generally used in sections to represent the commoner kinds of rock:

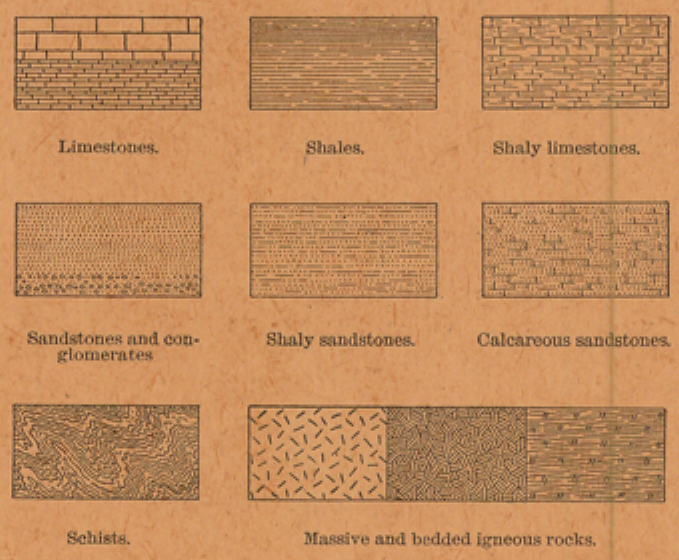


Fig. 3.—Symbols used to represent different kinds of rock.

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section.

The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to beds of sandstone that rise to the surface. The upturned edges of these beds form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shales.

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 that the intersection of a bed with a horizontal plane will take is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

When strata which are thus inclined are traced underground in mining, or by inference, it is frequently observed that they form troughs or arches, such as the section shows. The arches are called *anticlines* and the troughs *synclines*. But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets. That they are now bent and folded is regarded as proof that forces exist which 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 slipped past one another. Such breaks are termed *faults*.

On the right of the sketch the section is composed of schists which are traversed by masses of igneous rock. 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 well-founded inference.

In fig. 2 there are three sets of formations, distinguished by their underground relations. The first of these, seen at the left of the section, is the set of sandstones and shales, which lie in a horizontal position. These sedimentary strata are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has swelled upward from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable*.

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

The horizonal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger strata thus rest upon an eroded surface of older strata the relation between the two is an *unconformable* one, and their 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 plicated by pressure and traversed by eruptions of molten rock. But this pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that an interval of considerable duration elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists suffered metamorphism; they were the scene of eruptive activity; and they were deeply eroded. The contact between the second and third sets, marking a time interval between two periods of rock formation, is another unconformity.

The section and landscape in fig. 2 are ideal, but they illustrate relations which actually occur. The sections in the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profiles of the surface in the section correspond 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 which appears in the section may be measured by using the scale of the map.

Columnar section sheet.—This sheet contains a concise description of the rock formations which occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thicknesses of the formations, and the order of accumulation of successive deposits.

The rocks are described under the corresponding heading, and their characters are indicated in the columnar diagrams by appropriate symbols. The thicknesses of formations are given in figures which state the least and greatest measurements. The average thickness of each formation is shown in the column, which is drawn to a scale — usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement: the oldest formation is placed at the bottom of the column, the youngest at the top, and igneous rocks or surficial deposits, when present, are indicated in their proper relations.

The formations are combined into systems which correspond with the periods of geologic history. Thus the ages of the rocks are shown, and also the total thickness of each system.

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

CHARLES D. WALCOTT,
Director.

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