DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS

OF THE

UNITED STATES

RARITAN FOLIO

NEW JERSEY

BY

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SURVEYED IN COOPERATION WITH
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GEOLOGIC ATLAS OF THE UNITED STATES.

The Geological Survey is making a geologic atlas of the United States, which is being issued in parts, called folios. Each folio includes topographic and geologic maps of a certain area, together with descriptive text.

THE TOPOGRAPHIC MAP.

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

Relief.—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those of the most important ones are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the outline or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above mean sea level, the vertical interval represented by each space between lines being the same throughout each map. These lines are called *contour lines* or, more briefly, *contours*, and the uniform vertical distance between each two contours is called the *contour interval*. Contour lines and elevations are printed in brown. The manner in which contour lines express altitude, form, and grade is shown in figure 1.

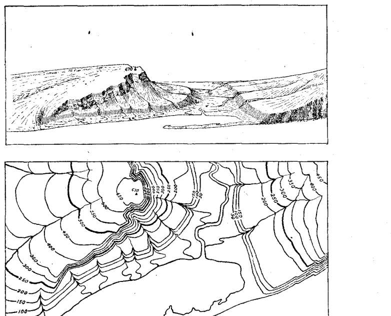


FIGURE 1.—Ideal view and corresponding contour map.

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

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

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

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

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

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

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

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

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

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

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

THE GEOLOGIC MAPS.

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

KINDS OF ROCKS.

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

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

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

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

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

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

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

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

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

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

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

FORMATIONS.

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

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

AGES OF ROCKS.

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

The sedimentary formations deposited during a period are grouped together into a *system*. The principal divisions of a system are called *series*. Any aggregate of formations less than a series is called a *group*.

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

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

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

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

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

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

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

Symbols and colors assigned to the rock systems.

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

SURFACE FORMS.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

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

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

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

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

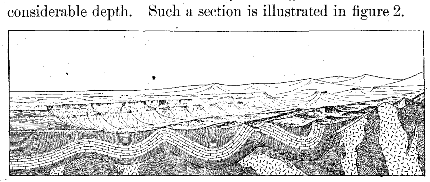


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

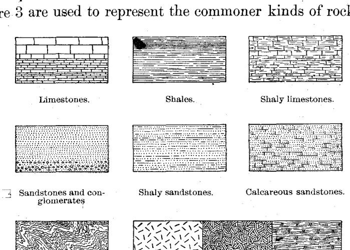


FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

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

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

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

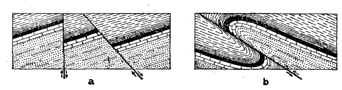


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

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

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

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

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

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

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

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

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

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

GEORGE OTIS SMITH,
Director.

May, 1909.

DESCRIPTION OF THE RARITAN QUADRANGLE.

By W. S. Bayley, H. B. Kümmel, and R. D. Salisbury.[a]

INTRODUCTION.

GENERAL RELATIONS.

Position and area.—The Raritan quadrangle lies between parallels 40° 30′ and 41° and meridians 74° 30′ and 75° and comprises four smaller (15′) quadrangles—the Hackettstown, Lake Hopatcong, High Bridge, and Somerville—covering an area of 905.27 square miles. It is in northern New Jersey (see fig. 1) and includes parts of Hunterdon, Middlesex, Morris, Somerset, Sussex, and Warren counties and contains the cities of Somerville, Dover, Washington, and Hackettstown. It is named from Raritan River, the chief stream within its borders.

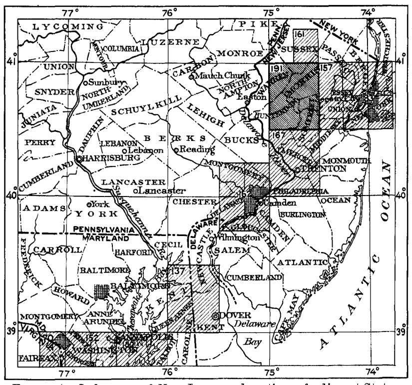


FIGURE 1.—Index map of New Jersey and portions of adjacent States.

The location of the Raritan quadrangle (No. 191) is shown by the darker ruling. Published folios describing other quadrangles, indicated by lighter ruling, are the following: Nos. 70, Washington; 83, New York City; 137, Dover; 152, Patuxent; 157, Passaic; 161, Franklin Furnace; 162, Philadelphia; 167, Trenton; 182, Choptank.

Geologic provinces.—The Atlantic slope of the United States is included in two geologic provinces—the Coastal Plain, which borders the Atlantic from Massachusetts Bay southward, and the Appalachian province, which extends from the Coastal Plain westward to the Mississippi lowland and from central Alabama northeastward into Canada. The line separating the two provinces runs obliquely across New Jersey from a point near Perth Amboy to Trenton. Each province is a fairly distinct geologic and physiographic unit, whose general geologic history, as recorded in its rocks, geologic structure, and physiographic development, is nearly the same throughout each part of the province. The provinces differ, however, in their rocks and geologic structure and hence have had dissimilar histories. In its general geographic and geologic relations the Raritan quadrangle is part of the Appalachian province, but its southeast corner is close to the inner margin of the Coastal Plain and, indeed, contains a few remnants of deposits that are peculiar to the Coastal Plain province.

GENERAL GEOGRAPHY AND GEOLOGY OF NORTHERN NEW JERSEY.

TOPOGRAPHY.

Appalachian province.—The Appalachian province comprises several major divisions, three of which—the Appalachian Valley, the Appalachian Mountains, and the Piedmont Plateau—enter New Jersey.

The Appalachian Valley, the central division of the province, is a broad belt of valleys and subordinate ridges lying between the Appalachian Mountains on the east and the Appalachian Plateau on the west and extending throughout the length of the province. Its surface is in general much lower than that of the adjacent divisions, though in parts of its length the crests of some of the subordinate ridges have approximately the same altitude as the neighboring Appalachian Plateau. From Virginia southwestward the minor ridges become progressively lower and the belt as a whole is occupied by a broad valley—the "Valley" of east Tennessee and the Coosa Valley of Georgia and Alabama. From Virginia to New York State the western side of the belt is broken by high, sharp ridges and only the eastern side is occupied by the great valley, to which various local names are given. Northeast of the Hudson the divisions of the province lose much of their definite character, but the Appalachian Valley is continued in the Champlain Valley of western Vermont.

In New Jersey the eastern part of the belt is occupied by the broad Kittatinny Valley and the western part by the narrow Delaware Valley, the two being separated by the bold even-crested ridge of Kittatinny Mountain, which, although one of the minor ridges in the Appalachian Valley belt, reaches a greater altitude than the Highlands east of the valley.

The Appalachian Valley is bounded on the east by the Appalachian Mountains, which in the middle Atlantic States form a rather narrow belt of irregular, more or less interrupted ridges, nowhere of great altitude but as a rule rising rather abruptly from the lower country on either side. South of the Potomac the belt is broader, in western North Carolina reaching a width of 60 miles and culminating in the highest summits of the eastern United States. In the southern Appalachians the rather sinuous divide between the streams flowing to the Ohio and those flowing directly to the Atlantic is called the Blue Ridge. For much of its length the Blue Ridge defines the eastern limit of the Appalachian Mountain belt and forms a bold scarp facing southeast, toward the Piedmont Plateau.

In New Jersey the Appalachian Mountains form a belt from 10 to 25 miles wide, known as the Highlands, which crosses the northern part of the State southeast of the Kittatinny Valley. The Highlands consist of several broad, rounded or flat-topped ridges, rising 400 to 600 feet above the lowlands on either side and separated by deep and generally narrow valleys. Near the Delaware the Highlands are lower and are broken by broad interhighland valleys. They continue southwestward into Pennsylvania for a few miles as low irregular ridges. They extend northeastward into New York to and across the Hudson, beyond which they lose their distinctive character.

The easternmost division of the Appalachian province, lying east and southeast of the mountain belt, is the Piedmont Plateau. From New York southward it is bounded on the east by the Coastal Plain. Its surface is that of a dissected plateau, which slopes gently eastward or southeastward from the base of the Appalachian Mountains and is broken here and there by knobs or ridges that rise several hundred feet above its surface. In the southern Appalachian region, where it lies well inland, the Piedmont Plateau stands at a considerable altitude, but toward the northeast it is lower, and in the vicinity of New York City it falls to sea level.

In New Jersey the Piedmont Plateau displays few of the characters of a plateau. It is chiefly a lowland of gently rounded hills separated by wide valleys, with some ridges and isolated hills rising conspicuously above the general surface, which slopes gently from about 400 feet above sea level at its northwestern margin to about 100 feet along its southeastern border near the Delaware and to sea level at New York Bay.

Coastal Plain.—All of New Jersey southeast of a line from Trenton to a point near Perth Amboy is part of the Coastal Plain. Its surface is in general a dissected plain that rises gradually from sea level at the coast to about 300 feet in central New Jersey. At its inner margin, along the boundary between it and the Piedmont Plateau, it includes a broad, shallow depression lying less than 100 feet above sea level and extending from Raritan Bay to the Delaware at Trenton.

The surface of the Coastal Plain extends eastward with the same gentle slope beneath the water of the Atlantic for about 100 miles, where, at a depth of approximately 100 fathoms, it is bounded by a steep escarpment, along which the ocean bottom slopes abruptly to abysmal depths. This submerged part of the Coastal Plain is known as the continental shelf.

Drainage.—Hudson and Delaware rivers flow in a general southerly direction obliquely across the eastern part of the Appalachian province, and the part of the province in northern New Jersey is drained by tributaries of those rivers or of New York Bay. The Kittatinny Valley is drained in part northeastward into the Hudson, in part southwestward into the Delaware. The western part of the Highlands is drained by tributaries of the Delaware, the southern and southeastern Highlands by tributaries of the Raritan, and the northern and northeastern Highlands chiefly by tributaries of the Passaic. The Raritan and Passaic flow into branches of New York Bay.

GEOLOGY.

Though the several divisions of the Appalachian province can be distinguished geologically in a broad way, yet throughout the province as a whole they exhibit no sharp geologic differences. In the central and southern Appalachians the Piedmont Plateau and the Appalachian Mountain belt are not separated by a sharp geologic boundary, and in many places geologic formations extend continuously from the mountain belt into the great valley. In the general region including northern New Jersey, southeastern New York, and eastern Pennsylvania, however, the conditions are somewhat different. Each of the physiographic subdivisions is strikingly different from the others in geologic character, although even here absolute lines can not be drawn, as some formations are common to all three.

Highlands belt.—The Highlands of southeastern New York, northern New Jersey, and eastern Pennsylvania are formed chiefly of highly metamorphosed rocks of pre-Cambrian age, which occupy a roughly hook-shaped area extending northeastward from the Reading Hills in Pennsylvania to southern Dutchess County in New York, thence recurving southward to Manhattan Island. The rocks consist of gneisses and schists, possibly in part of sedimentary origin, with some marble or crystallized limestone, and of intrusive igneous rocks, also gneissoid for the most part. They have been greatly deformed, probably more than once, and are now complexly folded and faulted. Infolded with the pre-Cambrian crystalline rocks, and for the most part occupying the narrow valleys which separate the ridges of the Highlands, are strips of more or less metamorphosed Paleozoic strata. The folds have the general northeast-southwest trend characteristic of the Appalachians and are roughly parallel to the trend of the Highlands as a whole. The foliation planes of the gneiss dip southeastward generally but not universally.

Kittatinny Valley.—Throughout its length the Appalachian Valley is underlain by early Paleozoic strata, chiefly of Cambrian and Ordovician age. The minor valleys are floored with less resistant rocks, such as limestone and soft shale, and the minor ridges are formed of sandstone, hard shale, and less soluble limestone. In the northern New Jersey region the Kittatinny Valley is occupied chiefly by limestone and shale of Cambrian and Ordovician age, Kittatinny Mountain is formed by resistant sandstone and conglomerate of Silurian age, and the Delaware Valley is occupied by shale and limestone of early Devonian age. The strata, which are of the same age as those infolded with the pre-Cambrian rocks of the Highlands, have been considerably folded and faulted but little or not at all metamorphosed. The folds and faults here, as in the Highlands area, have a general northeast-southwest trend. The oldest rocks are exposed along the eastern side of the valley at the western base of the Highlands. Northwesterly dips predominate.

Piedmont Plateau.—The rocks of different parts of the Piedmont Plateau differ widely in age. Southwest of the Delaware the Piedmont is occupied largely by metamorphic igneous and sedimentary rocks, similar in most respects to many of those of the Appalachian Mountains, but it includes several large areas of Triassic rocks, a few smaller areas of highly metamorphosed Paleozoic strata, and a great abundance of intrusive granite. Similarly, east of the Hudson the region that corresponds geographically and geologically to the Piedmont Plateau and that may be considered its northeastern extension is occupied chiefly by igneous and metamorphic rocks of pre-Cambrian and Paleozoic age, with included areas of Triassic rocks and others of highly metamorphosed sediments regarded by some geologists as Paleozoic and by others as pre-Cambrian. In northern New Jersey, however, the Piedmont Plateau is underlain almost wholly by Triassic strata and associated volcanic rocks. Near Trenton a small area of pre-Cambrian schists forms the northeastern extremity of the great pre-Cambrian area of the Piedmont of the southern Atlantic States, and several small areas of more or less metamorphosed Paleozoic sediments lie along the inner margin of the Piedmont at the southeastern base of the Highlands.

The Triassic area of New Jersey is part of a belt occupied by Triassic strata extending from the Hudson across New Jersey, Pennsylvania, and Maryland into Virginia. The rocks consist of shale, sandstone, and conglomerate, with intercalated volcanic flows and intrusive sills. The strata have been tilted, as a rule northwestward, and here and there warped into gentle folds, with more or less faulting. Although there are numerous local variations the general trend of the folds is northeast and southwest, as in the other districts, and a northwesterly dip prevails.

The Paleozoic strata occupying several areas along the base of the Highlands have been complexly folded and faulted and dip in various directions, although the prevailing dip is westward or southwestward.

[a] In general the parts of the text that treat of pre-Cambrian rocks, structure, and events were written by W. S. Bayley, those treating of the Paleozoic and Mesozoic geology by H. B. Kümmel, and those treating of Quaternary deposits and history by R. D. Salisbury and H. B. Kümmel. A considerable portion of the "Introduction" and a few minor parts of the text were prepared in the office of the United States Geological Survey.

Coastal Plain.—The Coastal Plain is formed chiefly of beds of clay, sand, gravel, and other lightly cohering rocks of Cretaceous, Tertiary, and Quaternary age. These strata occupy a belt beginning at Raritan Bay and extending southwestward along the coast into Mexico. Northeast of Raritan Bay similar strata underlie the southern parts of Staten Island, Long Island, and probably the other islands off the southern coast of New England, as well as the Cape Cod peninsula.

In New Jersey the beds lie nearly level, sloping gently southeastward to the coast. They are not appreciably deformed.

Surficial deposits.—Throughout northern New Jersey the valleys of the larger streams are floored with alluvium, and deposits of sand and gravel form terraces along the slopes bordering some of the valleys. Much of the surface, especially that north of an irregular line marked by a more or less prominent glacial moraine extending from Perth Amboy through Morristown, Dover, and Hackettstown to Belvidere, is mantled by a deposit of glacial drift, in some places sufficiently thick to obscure entirely the relief of the bedrock surface. Scattered bowlders of glacial origin are found in many places south of the line of the moraine.

GENERAL GEOLOGIC RECORD.

In pre-Cambrian times the ancient sedimentary rocks of the region, including considerable masses of limestone and some highly carbonaceous beds, were extensively intruded by massive igneous rocks, the whole complex being later subjected to great deformation and accompanying metamorphism. At the beginning of the Cambrian period the region, after being subjected to prolonged erosion, was invaded by the sea and was submerged for a long time, during which a thick series of sediments was laid down, which subsequently became the stratified rocks of the Cambrian and Ordovician systems. Near the close of the Ordovician period the land was elevated and the sea withdrew for a time. It is believed that the early Paleozoic strata of neighboring regions were somewhat deformed at this time, but this has not been demonstrated for the northern New Jersey region.

Late in the Silurian period, after an interval of erosion during which some of the material previously deposited was removed, the sea again invaded at least the western part of the area, and another considerable series of sediments was deposited. Toward the close of the Devonian period the sea again withdrew from the region, and the absence of strata of later age indicates that the area has not since been entirely submerged. Near the close of the Paleozoic era extensive crustal disturbances resulted in the deformation of the greater part of the Appalachian province, with the uplift of a large part of eastern North America and the formation of a great mountain system.

Late in the Triassic period a series of troughs or basins was formed east of the Appalachian Mountain belt, in which much material derived from the adjacent land was deposited as a thick body of sediment, including local conglomerates along the margins of the basins. During this deposition sheets of volcanic rock were erupted upon the surface and became interbedded with the sediments; other igneous masses were intruded into the sediments, perhaps at a somewhat later time. At its close tilting and faulting occurred, somewhat deforming the strata just deposited.

After another long interval of erosion the sea advanced from the southeast over part of the area, depositing beds of sand and clay during the later part of the Cretaceous period. While uplift was renewed the surface was worn to a lower level and the landward edge of the recently deposited strata was removed. Early in the Tertiary, during another subsidence, the sea again approached the southeastern border of the area, spreading another sheet of deposits. Minor oscillations of land and sea, with alternations of erosion and deposition, continued throughout the Tertiary and into the Quaternary and are recorded in the physiographic features formed and the stream gravels deposited at those times.

During the Pleistocene epoch a great sheet of land ice advanced southward over part of the area, slightly modifying the topography and leaving extensive deposits of glacial drift. At least two such ice advances are recorded in the drift deposits now existing in the area.

CLIMATE AND VEGETATION.

The mean annual temperature of the Kittatinny Valley and of the Highlands is 47.4° F. and of the Triassic plain 50.6°. The summer on the Highlands is not marked by so great extremes of heat as on the plains, the night temperature in particular being notably lower. In the autumn frosts come later on the hills and ridges of the Highlands than in the adjoining valleys, but the low and wet swampy depressions among the hills, especially north of the moraine, are not thus favored. Generally there are no frosts which injure vegetation much before October and in some years no severe frosts occur before the first of November. In many years snow falls a fortnight earlier in the Highlands than on the Triassic plain, and there is often a marked difference in the amount of snowfall on the Highlands and in the interhighland valleys.

The prevailing winds are from the west; in the summer from the southwest or south of west, and in the winter from north of west and northwest.

The average annual rainfall in the Highlands and Kittatinny Valley is about 44 inches. In ordinary dry years it falls as low as 35 inches and in wet years it reaches 50 inches or more. On the Triassic plain the average rainfall is somewhat greater—nearly 46 inches, owing to its nearness to the sea. In the Raritan quadrangle, however, the difference between the two regions is probably not so marked. The rainfall is almost equally distributed between the different seasons, although there is a slight excess in the summer—28 per cent as against 24 per cent for each of the other seasons. July and August have the heaviest average rainfall—each over 4 inches—due to the prevalence of summer thunderstorms. February and October are the driest months, the average rainfall for each being about 3.31 inches in the Highlands and 3.45 inches on the plain.

Kittatinny Valley, the interhighland valleys, and the Triassic lowland have been largely deforested, the remaining timber being chiefly scattered woodlots. North of the moraine the Highlands are well wooded, and south of it about 50 per cent of the area is still in timber, all of it second growth. The ridges that rise above the lowland are mostly forest clad.

The forests of northern New Jersey are of the mixed hardwood type, the chief components being chestnut, rock oak, white oak, red oak, hickory, maple, elm, and beech. Conifers are represented only by pitch pine and white pine, which occupy the thinnest soils on the ridges; by red cedar in old fields or openings; and by hemlock and black spruce in moist ground. By repeated unregulated cutting and to some extent by fires the value and productiveness of the forest has become low; this condition, however, is being remedied by degrees through the growing disposition of the owners to practice forestry, and a better forest is in prospect.

TOPOGRAPHY.

The Raritan quadrangle includes parts of the three divisions of the Appalachian province found in New Jersey. Its northwest corner is crossed by the Kittatinny Valley, nearly the entire width of which lies within it; the Highlands extend diagonally across its center; and its southeastern part lies within the Piedmont Plateau. The quadrangle includes no part of the Coastal Plain, the eastern margin of the Piedmont Plateau lying a few miles east of its southeast corner.

All the larger topographic features of the quadrangle are the result of long-continued erosion, which acted on rocks of various kinds of structure or texture and of different degrees of resistance, in several geologic periods, during which the land stood at various altitudes above sea level. The successive steps in the development of these features are discussed under the heading "Geologic history" (pp. 20–23).

RELIEF.

KITTATINNY VALLEY.

The Kittatinny Valley, only a small part of which is included in the Raritan quadrangle, is occupied by belts of shale and limestone, trending northeast and southwest, the limestone lying in subordinate valleys within the greater depression. The valley in which Blairstown is situated and the similar one extending southwestward from Andover are such minor limestone valleys, and the belt of higher ground between Blairstown and Johnsonburg is a shale ridge.

The general surface of the shale belts is a rolling plateau, trenched by streams and everywhere so much eroded as to obscure and in some places to obliterate its plateau character, which, however, is evident north and northeast of Jacksonburg, just outside the quadrangle. Many of the minor streams flow for considerable distances along the strike of the beds, thus cutting the plateau into fairly well marked parallel ridges, and then, turning at right angles, join the main streams by passing through deep, narrow "cloves." In other places the plateau is so much cut up by valleys that it is merely a confused assemblage of hills whose tops approach a common altitude. Smooth and flowing outlines nearly everywhere characterize the shale belts, and where the glacial drift is thin, as it is in many places, small circular shale knolls or ridges stand on the tops and sides of the larger hills. The alternation of hard and soft beds gives much of the surface a fluted appearance.

The surface of the shale belts ranges in general altitude from 750 to 1000 feet above sea level. It is highest toward the northwest and slopes southeastward and southwestward. The old plateau surface was far from level, but it was much less hilly than the present surface and its average altitude was about 300 feet below that of the bordering uplands.

The limestone belts are marked by irregular hills and ridges, similar in general features to those of the shale belts but less pronounced. The hilltops are remnants of a former plain that stood 100 to 250 feet below that marked by the tops of the shale hills. Certain rock benches along large streams that traverse the shale belts, as along Paulins Kill east of Marksboro, have been correlated with this surface, but in general it has not been recognized in the Kittatinny Valley except in the limestone areas.

In detail the relief of the limestone belts presents strong contrasts to that of the shale belts. Rough, angular weathered knolls give the surface a strikingly warty appearance, a feature that is emphasized where, as west of Allamuchy, rocky hills rise abruptly above plains of glacial drift. The limestone belts are also characterized by sinks, or depressions. These sinks differ greatly in size and shape, some being 20 to 50 feet deep, nearly circular, and steep sided, and others being mere shallow saucer-shaped depressions. Small streams flow into some of these depressions and disappear underground; others are occupied by swamps or small ponds.

THE HIGHLANDS.

General features.—The Highlands occupy about 465 square miles of the central, northeastern, and western parts of the quadrangle. The district is in general a plateau of erosion formed by resistant rocks and having a nearly uniform altitude, ranging from 800 feet above sea level in the southwestern part of the quadrangle to 1330 feet in its northeastern corner. The plateau, however, is so intersected by valleys that in many places it loses its plateau character and is made up of broad-topped, steep-sided ridges trending northeast and southwest and separated by valleys from 1 to 3 miles wide. So completely are the Highlands interrupted by these valleys and so widely are the parts separated, particularly in and west of the Raritan quadrangle, that the divisions have received distinct names, as Jenny Jump, Scott, Allamuchy, Pohatcong, Schooley, and Green Pond mountains. The mountain last named differs from the others in that the rocks forming it are not pre-Cambrian, like those of the Highlands proper, but are much younger. Geologically this mountain belongs with the interhighland valleys, topographically it is part of the Highlands.

The broad, flat tops of the mountains in the Highlands are remnants of a dissected plateau surface, sloping generally from an altitude of 1100 to 1200 feet at the north side of the quadrangle to 850 to 900 feet at the western side and to 700 feet along the southeastern margin of the plateau. A few summits rise 50 to 100 feet above the general surface.

Vermeule and Salisbury have divided the Highlands of New Jersey into the western Highlands, the central Highlands, and the Passaic Range, each consisting of a belt of high land trending northeast and southwest and separated from the other belts by rather extensive valleys. All the ranges enter the Raritan quadrangle, the first two crossing it and the third ending in its south-central part.

Western Highlands.—The western Highlands cross the quadrangle from a point near the middle of its north side, between Andover and Lubber Run, to a point near the middle of its west side. In the northwestern part the range faces the Kittatinny Valley and its southeastern part is separated from the central Highlands by the Musconetcong Valley and the valley of Lubber Run.

The surface of the western Highlands is very irregular, in this respect contrasting strongly with the central Highlands. It includes no extensive flats at high altitudes and no long, uninterrupted crest lines. The higher points are peaks, short ridges, or groups of individual hills, separated by little depressions, some of which have the character of distinct valleys. Though the surface of the range is seemingly very irregular, yet the highest crests have nearly the same altitudes, decreasing from a little more than 1200 feet above sea level at its north end to about 1140 feet at its west end. The highest point of the range in the quadrangle is a sharp peak which rises to 1248 feet east of Allamuchy.

Central Highlands.—The central Highlands cross the quadrangle from its northeast corner, between Green Pond and Lubber Run, to its western side, between Junction and High Bridge. Throughout this distance—about 35 miles—they maintain a fairly even width of about 4½ miles, but at Schooley Mountain their width is only about 3 miles. In the northern part of the quadrangle the surface is much broken into many knobs and short ridges, separated by irregular depressions, in the lowest of which lies Lake Hopatcong, whose surface stands 928 feet above sea level. The highest of the surrounding knobs stands about 1200 feet above sea level, but two in the extreme northeastern part of the quadrangle reach altitudes of 1324 and 1333 feet respectively, the latter being the highest point in the quadrangle.

That portion of the range between Netcong Gap and the valley of Spruce Run at Glen Gardner forms the well-known Schooley Mountain, whose fairly smooth flat top stands about 1000 feet above sea level and whose sides have steep slopes. The highest points in the range reach altitudes exceeding 1200 feet at the north but gradually decrease southwestward to 950 feet. Its surface is gently rolling and its sky line, as viewed from the northwest or southeast, is almost unbroken. It is a typical remnant of the former plateau surface of the Highland belt.

Passaic Range.—The Passaic Range lies east of the central Highlands and is separated from them by the upper valley of

Rockaway River and German Valley. It enters the quadrangle along the north half of the east side and extends southwestward like the other ranges, but unlike them it terminates within the quadrangle. For about 6 miles within the quadrangle it has an approximate width of 9 miles. Northeast of Gladstone a small valley divides it into two lobes, the eastern lobe ending a little north of Far Hills and the western lobe extending about 12 miles farther and ending near High Bridge.

The Passaic Range is lower than the central Highlands, its highest point, which has an altitude of 1130 feet, being Hickory Hill, near Middle Forge, in the northeastern corner of the quadrangle. The average altitude of the peaks in this part of the range is between 1000 and 1050 feet. From these points the altitude gradually decreases southwestward. Mine Mountain, near the end of the southeastern lobe, is a little over 920 feet above sea level, and a summit at Mountainville, near the end of the southwestern lobe, stands at 957 feet. The range on the whole is more dissected than the central Highlands and its separation into isolated points is rather conspicuous along its eastern side.

Because of the irregular dissection of the Passaic Range in the Raritan quadrangle its general northeast-southwest trend is not so noticeable as that of the other ranges, but along the east side of German Valley, in the Fox Hill Range, a linear series of steep-sided knobs 13 miles long and not much over half a mile wide, this trend is very marked. Toward the northeast the Fox Hill Range attains a width of about $1\frac{1}{4}$ miles and is somewhat plateau-like.

The Passaic Range is crossed by two gaps. The northern one is occupied by Rockaway River, which makes a right-angled turn at Wharton and crosses the range in a steep-sided valley with a fairly flat and partly swamp-covered floor, and the southern by Black River, which, like the Rockaway, suddenly changes from a longitudinal to a transverse stream, leaves the swampy valley in which it flows for some miles, and crosses the mountains through a narrow defile which in some places is a true gorge.

Interhighland valleys.—The northeast-southwest interhighland valleys which break the Highlands into separate mountain masses range in width from 1 to 3 miles. Their bottoms are by no means level, yet compared with the slopes and heights of the bordering uplands, it is not inappropriate to term them flat-bottomed. The main streams which drain them flow in steep-sided trenches with narrow flood plains, 80 to 100 feet and in some places even 200 feet below the general valley bottom. In Musconetcong Valley the valley floor shows two distinct levels, the higher 650 to 700 feet, the lower 450 to 500 feet above sea level. They are correlated with the two dissected plateau surfaces of the Kittatinny Valley.

PIEDMONT PLATEAU.

General features.—In its southern and southeastern portions the quadrangle includes about 353 square miles of the Piedmont Plateau. The surface as a whole is considerably lower than that of the Highlands, but the two districts are not separated by so prominent an escarpment as that in quadrangles farther northeast. The surface has a general slope southeastward but presents considerable diversity in altitude, ranging from 20 feet above sea level in the valley of the Raritan, where it leaves the quadrangle, to over 700 feet at the highest point. The district may be divided broadly into three parts—the Hunterdon Plateau, the Raritan Valley lowland or Somerville Plain, and the high hills and ridges, locally called mountains.

Hunterdon Plateau.—The southwest corner of the quadrangle, west of Flemington and south of Jutland, is occupied by a broad flat-topped plateau having an altitude of 500 to 550 feet and a steep escarpment, 250 to 300 feet high, facing east and northeast toward the lowland. It is known locally as the Hunterdon Plateau. At its northeastern margin it is surmounted by a group of hills, the highest point of which, north of Cherryville, stands at an altitude of 706 feet above sea level.

The Hunterdon Plateau is formed by argillite and sandstone, which are more resistant to erosion than the shale of the lowland. Its surface rises northward and northwestward, and just west of the quadrangle it merges into the southwestern part of the Highlands and appears to be a part of the same dissected plateau that is preserved here and there in the Highlands. Therefore, although geographically and geologically a part of the Piedmont area, the Hunterdon Plateau is topographically and physiographically a part of the Highlands.

Raritan Valley lowland.—The greater part of the Piedmont Plateau within the Raritan quadrangle is a low rolling plain sloping southeastward from an altitude of 200 to 300 feet near the base of the Highlands escarpment to about 100 feet in the southeast corner of the quadrangle. It is trenched by streams that flow in shallow, rather steep-sided, and as a rule flat-floored valleys. The Raritan leaves the quadrangle near its southeast corner at an altitude less than 20 feet above sea level, the lowest point in the area.

This plain, which has been eroded chiefly in soft red shale, is a part of the Somerville Plain, which occupies so much of the Piedmont area in New Jersey. Along most of its northwestern margin in the Raritan quadrangle, next to the Highlands, more resistant rocks form a belt of irregular hills that rise to altitudes of 400 to 500 feet. There is no clear evidence that these hilltops are remnants of a former plateau level, but they are fairly concordant in altitude, and in their position between the Highlands Plateau and the Somerville Plain they appear to correspond roughly to the upper of the two dissected plateaus in the Kittatinny and Musconetcong valleys.

Ridges and hills.—Several crescentic ridges and isolated hills capped by highly resistant igneous rock rise boldly 400 to 500 feet above the lowland. First and Second Watchung mountains and Long Hill extend several miles into the area from the Passaic quadrangle on the east. The Watchung Mountains are convex southward and westward, having steep escarpments 300 to 400 feet high facing in that direction and much gentler slopes on the inside of the curve. In the Raritan quadrangle the crest of First Watchung Mountain is a little less than 500 feet above sea level; and that of Second Watchung Mountain is somewhat higher, reaching 653 feet at the highest point.

In the southwestern part of the quadrangle, but east of the Hunterdon Plateau, Cushetunk Mountain rises boldly 500 feet above the lowland. It is roughly horseshoe-shaped, its inner and outer slopes being about equally steep and high, and the highest points of its crest reach 820 feet above sea level. Just south of Cushetunk Mountain, Round Mountain, a bold round knob, stands 600 feet above sea level and over 300 feet above the lowland at its base.

The crests of these ridges and hills stand at altitudes closely concordant with that of the southeastern margin of the dissected plateau of the Highlands, and, like the Hunterdon Plateau, in their physiographic relations they belong with the Highlands, though geographically and geologically they are a part of the Piedmont area.

DRAINAGE.

GENERAL DIRECTION.

About two-thirds of the quadrangle is drained through Raritan and Passaic rivers into New York Bay and the remainder is drained by several streams into the Delaware. The divide between the two drainage areas is a somewhat irregular northeast-southwest line that crosses the quadrangle from a point just west of its northeast corner to a point a little south of the middle of its west side and follows the crest of the central Highlands range, here made up of Brookland, Schooley, and Musconetcong mountains. It reenters the quadrangle a few miles farther south and crosses the southwest corner in a sweeping zigzag line along the crest of the Hunterdon Plateau.

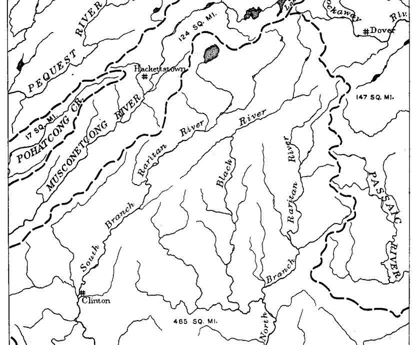


FIGURE 2.—Outline map showing drainage areas and main streams in the Raritan quadrangle.

About one-half the quadrangle, the central, southern, and southeastern parts, is in the drainage basin of the Raritan, which includes the larger part of the eastern slope of the Highlands within the area, German Valley, and all the Triassic lowland in the quadrangle except the part north of Second Watchung Mountain. The Passaic drainage basin includes the eastern and northeastern parts of the quadrangle, comprising the part of the Triassic lowland within the curve of the Watchung Mountains, Longwood and Green Pond valleys, and the part of the Passaic Range that lies east of an irregular line joining Bernardsville and Mine Hill. (See fig. 2.) Of the streams flowing to the Delaware, Musconetcong River drains the valley between the central and western Highlands and the adjacent slopes, and Pequest River and Paulins Kill drain the western slope of the western Highlands and the Kittatinny Valley. The back slope of the Hunterdon Plateau, in the southwest corner of the quadrangle, is drained by several short streams flowing to the Delaware.

STREAMS.

Raritan drainage.—Raritan River, the chief stream of the quadrangle and the one from which it is named, is formed by the confluence—3 miles above Raritan—of its north and south branches. South Branch, which drains German Valley, the adjacent slopes of the Highlands, and the part of the Triassic lowland that lies west and south of Cushetunk Mountain, rises in Budd Lake, 933 feet above sea level. It descends about 280 feet in the first 3 miles to a point where it enters German Valley at Bartley. The next 12 miles of its course is along German Valley, where its descent is only about 200 feet. Below Califon it enters a gorge 4 miles long through which it descends 240 feet, emerging from the Highlands below High Bridge at an altitude of 220 feet. From that point to its confluence with North Branch it falls only about 170 feet in 23 miles, taking a broadly curving course across the Triassic lowland. The river is 42 miles long and drains 276 square miles, most of which is within the quadrangle and includes about 100 square miles of the Highlands, but it has no important tributary except Spruce Run, which rises on Schooley Mountain and flows southwestward to Clarksville, where it turns southeastward and falls 160 feet in $2\frac{1}{2}$ miles through a deep gorge. It joins the main stream at Clinton.

North Branch drains a large area of the Passaic Range in the east-central part of the quadrangle and that part of the Triassic lowland between Cushetunk Mountain and the Watchung Mountains. The uppermost part of the main North Branch, known as Indian Brook, rises 4 miles southwest of Dover at an altitude of 1000 feet. At Ralston, about 6 miles downstream, where it flows for about 2 miles in a narrow valley occupied by Paleozoic rocks, it has descended to an altitude of only 400 feet. South of Ralston it turns into the Highlands again and crosses the southwest end of Mine Mountain in a tortuous gorge, emerging north of Far Hills at an altitude of about 200 feet above sea level. From that point to its confluence with South Branch it winds across the Triassic lowland, descending about 150 feet. Its total drainage area is 192 square miles, of which 92 square miles is drained by Lamington River, its principal tributary, which joins the main stream at Burnt Mill.

Lamington River, or Black River, as it is called above Pottersville, rises about a mile east of the outlet of Lake Hopatcong at an altitude of 1000 feet above sea level. It descends rapidly to Rustic, where it enters Succasunna Plains, across which it flows at an altitude of a little more than 700 feet. South of Succasunna it enters the valley separating the Fox Hill Range from the main Passaic Range and flows southwestward for 7 miles toward the head of the valley. North of Hacklebarney it turns southward and crosses the Passaic Range in a deep gorge, 6 miles long, which contains some of the wildest scenery in that part of the Highlands, descending 460 feet to Pottersville, where it emerges upon the Triassic lowland after plunging over a low fall. Its only important tributary is Rockaway Creek, which enters it from the west about 2 miles above Burnt Mill, where Lamington River joins the North Branch of the Raritan at about 80 feet above sea level.

The southeast corner of the quadrangle lies in the drainage basin of the united Raritan, which takes a general easterly course and leaves the quadrangle below Bound Brook at an altitude of only 17 feet above sea level. Below Somerville the stream is joined from the south by Millstone River, a large stream that enters the quadrangle from the south and flows but a few miles within it. Middle Brook and Bound Brook, which drain the southern slope of First Watchung Mountain, the crescentic Washington Valley between First and Second Watchung mountains, and a little of the inner slope of Second Watchung Mountain, enter the Raritan at Bound Brook.

Passaic drainage.—Passaic River rises at Mendham at an altitude of 600 feet and descends rapidly to an altitude of 280 feet at Franklin, where it emerges from the Highlands. It takes a general southerly course across the low ground, cutting through Long Hill in a short, narrow gorge at Millington. At the north foot of Second Watchung Mountain it turns abruptly northeastward and leaves the quadrangle at an altitude of less than 200 feet. It drains a little of the eastern slope of Mine Mountain and all the area within the curve of the Watchung Mountains. Whippany River, a tributary of the Passaic that joins the main stream outside the quadrangle, drains a part of the eastern slope of the Passaic Range. It rises east of Mount Freedom at an altitude of about 900 feet above sea level, flows southward a short distance and then northeastward, and leaves the east side of the quadrangle in the outskirts of Morristown at an altitude of about 300 feet.

Rockaway River, one of the chief branches of the Passaic, drains the northeastern part of the quadrangle, which it enters a little west of the northeast corner. It flows southwestward for 8 miles through Longwood Valley and there turns southeastward, flowing past Wharton and Dover and cutting through the Passaic Range in a tortuous but for the most part open valley, and leaving the east side of the quadrangle near Rockaway. In its course across the area, which lies wholly in deep valleys, it descends only about 240 feet, from 760 feet to 520 feet above sea level.

Delaware drainage.—Musconetcong River, the principal stream flowing to the Delaware, drains Musconetcong Valley and the adjacent slopes of the Highlands. It emerges from Lake Hopatcong at 928 feet above sea level, flows through Stanhope Reservoir at 859 feet, and takes a general westerly course for a few miles to Waterloo. From Waterloo to the point where it leaves the quadrangle, west of Junction, it takes a fairly direct southwesterly course along Musconetcong Valley. At Waterloo it is at 640 feet, at Hackettstown 520 feet, at Penwell 400 feet, and at the western margin of the quadrangle 320 feet above sea level. Its only important tributary is Lubber Run, which enters the quadrangle from the north and flows almost directly southwest to its junction with the main stream below Stanhope. Near the junction it receives the outlet of Cranberry Reservoir.

Pohatcong Creek rises on the slope of Pohatcong Mountain northeast of Mount Bethel and flows southwestward to the Delaware, draining the valley between Pohatcong and Scott mountains.

Pequest River drains the west slope of the western Highlands and a large part of the Kittatinny Valley. It enters the quadrangle from the north at Andover at 580 feet above sea level and flows southwestward for 13 miles, descending less than 70 feet in the distance. Near Danville it leaves the embayment of Kittatinny Valley occupied by the Great Meadows and turns sharply eastward into the Pequest Valley, in which it flows southwestward for 6 miles, descending 100 feet more. At Pequest Furnace it turns westward and flows out of the quadrangle in a gorge cut through the Jenny Jump Mountain range. Beaver Brook, an important tributary of the Pequest, drains the part of the Kittatinny Valley next northwest of Jenny Jump Mountain.

Paulins Kill, another stream flowing to the Delaware, crosses the northwest corner of the quadrangle and drains the northwest side of the Kittatinny Valley. In the southwest corner of the quadrangle, Lockatong and Wickecheoke creeks drain a part of the Hunterdon Plateau, and flow to the Delaware.

LAKES AND SWAMPS.

Lakes are fairly numerous in the part of the quadrangle that lies north of the terminal moraine of the Wisconsin ice sheet, which crosses the quadrangle from east to west on a line near Rockaway, Wharton, Shippenport, Saxton Falls, Vienna, and Townsbury. South of the moraine lie numerous mill ponds, none of them large, but no natural lakes except those which, like Budd Lake and Shongum Pond, lie in valleys that are dammed by the moraine. Of the lakes north of the moraine, Stanhope and Cranberry reservoirs and White Meadow Pond are almost wholly artificial and Lake Hopatcong and Denmark and Middle Forge ponds have been artificially enlarged by damming their outlets.

Lake Hopatcong is the largest lake in New Jersey. It covers nearly 4 square miles and lies 928 feet above sea level. Its outline is very irregular and its shore line, most of which is steep and densely wooded, is more than 40 miles long. It contains several islands. The lake is used as a storage reservoir for the Morris Canal and its water enters the canal at the summit level; hence not all of its water follows the normal course of drainage to the Delaware, as part of it is diverted eastward and eventually reaches New York Bay.

Budd Lake occupies a drift-dammed hollow at the northeast end of Schooley Mountain. Its area is 475 acres and it lies 933 feet above sea level. Its water finds outlet southward across the mountain into German Valley and the South Branch of the Raritan.

Other large lakes are Stanhope Reservoir (339 acres), Denmark Pond (172 acres), Cranberry Reservoir (154 acres), and Green Pond in Warren County (117 acres). Only the southwest end of Green Pond in Morris County is within the quadrangle. Cedar Lake, southwest of Blairstown, lies in a limestone sink and is drained by an underground outlet, and White Pond, north of Marksboro, is distinguished by a deposit of white marl, whence its name.

Small swamps are abundant in the region north of the terminal moraine, as well as in the undrained hollows in the moraine itself. Practically all these swamps are due to interference with drainage by glacial deposits. The area called Great Meadows, along Pequest River, is an imperfectly drained part of the bed of a Pleistocene lake that was formed behind the terminal moraine after the retreat of the ice.

Other swampy areas occupy low places in front of the terminal moraine, between it and higher ground on the south. A small swamp occupies the southwest end of Pequest Valley north of Oxford, and a much larger one extends from Succasunna Plains for 7 miles southwestward along the valley east of the Fox Hill Range. Others lie along Passaic River between Logansville and the point where it turns northeastward, at the north base of Second Watchung Mountain. Except in such places the part of the quadrangle south of the terminal moraine is well drained and is almost wholly free from swamps.

RELATION OF DRAINAGE TO GEOLOGY.

To a certain extent, especially in minor features, the courses of the streams of the quadrangle show some adjustment to the geologic structure or to the major features of relief. The main streams of the Kittatinny Valley flow southwestward, approximately parallel to the strike of the belts of rock, and as a rule are located along limestone belts rather than shale belts. Pequest River flows for much of its length on limestone and along the strike, as does Pohatcong Creek; also Musconetcong River from Waterloo down. Parts of the South Branch of the Raritan, of Black River, and of Rockaway River have similar relations. Many of the smaller streams, especially those in the Highlands, have courses that are directly dependent on the rock structure or on the larger features of the relief. The main divide—that separating the drainage flowing to the Delaware from that flowing to New York Bay—is also, for many miles of its length, adjusted and lies along the axis of the central Highlands. A similarly well adjusted divide between the Pequest and the Musconetcong follows the crest of Allamuchy Mountain.

On the other hand all the principal streams except Musconetcong River are, when their entire courses are considered, to a large extent independent both of the geologic structure and of the larger features of relief. Pequest River rises and flows for miles in the Kittatinny Valley but turns eastward to enter one of the interhighland valleys, from which it cuts its way out again through a mountain range. The North Branch of the Raritan flows from one highland range diagonally across a small limestone valley and into and across another highland range. Rockaway River flows for 8 miles along a valley that extends for 20 miles farther in the same direction but leaves the valley and cuts its way out through the Passaic Range. At Rustic, 2 miles southwest of the point where the Rockaway leaves the valley, Black River enters it, crosses Succasunna Plains diagonally, leaves it to flow for 7 miles toward the head of the small valley east of the Fox Hill Range, and then cuts through the Passaic Range in a deep mountain gorge. Near Bartley, 4 miles beyond Succasunna Plains, the South Branch of the Raritan enters the large valley and follows it to its southwest end. Thus this Longwood-German Valley trough, having a length of 28 miles in the Raritan quadrangle, is occupied in different parts by three different main streams, each of which in turn leaves it to cut a gorge through the Passaic Range on the southeast.

Several of the minor divides display striking peculiarities. That between the drainage basins of Passaic and Raritan rivers crosses the Passaic Range as an irregular line bearing no relation to the rock structure or to the form of the range as a whole. Even on the Watchung Mountains it does not everywhere follow the crest of a ridge, as a part of the north slope of Second Watchung Mountain is drained southward into the Raritan through deep notches in the ridge. Across the Longwood-German Valley trough the divide is formed by the terminal moraine. The divide between Black River and the South Branch of the Raritan also is peculiar in several places and lies in part across the broad, relatively low area joining Succasunna Plains and German Valley. Round Valley, between the arms of Cushetunk Mountain, is nearly all drained by Prescott Brook, which flows southwestward to South Branch, but the northwest corner of the valley is drained by a small stream that cuts through the northern arm of the mountain and flows to Rockaway Creek, a tributary of Lamington River.

The peculiarities of the drainage system of the area have not yet been fully explained, but the geologic history of the larger features has been fairly well interpreted. The region has passed through several cycles of erosion and at least once the surface has been wholly reduced to base-level. At a comparatively recent time a large part of it was glaciated. The courses of at least the main streams are partly inherited from those established in a former cycle or perhaps on a cover of strata now entirely removed. The main features of the relief having been developed later, after the region had been uplifted and after renewed erosion had begun to reduce a large part of the surface to a new base-level, the inherited courses are not everywhere adjusted to the geologic structure. Other apparently anomalous features have been introduced by the glacial diversion of streams and modifications of drainage. Probably all the lakes and nearly all the swamps owe their existence to such glacial modifications.

CULTURE.

The southern, southeastern, and northwestern parts of the quadrangle and the interhighland valleys are fairly thickly populated. The Highlands, on the other hand, are more scantily settled, especially in that part north of the terminal moraine. The more level parts of the Highlands, however, especially on Schooley Mountain, are well settled, and Mine Mountain, in the neighborhood of Bernardsville and Gladstone, has become a popular locality for country houses surrounded by large estates.

The principal cities and towns are Somerville, Bound Brook, Raritan, and Flemington, situated in the lowland in the southern and southeastern parts of the quadrangle; Hackettstown and Washington in the interhighland valleys; Dover, Wharton, Rockaway, and Stanhope in the Highlands in the northern and northeastern part; High Bridge, Junction, and Oxford in the Highlands in the western part; and Blairstown in the Kittatinny Valley. Smaller towns and villages are numerous. About 70 per cent of the population live in cities, towns, and villages.

The quadrangle is covered with a network of highways that render nearly all parts of it readily accessible. Most of the roads in the valleys and the main roads across the mountains are good, a number of them having been rebuilt in recent years according to modern principles of road engineering. On the other hand a few mountain roads have steep grades and rough surfaces and are impassable for any but the lightest vehicles.

Several main lines of railroad cross the quadrangle and branch lines reach nearly all parts of it. The Delaware, Lackawanna & Western Railroad traverses the Highlands in the northern part of the quadrangle, following the valleys of the Rockaway and Musconetcong for considerable distances and crossing the central Highlands through the gap at Shippenport. The main line formerly ran down the Musconetcong Valley to Washington and crossed the western Highlands through a tunnel beneath Scott Mountain, but it has recently been shortened by a cut-off which crosses Allamuchy Mountain in the northwestern part of the quadrangle in deep cuts. Several branches of this railroad penetrate various parts of the quadrangle.

The Lehigh Valley Railroad and the Central Railroad of New Jersey cross the southern part of the quadrangle, the former passing through a tunnel beneath Musconetcong Mountain, the latter through a gap at Junction. Each has several branches within the area, the most important of which is that of the Central Railroad of New Jersey which runs from High Bridge through the length of German Valley to Dover and Rockaway. The Philadelphia & Reading Railway crosses the southeast corner of the quadrangle, and the Lehigh & Hudson River Railway and New York, Susquehanna & Western Railroad traverse the Kittatinny Valley. There are also one or two minor roads in the area.

The Morris Canal, which connects Easton and Jersey City, and upon which considerable coal was once carried from the Lehigh Valley region to New York, crosses the northern part of the quadrangle, following nearly the same route as the Delaware, Lackawanna & Western Railroad. Its summit level is at Netcong and Port Morris, and it descends westward to the Delaware by Musconetcong and Pohatcong valleys, and eastward to Newark Bay and the Hudson along the courses of the Rockaway and the lower part of the Passaic. Lake Hopatcong and Cranberry and Stanhope reservoirs supply water for the canal, and at one or two points its course for short stretches is coincident with Musconetcong and Rockaway rivers. Navigation on the canal has practically ceased and its abandonment is strongly urged in many quarters and strongly opposed in others. The Delaware & Raritan canal crosses the southeast corner of the quadrangle.

Agriculture is the chief occupation of the rural part of the population, a large part of the surface south of the terminal moraine, especially in the Kittatinny Valley and in the Piedmont area, being under cultivation. There is a limited amount of lumbering in the northern part. Iron mining is locally important at Oxford and in the neighborhood of Dover and Wharton, and was formerly important at Chester. There are blast furnaces at Wharton, Pequest, Oxford, and Stanhope. Considerable manufacturing is carried on in the larger cities and towns, especially in Bound Brook, Dover, and Washington.

The central-eastern part of the quadrangle, in the neighborhood of Morristown, which is just east of the area, Bernardsville, Peapack, and Mendham, is largely occupied as a region for summer residences by city dwellers, and the regions about Lake Hopatcong, Budd Lake, and Cranberry Reservoir are well-known and popular summer resorts.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The rocks of the Raritan quadrangle range in age from pre-Cambrian to Quaternary. They are in part igneous and in part sedimentary; some are highly metamorphosed, others are not metamorphosed at all, and still others are incoherent surficial deposits.

The oldest strata are pre-Cambrian limestones and associated sedimentary rocks, metamorphosed to marble, schists, and gneisses and extensively intruded by several varieties of igneous rocks. The next oldest strata are Paleozoic rocks, in part considerably metamorphosed, ranging in age from Cambrian to Devonian. Another group of strata, with associated igneous rocks, is of Triassic age.

A large part of the quadrangle is covered with unconsolidated materials of Quaternary age, and about one-fourth of it, in its northern part, is covered to a greater or less thickness with glacial deposits. Scattered deposits of glacial material occur farther south, alluvial deposits lie in the valleys, and a blanket of residual material derived from the weathering of the rocks covers much of the remaining surface.

The sequence, general character, and approximate thickness of the stratified rocks of the quadrangle are shown graphically on the columnar-section sheet. The several systems will be described in order of age, beginning with the oldest.

PRE-CAMBRIAN ROCKS.

GENERAL FEATURES.

Distribution and age.—Pre-Cambrian crystalline rocks, constituting a basement or floor upon which the Paleozoic strata were deposited, probably underlie the whole of the Raritan quadrangle, but they outcrop only in the Highlands, where they are the characteristic rocks and occupy most of the area. They are covered in places by Paleozoic strata, which lie in strips trending northeast and southwest, parallel to the general structural trend.

The pre-Cambrian age of the rocks is shown by the fact that they are overlain by Cambrian conglomerate, part of the Hardyston quartzite, containing waterworn pebbles of gneiss.

Two views have been held with regard to the age of the white crystalline limestone of the Wallkill and Vernon valleys in the Franklin Furnace quadrangle, with which the similar rocks at the northeast end of Jenny Jump Mountain and at other localities in the Raritan quadrangle and on the east slope of Turkey Mountain in the Passaic quadrangle have been correlated. This limestone has been regarded on one hand as a metamorphosed form of the blue Paleozoic limestone of the Kittatinny Valley and on the other as a formation entirely distinct from that rock and far older. Wolff and Brooks[a] regarded the limestone as the oldest rock in the Franklin Furnace area and reported it to be overlain by the Cambrian conglomerate. Their conclusion has been confirmed by the work of the present author and is here accepted without qualification.

General character.—The pre-Cambrian rocks are mainly granitoid gneisses and pegmatites but include also subordinate amounts of magnetite, various schists, white crystalline limestone or marble and associated beds, and a few small quartz veins.

The various gneisses grade into one another through a number of intermediate forms, but several distinct types, composed of characteristic groups of minerals, occur throughout the Highlands area. In thin sections under the microscope these types are as a rule easily recognizable, but in the field they can not always be differentiated with certainty.

The gneisses occur in tabular masses or thin lenses which on the surface appear as parallel belts, some of them extending for long distances. The same arrangement occurs also on a smaller scale. Masses composed of thick layers of one kind of gneiss contain also thin layers of a different kind. In some parts of the area several kinds of gneiss are interleaved in approximately equal proportions in layers of nearly equal thickness, which, like the larger masses, have the shape of flat lenses. In places the lenses of the less prominent type are so short that the rock as a whole appears mottled rather than banded, but as a rule the banded structure is very prominent. In some places the layers of the subordinate type are few, appearing on the surface as narrow streaks in the predominant type. In other places the layers are numerous and are rather uniform in width, so that the surface is a series of ribbon-like strips of different colors extending for long distances.

Separation into formations.—The alternation of different types of gneiss is everywhere observable, and the types are so intermingled that the details of their distribution can not be represented on a map on the scale of those in this folio. Moreover, as they grade into one another and are not separated by distinct boundaries, their mapping in any area has been based on the dominant type in that area. Hence their delineation on the map is largely arbitrary; the boundaries drawn inclose areas in which the types indicated preponderate. Rocks intermediate between those selected as types are included with the type to which they are most closely allied.

For purposes of mapping, the pre-Cambrian rocks are divided into the Franklin limestone, the Pochuck gneiss, the Losee gneiss, and the Byram gneiss. Only the more important areas of graphitic schist are shown on the map. The areas of pegmatite that occur in the pre-Cambrian rocks are as a rule well defined, and might be represented with accuracy on a large-scale map, but no attempt has been made to show them on the maps in this folio, for pegmatite does not constitute the prevailing rock in any considerable area. The lenses of magnetite, all of which are small, are not shown on the areal-geology map, but on account of their commercial importance their positions are indicated on the economic-geology map.

[a] Wolff, J. E., and Brooks, A. H., The age of the Franklin white limestone of Sussex County, N. J.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 425–457, 1898.

Origin and relations. — In former years the prevailing opinion was that the typical gneisses of the Highlands region are of sedimentary origin, though it was rather generally admitted that some of the more massive rocks might prove to be igneous. This view of their origin was advanced in 1836 by Rogers,[a] the first official geologist of New Jersey, was consistently upheld by his successors, Kitchell,[b] Cook,[c] and Smock,[d] and culminated in 1886 in a report by Britton,[e] in which the pre-Cambrian rocks of New Jersey, there designated Archean, were divided into three groups, based primarily on differences in the perfection of gneissic structure, though for one group the presence of iron-ore deposits was taken as a distinguishing feature.

The first geologist to throw well-sustained doubt on the sedimentary hypothesis was Nason,[f] who pointed out in 1889 that existing knowledge was inadequate to justify a decision whether the gneisses of the Highlands are derived from sedimentary or from igneous rocks or from a mixture of the two. A special study by Wolff[g] of the rocks in the vicinity of the iron mines at Hibernia led him (1893) to suggest a sedimentary origin for the rocks of that particular district; later, however (1896),[h] he regarded the granitic rocks occupying extensive areas in the Franklin Furnace region as undeniably intrusive.

The facts from which the conclusion was drawn that the gneisses are sedimentary rocks now seem inadequate, and the conclusion itself appears not to have been based on logical deduction from observed facts. The gneisses, with few exceptions, correspond closely in mineral and chemical composition to ordinary coarse-grained igneous rocks like granites and diorites. The light-colored granitoid gneisses are undoubtedly of igneous origin and are, in places, shown to be intrusive by irregular cross-cutting contacts, by the manner in which they inclose masses of older rocks, and by the development of metamorphic minerals along their borders. Large amounts of preexisting rock material may have been more or less completely dissolved and assimilated by the invading magmas and some of the peculiar phases of the gneisses may be due to this fact.

The opinion of many of the earlier students of the Highlands that the gneisses are metamorphosed sedimentary beds was based chiefly upon their interlamination and their common association with layers of white Franklin limestone. Some writers have asserted that the axes of the Highland ridges are composed of massive rocks and their flanks of schistose rocks, indicating that the rocks lie in distinct folds with igneous rocks in the axes and overlying metamorphosed sedimentary rocks on the flanks. Careful search, however, has disclosed no such distribution of rock types in the Raritan area. Nothing seen in the field indicated that the gneisses are altered sediments, nor were any traces of clastic grains seen in thin sections, except in those made from crushed rock collected near faults.

In all the gneisses foliation is conditioned both by the interlamination of different varieties of rock and by the more or less elongated or flattened form of the component mineral grains and their arrangement with their longer dimensions nearly parallel. Foliation of the first sort may be called structural and of the second sort textural. Textural foliation may be developed during the first crystallization of a rock magma when solidification takes place under pressure, as, for instance, while the material is flowing, or it may be induced through processes of recrystallization accompanying complete deformation of the rock after its solidification. Elsewhere in pre-Cambrian rocks, notably in northern New York and eastern Canada, foliation occurs in different stages of development, leaving in certain localities no doubt of its secondary origin. Throughout New Jersey, however, evidence of crushing in the minerals of the gneisses is almost entirely lacking except in certain narrow zones which are regarded as fault zones, and appearances strongly favor the belief that the gneissic foliation of the rocks is original. Moreover, both the interbanding and the linear structure were produced before the deposition of the Cambrian quartzite, as fragments of the gneisses exhibiting a linear arrangement of particles are found in the conglomeratic beds of the quartzite. They are therefore not to be correlated with the deformation of the Paleozoic rocks but are much older.

Less abundant than the granitoid gneisses, but still of considerable importance, is the dark Pochuck gneiss, consisting of rocks having the chemical composition of diorites or gabbros, but differing from them mineralogically in containing oligoclase rather than a more basic feldspar. The Pochuck gneiss, then, is closely allied to the other gneisses of the area in the character of its mineral components but has the chemical composition of a gabbro.

The classification of the Pochuck gneiss is complicated by the fact that some of its phases are probably older than the Losee and Byram gneisses and others are contemporaneous with those rocks. The dark rocks are nearly everywhere foliated and are interlaminated parallel to the foliation with sheets of light-colored material similar in composition to phases of the Losee gneiss and probably to be classed with them. Besides being thus interlaminated with the Losee gneiss, the dark gneisses are broadly interleaved with both the Losee and Byram gneisses, and the white crystalline limestone is similarly interleaved with the granitoid gneisses, so that the two rocks—the dark gneiss and the limestone—together seem to constitute a matrix holding the intrusive granitoid rocks in relatively thin extended plates. In a few places, however, the more massive phases of the dark gneiss are intrusive in the limestone, and at certain localities, especially near magnetite bodies, thin seams of black hornblende rock apparently intrude Losee and Byram gneisses and are consequently younger. This phase of the Pochuck gneiss may be a differentiate of the same magmas that formed the light-colored rocks. It is composed of the more basic minerals found in those types and of a feldspar similar to that of the granitoid gneiss with which it is most closely associated.

The portions of the Pochuck older than the other gneisses may be old igneous rocks into which the later gneisses were intruded, or they may be old sedimentary rocks entirely recrystallized through the influence of the Losee and Byram magmas. No evidence bearing on the question has been discovered in the Raritan quadrangle, but observations in the Adirondacks and eastern Canada, where the geologic conditions appear to be nearly identical with those in the New Jersey Highlands, indicate that in those regions rocks closely resembling the Pochuck gneiss are metamorphosed sediments. It seems probable that most of the older rocks mapped as Pochuck in New Jersey are of similar origin.

COMPARISON WITH OTHER AREAS.

A comparison of the geology of the New Jersey Highlands with that of the Adirondacks and that of eastern Ontario shows that the general equivalents of the formations recognized in New Jersey occur in the northern districts and that in general the three areas are essentially similar. The oldest rocks in the northern districts are crystalline limestone, quartzite, hornblendic and micaceous schists, amphibolite, and garnetiferous schist, all of which are regarded as metamorphosed sedimentary rocks. Beneath them and interleaved with them are augite gneisses that may be mashed intrusive granites or may be the extreme phases of metamorphism of arkose or tuff. This complex is invaded by gabbros, granites, and syenites that are of practically the same composition as the Byram gneiss.

The geologic conditions are thus very similar in the Adirondacks, in eastern Ontario, and in the New Jersey Highlands, except that in New Jersey there are no gabbros. In the northern districts the sedimentary rocks and the schists derived from them were collectively termed the Grenville series by the special committee of the general international committee on geologic nomenclature.[a] Granitic gneisses intrusive into them but structurally beneath them were called the Laurentian gneiss. No definite correlation in age can be made, but the sedimentary part of the pre-Cambrian rocks in the New Jersey area appears to be the general equivalent of the Grenville series.

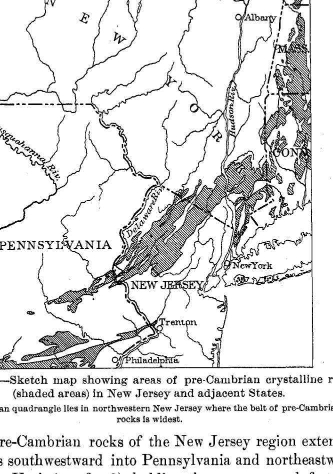


FIGURE 3.—Sketch map showing areas of pre-Cambrian crystalline rocks (shaded areas) in New Jersey and adjacent States.

The Raritan quadrangle lies in northwestern New Jersey where the belt of pre-Cambrian rocks is widest.

The pre-Cambrian rocks of the New Jersey region extend a few miles southwestward into Pennsylvania and northeastward into New York (see fig. 3), holding the same general features and relations throughout the belt. The pre-Cambrian rocks extending northeastward from localities near New York City

[a] Rogers, H. D., Final report on the geology of the State of New Jersey, p. 13, Philadelphia, 1840.

[b] Kitchell, William, New Jersey Geol. Survey First Ann. Rept., for 1854, p. 32, 1855.

[c] Cook, G. H., Geology of New Jersey, pp. 331–335, Newark, 1868.

[d] Smock, J. C., New Jersey Geol. Survey Ann. Rept. for 1878, p. 19, 1873.

[e] Britton, N. L., Idem for 1886, pp. 76–88, 1887.

[f] Nason, F. L., Idem for 1889, p. 54, 1889.

[g] Wolff, J. E., Idem for 1893, pp. 359–369, 1894.

[h] Wolff, J. E., Idem for 1895, p. 19, 1896.

[a] Jour. Geology, vol. 15, pp. 215–217, 1907.

into Connecticut, and those extending southwestward from the vicinity of Trenton far into the Piedmont area of the southern Atlantic States, are in general similar to those of the Highlands but more metamorphosed.

The pre-Cambrian rocks of South Mountain in Pennsylvania and farther south along the Blue Ridge are very different from those of New Jersey, although they occupy a similar geologic and physiographic position. The relation of the New Jersey pre-Cambrian rocks to those of the highlands of western New England has not yet been worked out.

FORMATIONS MAPPED.

FRANKLIN LIMESTONE.

Definition.—The Franklin limestone consists of crystalline white limestone and dolomite, in places rather siliceous. It is named from Franklin Furnace, N. J., where it is extensively and characteristically developed. Associated with the limestone nearly everywhere are belts of black gneiss, some at least of which are undoubtedly intrusive, veins of pegmatite, and here and there belts of magnetite, the whole cut in places by diabase dikes of presumed Triassic age.

The areas shown as Franklin limestone on the map include certain siliceous and slaty rocks commonly associated with the limestone, but these are too small to warrant their being mapped separately. (See p. 7.)

Distribution.—The Franklin limestone occurs in several small isolated areas, chiefly in the north-central part of the quadrangle, and in two larger ones that form belts parallel to the general trend of the pre-Cambrian rocks. One of the larger areas is along the east side of Jenny Jump Mountain near its northeast end, and the other extends from Pequest southward beyond the limits of the quadrangle. All the other areas in the Raritan quadrangle are small and are more or less isolated, some of them being miles from any other known occurrence. Others, although disconnected, are so situated in belts as to suggest that they are parts of formerly continuous masses which have been separated by the intrusion of other rocks. Several such belts or groups occur in Byram Township, in the northern part of the quadrangle.

Character.—The limestone of the larger areas is in nearly all places more or less distinctly bedded, especially in the area at the northeast end of Jenny Jump Mountain, where the bedding is emphasized by the interstratification of limestone and massive quartzose beds. Many of the smaller exposures, however, show no definite stratification.

Where the rock shows no distinct bedding the graphite and silicates that it contains are commonly arranged in bands, producing a sort of schistosity which, so far as noted, is either parallel to the schistosity of the surrounding gneisses or to the contacts of the limestone with intrusive masses. This structure is probably due to metamorphism induced by the intrusive granitoid gneisses.

The typical limestone of the larger areas, especially in masses free from pegmatitic and dioritic intrusions, is a coarse-grained to fine-grained white marble containing scattered grains of quartz and pyrite, flakes of graphite, and a few crystals of a nearly white pyroxene. At most places in the Raritan quadrangle, however, the rock is fairly siliceous. At some localities it consists of calcite and quartz, and perhaps represents a gradation between the limestone and the associated siliceous sediments; at others it is a mixture of calcite or dolomite with several or all of the following minerals: Quartz, magnetite, chondrodite, pyroxene, garnet, phlogopite, sphene, tremolite, talc, asbestos, serpentine, graphite, and rarely tourmaline. Sphalerite and galenite have not been noted in the Raritan quadrangle, but both occur in large quantity at the Sulphur Hill mine, just north of the area, and sphalerite is abundantly disseminated through the limestone at a point just west of the quadrangle.

Two phases of the limestone warrant special mention because of their unusual appearance. One of these is found in a very small area on the southeast side of Jenny Jump Mountain, near the junction of the road along the base of the mountain with the road crossing the ridge to Hope. The rock is coarse grained, mottled pink and white, dotted with spots of light-green pyroxene, and spangled with small glistening plates of phlogopite. At one time it was quarried as an ornamental marble. The other unusual phase has been described several times as an ophicalcite. It is a breccia of white angular and rounded fragments of calcareous quartzite in a dark-green or black matrix composed of calcite, serpentine, phlogopite, and graphite. The serpentine appears to have been derived from chondrodite. An analysis[a] of this rock given below shows that it consists approximately of 61 per cent calcite, 2 per cent dolomite, and 37 per cent serpentine, as follows:

Analysis of ophicalcite from Saunders quarry, near Mendham, Morris County, N. J.

CaO	33.95
MgO	18.21
CO_2	27.66
Al_2O_3, Fe_2O_3	1.60
Insoluble	16.40
	97.82

[a] New Jersey Geol. Survey Ann. Rept. for 1878, p. 104.

Of the minerals commonly occurring in the limestone, graphite is most widely distributed. Pyroxene is also abundant, occurring in isolated crystals with well-defined outlines and as groups of crystal aggregates. It is a light-green, almost colorless variety, having many of the properties of diopside. Its maximum extinction is 32°. As a rule it is perfectly fresh, but in a few places it is partly changed to serpentine and in others it is altered peripherally to a bright-green hornblende.

Chondrodite is next in importance, occurring in small quantity in most specimens, and in extremely large quantity near intrusive masses. In only a few places has it been found unchanged, with the golden-yellow color characteristic of the fresh mineral. Generally it is altered to serpentine and magnetite, the latter forming zones about the borders of the altered grains and traversing the serpentine in tiny veins. With increasing alteration the grains become darker, and finally they appear as black, irregularly shaped masses scattered through the rock.

Phlogopite occurs in golden-yellow and brown flakes. It is widely distributed but is in small amount in most specimens. Garnet is rare. It occurs at the Glendon mine and at a few other localities, especially where the limestone contains considerable magnetite.

Tourmaline appears as little individual rods with brown and indigo-blue pleochroism, and in little bunches of rods associated with epidote, calcite, and cloudy, almost amorphous silica, and filling the little spaces between grains of calcite and pyroxene. The tourmaline and associated minerals, which occur in large amounts and at only a few widely separated places, appear to be of pneumatolytic origin.

Nearly all the minerals just described are found only in limestone that lies near igneous rocks. They are especially abundant in portions that have been intricately cut by diorites, and are consequently believed to have resulted from contact action.

Tremolite, talc, and asbestos occur only in sheared phases of the limestone. The first two are comparatively rare, but asbestos occurs at a number of places on Jenny Jump Mountain, at one or two in such large quantities that attempts have been made to mine it.

Chemical composition.—The chemical composition of the white limestone has always been a matter of interest because of its possible bearing on the formerly mooted question of the relationship of the rock to the Kittatinny limestone, which is strongly magnesian. Nason,[a] judging from the result of a series of analyses, concluded that the white limestone is a dolomite except where intruded by granite (pegmatite) dikes. Recent work of H. B. Kümmel and R. B. Gage,[b] however, shows conclusively that the Franklin limestone ranges from almost pure calcite to nearly typical dolomite, and that it is not, so far as determined, influenced by intrusive rocks. Its content of magnesium carbonate differs greatly from place to place, in some beds constituting 40 per cent of the rock but in most of them being less than 5 per cent. A few analyses are quoted below:

Analyses of Franklin limestone from the Raritan quadrangle.[a]

	1	2	3	4	5
Calcium carbonate	88.15	68.01	83.40	85.90	94.93
Magnesium carbonate	.50	2.68	9.71	7.97	3.31
Iron and aluminum oxides	.80	6.84	1.82	1.98	.64
Silica	9.40	19.90	4.98	4.36	.80
	98.85	97.43	99.91	100.21	99.68

[a] Gage, R. B., New Jersey Geol. Survey Ann. Rept. for 1905, pp. 183–184, 1906.

1. Average of samples from old Andover quarry.
2. Average of samples from quarry opposite Cranberry Reservoir.
3. Average of samples from ledges at northeast end of Jenny Jump Mountain, near Howell mine.
4. Average of samples of mottled marble from old quarry on southeast slope of Jenny Jump Mountain, 2 miles northwest of Danville.
5. Average of samples from quarry 1 mile south of Buttzville, on road to Ahles mine (in Delaware Water Gap quadrangle).

Relations.—The Franklin limestone is cut by pegmatite and by dioritic dikes similar to the more massive phases of the Pochuck gneiss. The dioritic intrusions are in part scapolitic, the scapolite replacing all or a great part of the plagioclase. This change is regarded as due to the reaction of absorbed limestone on the intrusive magma.

The relations of the limestone to the granitoid gneisses are not so clear. In most places the limestone occurs in small rudely lenticular masses lying parallel to the schistosity and to the banding of the gneiss and entirely surrounded by the gneiss. The dip of the limestone beds, where observable, is commonly southeast, conforming with the dip of the foliation of the gneiss. Moreover, mine pits show that the limestone bodies extend downward long distances as thin plates or lenses in the gneiss. These relations, which are common throughout the Highlands, led many of the early geologists to regard the condition as one of true interbedding and the limestone lenses and the gneisses as interstratified members of a series of sedimentary beds.

Exposed contacts between the limestone and the gneisses are extremely rare and are nowhere sufficiently characteristic to establish the relations between the rocks. At two places in the quadrangle, however, the limestone is associated with a fine-grained gray rock which under the microscope appears to be an extremely fine grained phase of one of the granitoid gneisses. The most marked occurrence is at the north end of the Andover quarry, where a thin layer of fine-grained white siliceous rock that is irregular in thickness and tapers to an edge projects into the limestone. At its contact with the limestone this rock is coarse grained, the individual grains being arranged with their longer axes at right angles to the contact. The layer can not be traced into the gneiss because of lack of exposures, but the study of thin sections indicates that it is a phase of the Losee gneiss. It appears to be intrusive in the limestone.

[a] Am. Geologist, vol. 13, pp. 154–156, 1894.

[b] Kümmel, H. B., New Jersey Geol. Survey Ann. Rept. for 1905, pp. 175–191, 1906.

The larger areas of the Franklin limestone, like the smaller ones, are also lenticular or oval, their longer axes lying parallel to the banding of the surrounding gneisses. They may be remnants of a once more widely distributed series of beds that were intruded by the gneisses parallel to the bedding, and the small areas scattered through the gneiss may be inclusions separated from the main masses and carried to the positions they now occupy. In one or two places limestone is known to occur underground beneath surface exposures of gneiss. At these places it is probably entirely inclosed in the gneiss.

At no place in the Raritan quadrangle are the relations between the Franklin limestone and the later Hardyston quartzite to be seen, but in the Franklin Furnace quadrangle they are so plain that there can be no doubt that the quartzite unconformably overlies the limestone. One of the most noticeable differences of the two formations is the presence of pegmatite and diorite in the limestone and their absence from the quartzite. In the Raritan quadrangle this difference is strikingly displayed near the Glendon mine, where the limestone and quartzite are almost in contact; the limestone is associated in the most intricate manner with intrusions of pegmatite and scapolitic diorite, and the quartzite is entirely free from both.

Age.—The relations of the Franklin limestone to the gneisses and to the Hardyston quartzite show that it is older than either, having been intruded by the former and unconformably overlain by the latter. Further, at Cranberry Reservoir a fragment of slate similar to that associated with the limestone is inclosed in a mass of Pochuck gneiss that grades into Byram gneiss.

The limestone is clearly pre-Cambrian, but whether it is to be regarded as Algonkian or older has not been determined. In the area studied no facts serving to separate the pre-Cambrian rocks into earlier and later series have been noted, other than the general relation already stated that the limestone and associated sedimentary rocks are older than the gneisses intruded into them. The sedimentary rocks, as stated on page 5, appear to be the general equivalent of the Grenville series of Canada.

At several places in neighboring quadrangles there are quartzites and conglomerates that have substantially the same relation to the gneisses as the Franklin limestone does. The existence of these rocks indicates clearly that at the time of their deposition there was a land area from which the sand and pebbles were derived. The rocks of this land were of Archean age. No traces of it have yet been found in the Highlands, though its former existence is assured by the waste derived from it.

Local details.—The most important occurrence of the limestone in the Raritan quadrangle is at Jenny Jump Mountain, two narrow belts, each about 350 feet wide and 1¾ miles long, lying along its eastern base near its northern end, and an irregular area, apparently a wide continuation of the belts, lying at its northern end. The rock of the narrow belts is almost exclusively limestone, with a few bands of magnetite and of black gneiss. In the broad area limestone and siliceous rocks are intricately folded together and cut by diabase and pegmatite dikes. They are interbanded with wide belts of black gneiss similar to the Pochuck gneiss.

Limestone fragments have been found on the dumps of several old mines along the slope of the mountain, as at the Dietz mine near Green Pond and at the Davis and other mines near the north end of the mountain.

The largest area of limestone in the Highlands, in the vicinity of Pequest, extends in a crescentic area from Pequest furnace westward to Oxford Church, a distance of 3 miles. It lies almost wholly in the Delaware Watergap quadrangle, only the eastern end being in the Raritan quadrangle. The rock in this area is mainly white limestone and is remarkably free from intrusions.

Several small groups of exposures occur as patches on the slopes of gneiss hills bordering an indefinite trough that crosses Byram Township directly in the trend of the Sparta Valley of the Franklin Furnace quadrangle. This valley, which extends northeastward for about 10 miles, is largely underlain by the limestone.

The largest exposures occupy a belt 100 to 200 feet wide and 1200 feet long along the west side of the outlet of Stag Pond. The rock is mainly white granular limestone, which at one time was quarried for lime burning. In some places, especially near bands of scapolitic gneiss of the Pochuck type, it contains large quantities of chondrodite, phlogopite, serpentine, quartz, and graphite. It is cut by a few pegmatite dikes.

In the little valley southwest of Stag Pond are three other exposures of white limestone, two at the northern end and one at the southern end. So far as can be determined they are not connected, but as the valley floor is largely covered with limestone bowlders it is all mapped as limestone. Another locality in line with these is at the northern base of the prominent hill just west of Wright Pond. There are no outcrops at this place, but the soil of a considerable area is graphitic, and pits dug at several points many years ago to secure fluxing material for the Stanhope furnace uncovered limestone. The rock ranges from a fine-grained bluish variety to a coarse white crystalline phase. It contains abundant augite, chondrodite, phlogopite, and graphite, and is cut by pegmatite and by bands of black gneiss. A near-by deposit of magnetite also apparently lies in the limestone.

In the large hole of the Roseville mine east of Wright Pond a small mass of extremely coarse-grained limestone, containing an unusual amount of chondrodite and some light-colored mica is seen to be interbanded with the ores and gneisses.

A small body of limestone occurs on a little island in Cranberry Reservoir, and two more in the plain to the east. The latter were at one time quarried for fluxing material, the rock being impure limestone containing graphite, chondrodite, mica, augite, serpentine, and some quartz, cut by pegmatite and scapolitic diorite. The outcrop on the island is bluish, well-banded, contorted, jointed, and minutely faulted limestone, apparently lying upon gneiss. In places it is mottled blue and white. Some parts of the ledge contain graphite. Other parts have a distinct fetid odor.

A small body of the limestone occurs at the old quarry one-half mile north of Andover, in the east side of a small knoll, the west side of which is underlain, at least in part, by Pochuck gneiss. The limestone is white, coarse grained, and homogeneous, and is very free from siliceous impurities. It was once quarried for fluxing material. It is intruded at the north end of the quarry by what is regarded as a tongue of Losee gneiss, as already described.

At the Glendon mine, one-half mile south of Decker Pond, the limestone lies between the gneiss and the Hardyston quartzite. It occurs in the mine holes and in a number of outcrops extending about 1000 feet northward over a width of 300 to 500 feet. It is intimately associated with pegmatite and with scapolitic diorite. The rock is extremely impure, containing magnetite, chondrodite, mica, pyroxene, graphite, garnet, and other minerals. The parts richest in magnetite were once mined as iron ore.

In the eastern part of the quadrangle the Franklin limestone is exposed in a small quarry southeast of the junction of the road running north from Washington Corners with the main road from Morristown to Mendham. The rock is a breccia of calcite and quartz fragments in a matrix of calcite and serpentine containing considerable chondrodite and some graphite. It is intruded by pegmatite. This is the rock whose analysis is given on page 6.

On the dump of a pit said to have been dug in search of graphite, south of Ralston on the east side of Peapack Brook where it crosses the road from Gladstone to Mendham, there are fragments of rock consisting of a mixture of limestone, chondrodite, and calcite.

ROCKS MAPPED WITH FRANKLIN LIMESTONE.

As already stated (p. 6) certain siliceous schists and calcareous sandstones that are associated and in places interbedded with the Franklin limestone because of their relatively insignificant mass are mapped with that formation, as are also two areas of slaty rocks concerning the age and relations of which little is known.

Quartzite.—The principal sedimentary rock associated with the limestone is a light-gray or white quartzite, which contains considerable calcite, a little scattered light-colored mica, a few small particles of pyrite, and some flakes of graphite. Thin sections show a little tremolite, some titanite, and some apparently secondary quartz. A few aggregates of quartz, kaolin, chlorite, and a saussurite-like substance with round outlines suggest the presence of altered fragmental grains. Other specimens contain a colorless pyroxene instead of tremolite, all the other constituents being the same. Here and there are flakes of biotite, and in places a considerable quantity of serpentine, generally as a fibrous layer between pyroxene and calcite. The graphite, which is visible in hand specimens, is interstitial between the larger components, except in specimens containing serpentine, in which it occurs in that mineral. Although no distinct and undoubtedly fragmental grains have been found in any of these rocks, their general appearance suggests that they are calcareous sandstones that have been subjected to the same metamorphic changes as the limestone with which they are associated and in which similar minerals have been developed.

No definitely conglomeratic pre-Cambrian rocks have been found in the Raritan quadrangle, but some found in neighboring quadrangles, at Marble Mountain on the Delaware and elsewhere, are presumed to belong to the same sedimentary series, although their relation to the Franklin limestone has not been determined.

Slaty rocks.—Rocks resembling slate and of presumably pre-Cambrian age have been found at two localities in the quadrangle. A small irregular mass of dense bluish-gray rock entirely surrounded by black gneiss occurs on a small hillock at the northeast end of Cranberry Reservoir. It appears to be a large inclusion in the gneiss. The rock has the appearance of hornstone and is composed of small sharp-edged fragments of quartz and plagioclase, a few grains of green hornblende, and here and there a grain of magnetite, all in an almost nonpolarizing groundmass of yellow-green fibers, a little epidote, and considerable apparently devitrified glass.

At Pottersville Falls on Black River and for a few hundred yards below the falls along both banks of the river finely banded and slightly schistose, dense, light or dark gray or purple rocks are almost continuously exposed. They resemble ancient rhyolitic lavas and exhibit traces of apparent flow structure. Nothing else like them is known in the quadrangle. No contacts were found and their relation to the adjacent gneisses is unknown. The rock is composed of lenses and round masses of quartz and epidote in a fine granular quartz aggregate crossed by streaks of tiny brown grains, the character of which has not been determined. Some of the larger grains are apparently epidote. The schistosity is due in large measure to the arrangement of the particles and of the groundmass in sinuous light and dark bands resembling flow banding.

GRAPHITIC SCHIST.

Occurrence.—Graphitic schists occur among the other pre-Cambrian rocks of the quadrangle at a number of localities, especially in the Passaic Range. There are two general types which are believed to be of different origin, but because of the relatively insignificant size of the occurrences and because their chief interest is as a possible source of graphite they have been mapped under one head as graphite schist.

Graphitic quartz-mica schist.—At a point about a mile south of High Bridge, and at a few other places, west of the city, explorations for graphite have uncovered a highly graphitic quartz schist which is probably of sedimentary origin but which is so much weathered that it is difficult to make out its exact character. In the freshest specimens it appears to be a fairly thin-bedded schist with quartz, a bronze-colored mica, and a small quantity of kaolinized feldspar as its principal constituents. The feldspar is mainly oligoclase, but orthoclase, microcline, and perthitic intergrowths are common. The graphite is much intergrown with the biotite, the two commonly occurring in alternating plates. In some occurrences the proportion of graphite is very small, but in others it is as great as 3 to 4 per cent of the rock mass. A few large grains of quartz or feldspar resemble sand, but no certain proof of clastic origin can be found. Pyrite occurs in cubes, as a rule near flakes of graphite, many of them coated with the sulphide.

In the Raritan quadrangle the quartz-graphite schist is found only in very small masses in the midst of the gneisses, generally interstratified with thin seams of lustrous black hornblende schist, but elsewhere in the Highlands it occurs also in close association with the Franklin limestone. The schist is ordinarily in thin layers, few being more than 25 feet thick. Most of them are short, but a few are known to extend with unimportant interruptions for one-half mile or more. Because of its common association with the limestone, its occurrence in small lenticular masses, and its composition it is inferred that the schist is a metamorphosed sedimentary rock older than the gneisses by which it is surrounded.

Garnetiferous graphite schist.—The rocks included under garnetiferous graphite schist are coarse and fine grained aggregates of quartz, feldspar, biotite or muscovite, garnet, magnetite, pyrite, and graphite, with a very schistose structure which is strongly emphasized where the amount of mica is large. The rock weathers rusty red and becomes very friable.

Rocks of this sort are rare in the Raritan quadrangle. The few occurrences are in thin layers conforming with the structure of the inclosing gneisses. Several such layers lie just west of Lake Hopatcong, and a few small outcrops are scattered irregularly in other parts of the quadrangle. Some of them have been explored for graphite, and these are mapped on the economic-geology sheet.

In the Passaic quadrangle, especially in the vicinity of Hibernia and in the area between Hibernia and Splitrock Pond, the garnetiferous graphite schist is more abundant, although even there it occupies comparatively small areas.

Similar rocks in the Adirondacks are generally regarded as metamorphosed sediments, and the garnetiferous graphite schist in the neighborhood of Hibernia has been so regarded.[a] The facts presented in support of this conclusion seem inadequate, however, and though it is possible that some of the graphite schists of the Raritan quadrangle are altered sedimentary rocks, others can be shown to have had a different origin.

Many of the pegmatite dikes that cut the gneisses contain graphite and some of them have been mined for that mineral. In places the pegmatites are crushed, and in a few localities, where crushing has been very great, they grade into coarse graphite schist containing garnet, mica, and pyrite, minerals not characteristic of the uncrushed rock. In places the coarse schists grade into the finer-grained varieties, so there seems to be no reason why all these peculiar rocks may not be regarded as sheared pegmatites. Moreover, the schists occur in such thin layers and some of them extend for such long distances that it is almost impossible to conceive of their having once been part of a series of sediments of which all the rest have disappeared.

POCHUCK GNEISS.

Name.—The Pochuck gneiss is named from Pochuck Mountain, in the Franklin Furnace quadrangle, where it is characteristically developed.

Distribution.—In the Raritan quadrangle the Pochuck gneiss occupies small areas in which it is the predominant rock, and it is interstratified with the Losee gneiss wherever that rock occurs. Many small masses of the Pochuck gneiss are also intruded into the Franklin limestone.

The principal areas in which the rock predominates are a strip along the eastern slope of Jenny Jump Mountain, an irregular area about Cranberry Reservoir and extending northeastward therefrom, a strip along the northwestern side of the low mountain ridge south of Washington, a belt extending northeastward from Califon to Horton, and a small strip northeast of Denmark Pond in the northeast corner of the quadrangle. All these areas except that surrounding Cranberry Reservoir are long narrow belts trending northeast and southwest. Only two, the Jenny Jump Mountain belt and that passing through Hacklebarney, are entirely within the limits of the quadrangle.

The Pochuck gneiss is found also in thin plates interlaminated with the Losee gneiss in other parts of the quadrangle, the two forming ledges with alternate white and black or gray and black stripes, the light color generally predominating. It is also generally associated with the ore bodies, but in bands so narrow that it is impracticable to map them. It constitutes one or both of the walls in many mines and also the "vein rock" intermingled with the magnetite. Indeed, some of the ore is nothing more nor less than a magnetitic Pochuck gneiss, as at the Pequest mine and at the Beach Glen mine in the Passaic quadrangle.

Character and varieties.—The rocks included in the Pochuck gneiss are all dark colored and generally black, on account of their large content of pyroxene, hornblende, and biotite. They have a wide range in mineralogic composition and are composed mainly of oligoclase, orthoclase, diopside, hornblende, hypersthene, biotite, magnetite, and quartz, in various proportions. Some specimens contain all these minerals, but as a rule two or more are absent. Magnetite is the most constant component, though oligoclase, hornblende, and green pyroxene are generally present. The rock at a few localities, however, contains microcline and microperthite in place of most of the oligoclase.

Much of the feldspar of the dark gneisses associated with the Franklin limestone is replaced by scapolite, the other constituents remaining unchanged. In the literature of the New Jersey Highlands these scapolitic gneisses have usually been called "gefleckter gabbros." In appearance they do not differ from the nonscapolitic phases, except that the scapolite grains are whiter and a little more opaque than the feldspar grains.

The greater part of the Pochuck gneiss is schistose, but the rock of the belt passing through Hacklebarney is medium fine grained, dark gray, and massive, its texture resembling that of fine-grained diabase.

Most of the Pochuck gneiss may be regarded as a basic phase of the siliceous type with which it is associated; that is, its principal feldspathic mineral is oligoclase, where it is associated with the Losee gneiss, and microperthite, with or without microcline, where it is associated with the Byram gneiss. Moreover, where associated with the Losee gneiss the Pochuck gneiss commonly contains considerable diopside, but where associated with the Byram gneiss it contains little diopside and so much hornblende as almost to exclude the pyroxene. The fragments of Pochuck gneiss included in the Byram gneiss are, so far as has been determined, of the variety containing microperthite.

The gradation between the Losee and the Pochuck gneisses and the wide range in mineral composition of the latter are shown in the table below.[a]

Mineral composition of Losee and Pochuck gneisses.

	1	2	3	4	5	6	7	8
Quartz	1.94		16.71		1.51	2.40		
Orthoclase	15.18	15.91		8.35	9.02	14.30		9.49
Oligoclase	70.12	28.35	64.47	72.50	27.31	27.50		51.59
Diopside		20.93			24.43	33.01	38.47	19.01
Hypersthene	10.10							
Hornblende		30.51	17.50	17.05	21.27	.51	39.06	
Biotite								17.72
Magnetite	2.66	4.32	1.32	1.69	16.47	22.25	22.47	2.18
Apatite				.36				
	100.00	100.02	100.00	99.95	100.01	99.97	100.00	99.99

1. Normal Losee gneiss, Montville quarries, Passaic quadrangle.
2. Pochuck gneiss band in Losee gneiss (No. 1), Montville quarries, Passaic quadrangle.
3. Rather basic phase of Losee gneiss from north of Durham pond, Passaic quadrangle.
4. Rather basic phase of Losee gneiss from side of Morris County Railroad, just northeast of Raritan quadrangle.
5. Typical black Pochuck gneiss from Pikes Peak mine, Stickle Pond, Passaic quadrangle.
6. Typical black Pochuck gneiss from Rockaway Valley mine, Passaic quadrangle.
7. Typical black Pochuck gneiss from Charlottesburg mine, Greenwood Lake quadrangle.
8. Biotitic phase of Pochuck gneiss from Charlottesburg mine, Greenwood Lake quadrangle.

Chemical composition.—Chemical analysis of a specimen of a black schistose variety of the Pochuck gneiss associated with the ore at the Pardee mine (which is just outside the quadrangle, in the extension of the belt crossing its northeast corner) was made by W. T. Schaller, whose results are given in the following table, together with the analysis of a norite forming the wall rock of the titaniferous ore at the Kent mine, near Lincoln Pond, Elizabethtown, Essex County, N. Y.[b] The norms of the two rocks, calculated according to the quantitative system, are similar, except that the Pochuck gneiss contains 3.5 per cent less of salic minerals and correspondingly more of femic minerals. The component molecules are practically the same. In the quantitative system[c] both norms fall in the group auvergnose (III.5.4.4).

[a] Wolff, J. E., New Jersey Geol. Survey Ann. Rept. for 1893, pp. 359–369, 1894.

[a] U. S. Geol Survey Geol. Atlas, Passaic folio (No. 157), and New Jersey Geol. Survey folio No. 1, p 4, 1908.

[b] Kemp, J. F., U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 407, 1899.

[c] Cross, Iddings, Pirsson, and Washington, A quantitative chemico-mineralogical classification and nomenclature of igneous rocks: Jour. Geology, vol. 10, pp. 555–690, 1902; Quantitative classification of igneous rocks based on chemical and mineral characters, 1903.

Analyses of Pochuck gneiss and of norite.

	Gneiss.	Norite.
SiO_2	43.98	44.77
Al_2O_3	12.01	12.46
Fe_2O_3	6.60	4.63
FeO	12.20	12.99
MgO	5.46	5.34
CaO	11.99	10.20
Na_2O	2.93	2.47
K_2O	1.10	.95
H_2O-	.29	.12
H_2O+	1.04	.48
TiO_2	2.25	5.26
CO_2	.18	.37
S		.26
P_2O_5	.28	.28
NiO		Trace.
BaO		Trace.
MnO	.05	.17
	100.36	100.75

Norms of Pochuck gneiss and of norite.

	Gneiss.		Norite.	
Orthoclase	6.67		5.6	
Albite	15.20	43.38	20.9	46.8
Anorthite	16.40		20.3	
Nepheline	5.11			
Diopside	33.05		21.5	
Hypersthene		40.77	11.2	34.4
Olivine	7.72		1.7	
Magnetite	9.51	13.77	6.7	16.7
Ilmenite	4.26		10.0	
		97.92		97.9

Structure.—The structure of the Pochuck gneiss differs in different belts, ranging from almost massive to very gneissic, the rocks which have the more hornblende and biotite being the more gneissic. In a few places the rock is not foliated, being uniformly black, with a slight schistosity. In most places, however, narrow layers of light-colored feldspathic rock (Losee type) alternate with layers of the dark rock. Few of these layers are more than one-tenth inch thick, but many may be crowded together in groups that are half an inch or more thick and that are interlaminated with other thicker layers composed exclusively of Pochuck or Losee gneiss.

The massive varieties are granular crystalline rocks closely resembling coarse-grained gabbros. This type occurs principally as intrusive masses in the Franklin limestone, though at a few places it forms layers in the gneisses.

Relations.—It has been stated (p. 6) that a dark rock allied to the Pochuck gneiss intrudes the Franklin limestone and is intruded by the Losee gneiss, but the relation of the main mass of the Pochuck gneiss to the limestone has not been determined. The more massive phase of the gneiss is unquestionably intrusive in the limestone. It occurs as dikes cutting the limestone beds obliquely and as bosslike or sill-like masses whose contacts with the sedimentary rocks are very irregular.

The relations of the Pochuck gneiss to the Losee gneiss are more complex. As a rule the two gneisses are interleaved and have sharp contacts, but in places rocks mineralogically and chemically intermediate occur, and these also form distinct layers having sharp contacts with the Losee and Pochuck gneisses. Some of the layers branch or split, and thus apparently one rock is intrusive, but it is impossible to decide which one. In the Franklin Furnace quadrangle Spencer found the Pochuck gneiss intruded by the Losee gneiss.

The relations of the Pochuck gneiss to the Byram gneiss are even more difficult to ascertain. There are gradation phases between the black Pochuck gneiss and the light-gray Byram gneiss, but the gradation phases are interleaved with the purer types, in many places with sharp contacts. No intrusions of either type are found in the other, but sharp-edged masses of black gneiss are not infrequently discovered in Byram gneiss. These are regarded as inclusions and are thought to indicate that some of the Pochuck types were solid when certain of the Byram types were intruded.

On the other hand, in some places the dark pencils in the Byram gneiss coalesce, forming large flat lenses whose composition is identical with that of some of the Pochuck bands interlaminated with the granitoid gneisses. Some of these lenses are so large that they form definite layers. If the dark pencils are simply aggregates of the dark minerals of the Byram gneiss, as they appear to be, then some of the layers of black gneiss are contemporaneous with the main mass of the Byram gneiss with which they are associated.

It therefore seems probable that the black gneisses which have been included under the term Pochuck gneiss should properly be divided into two groups of different age and possibly of different origin, the first group comprising gneisses, possibly of sedimentary origin, older than the Byram and Losee gneisses, and the second group comprising dark gneisses of igneous origin contemporaneous with the Byram and Losee gneisses. The latter group would probably include the dark gneisses intrusive in the Franklin limestone. The two groups have not been mapped separately because of the impossibility of discriminating them in the field.

LOSEE GNEISS.

Name.—The Losee gneiss is so named because of its excellent development near Losee Pond, in the Franklin Furnace quadrangle. It was called the Losee Pond granite by Wolff and Brooks.[a]

Distribution.—The Losee gneiss in the Raritan quadrangle occupies a number of comparatively narrow northeast-southwest belts, some of which terminate within the quadrangle and others extend beyond its borders. The Losee gneiss is commonly interlaminated with well-defined narrow bands of black Pochuck gneiss, with which it is in sharp contact, and in places with ill-defined bands of Byram gneiss, into which it grades. The interlamination of the Byram and Losee gneisses forms a rock which in the field appears to differ in character from place to place without any sharp line of demarcation between the different phases.

The belts of Losee gneiss represented on the map are therefore not to be interpreted as areas that consist entirely of that gneiss but rather as areas in which the Losee preponderates, though they may contain also either Pochuck gneiss or Byram gneiss.

The best-defined belts of the Losee gneiss are that forming the crest and a part of the northeast slope of Jenny Jump Mountain and that occupying the valley of Lubber Run and its southwestward extension to Waterloo. In these belts the Losee gneiss predominates almost to the exclusion of other types. Associated with it is a small quantity of Pochuck gneiss, but this occurs in a few narrow black bands that sharply contrast with the main mass of the rock, which is a white or light-green phase of the Losee containing almost no dark minerals and having very little schistosity.

In other parts of the quadrangle the Losee gneiss is also mapped as occurring in belts, but in those areas it is an intermediate phase which is intimately associated with Byram gneiss, from which it is distinguished with great difficulty. The boundaries of the belts are drawn at places where the characters of the predominant rock are more like those of the Losee gneiss than those of other types, and they are therefore more or less arbitrary.

Character and varieties.—Although all gradations seem to exist between the Losee gneiss and the other gneisses, nevertheless the typical Losee rock is well characterized in the field and under the microscope. In the field it is distinguished by its white or light-green color in fresh exposures. On weathered surfaces, where decomposition is only superficial, the ledges are in many places snow-white. Where deeply weathered the rock has a bronzy color, which is deeper where the proportion of light-colored pyroxene is larger. It is often impossible to distinguish such rock from weathered Byram gneiss.

The gradation phases of the Losee gneiss range from a uniform gray rock showing no dark components to a yellowish or purple rock speckled uniformly with tiny black scales or irregular dark blotches. In a few places the dark components are aggregated into little pencils or lenses whose longer dimensions are parallel, lying in a white or light-gray fine-grained feldspathic matrix. In such phases, which resemble closely some phases of the Byram gneiss, the nature of the rock can be recognized only by recourse to the microscope. The Losee gneiss, whatever its general appearance, is characterized by the presence of orthoclase and oligoclase, and the Byram gneiss by the presence of microperthite and microcline.

Mineral composition.—The Losee gneiss consists mainly of oligoclase and quartz, with smaller amounts of bright-green diopside, hypersthene, biotite, apatite, magnetite, sphene, and locally zircon. Microcline, microperthite, and orthoclase occur in the typical rock in minor amounts only, though they are found in large quantities in many specimens representing intermediate phases between the Losee and the Byram gneisses. Of the dark components diopside is most abundant, followed by hornblende, hypersthene, and biotite in the order named. Magnetite is present in all specimens but in many is in minute quantities only.

With increase in the proportion of pyroxenes and hornblende the Losee gneiss grades into the Pochuck gneiss. Correspondingly the proportion of magnetite and apatite is notably increased and the amount of quartz is commonly diminished.

The range in composition of the phases included in the Losee gneiss is shown by the following table, in which columns 1 to 6 indicate the relative percentages by weight of the various components as determined by measurement in thin sections. Columns 7 and 8 show the mineral composition of the average rock of two distinct belts of a light-hued phase in the Franklin Furnace quadrangle.[b] Mineralogically the more siliceous varieties are quartz granodiorite and the less siliceous are augite diorite.

[a] U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 439–442, 1898.
[b] U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), and New Jersey Geol. Survey folio No. 1, p. 4, 1908.

Mineral composition of various phases of the Losee gneiss.

	1	2	3	4	5	6	7	8
Quartz	16.07	13.75	19.59	0.43	25.84	11.82	26.68	35.39
Oligoclase	63.14	61.52	43.49	36.30	38.07	17.05	66.07	57.90
Orthoclase	16.16	16.66	4.62	3.70	30.86	38.54		
Microcline							1.91	
Diopside		2.52	8.02	40.12				
Hypersthene	4.62	2.44	22.58		4.22	21.44		
Hornblende				8.10		9.70		3.28
Magnetite		3.06	1.82	11.35	.97	1.45	1.92	1.73
Biotite							3.36	1.67
	99.99	99.95	100.07	100.00	99.96	100.00	99.94	99.97

1. Ledge of dark-gray variety on New York, Susquehanna & Western Railroad just east of Smith Mills, Greenwood Lake quadrangle, about 1 mile north of locality of 2.
2. Top, north end of Kakeout Mountain, Passaic quadrangle. Very similar to 1; contains bands of Pochuck gneiss.
3. Small ledge of bronzy rock, northwest of Durham Pond, Passaic quadrangle.
4. White variety of Losee gneiss. Ledge few feet from old shaft of Wood mine, near Hibernia, Passaic quadrangle.
5. Light-gray variety. Top of hill one-half mile west of locality of 4.
6. Dark-brown or bronze variety. South side of Sheep Hill, north of Boonton, Passaic quadrangle.
7, 8. Average rock of two belts of light gneiss in Franklin Furnace quadrangle.

Chemical composition.—The Losee gneiss is characterized by high soda and low magnesia and potash. Alumina, lime, and silica vary greatly, owing mainly to the presence or absence of augite, the silica decreasing and the alumina and lime increasing as the pyroxene increases.

All components vary greatly where the Losee grades into the Byram, the most striking variation being in the potash, which increases rapidly as the Byram gneiss is approached.

Analyses of three varieties of the Losee gneiss from the Raritan quadrangle, with the calculated norms, are given below.

Analyses of Losee gneiss from points in the Raritan quadrangle.

[W. T. Schaller, analyst.]

	1	2	3
SiO_2	77.53	52.97	61.54
Al_2O_3	13.60	23.27	17.98
Fe_2O_3	.23	1.31	3.11
FeO	.16	3.31	3.21
MgO	Trace.	2.20	.32
CaO	.73	10.08	2.29
Na_2O	6.65	4.09	5.85
K_2O	1.20	.62	4.77
H_2O-	.15	.53	.09
H_2O+	.18	.69	.78
TiO_2	.16	.38	
CO_2	Trace.	.26	.42
P_2O_5	.03	.22	.18
MnO	Trace?	.19	.08
	100.62	100.12	100.62

1. White Losee gneiss. Knob northeast of Berkshire Valley.
2. Augitic Losee gneiss (gradation toward Pochuck gneiss). High Bridge Branch, Central Railroad of New Jersey, near Davenport mine.
3. Intermediate gneiss, between Byram and Losee. Dump of Oxford tunnel, Delaware, Lackawanna & Western Railroad.

Norms of varieties of Losee gneiss, calculated from chemical analyses.

	1	2	3
Quartz	32.84	1.98	3.60
Orthoclase	7.23	3.34	28.36
Albite	56.07	34.58	49.50
Anorthite	3.43	43.37	8.06
Diopside		3.43	
Corundum	.07		.15
Hypersthene		8.56	4.30
Apatite	.06	.34	.34
Magnetite		1.86	4.41
Ilmenite	.30	.76	
Hematite	.24		
Water	.33	1.22	.87
Calcite		.59	.95
	100.57	100.03	100.54

The first norm falls under noyangose (I.4.1.5), the second under labradorose (I.5.4.4), and the third under laurvikose (I.5.2.4).

Structure.—Nearly all specimens of the Losee gneiss show more or less gneissoid structure and many also exhibit foliation. In the light-colored varieties the gneissoid structure is obscured by the lack of contrast in the colors of the component minerals, but in the darker varieties it is easily discernible. In all it is due to the slightly lenticular shape of the quartz grains and the arrangement of the dark minerals in lines or streaks, thus giving rise to "pencils."

In the darker varieties the dark components are commonly aggregated into distinct lenses about an inch long and one-eighth inch to one-fourth inch thick, and these are distributed in lines, strongly emphasizing the linear structure imparted by the elongated quartz grains. The strike of this linear structure is generally northeast, and its pitch 15° to 40° in the same direction.

At a number of places along the contact of the gneisses with the Paleozoic and Newark rocks, and at a few places within the main gneiss areas where faults are supposed to exist, the rocks are more or less sheared. The Losee gneiss within the zones of shearing is more or less crushed. Where the rock is least altered all its components have been broken into sharp-edged fragments, which are embedded in a fine-grained clastic aggregate of the same minerals, with the addition of scattered wisps of light-colored mica and a little kaolin. Where alteration has been more profound all the original components except the quartz have disappeared and only their alteration products remain as evidence of their former existence. Kaolin, chlorite, epidote, secondary hornblende, and in some phases muscovite or biotite, all in thin plates, arranged in parallel position, make up the greater portion of the rock mass; through this are scattered sharp-edged fragments of quartz grains and a few particles of magnetite. Here and there garnets are embedded in the schistose aggregate. In phases in which schistosity is highly developed the rock appears to be a light-colored quartzose micaceous schist.

Relations.—The relations of the Losee gneiss to the other gneisses can not be determined in the area of the Raritan quadrangle, but in the Franklin Furnace quadrangle, farther north, the contacts between white granitic gneiss and black dioritic gneisses indicate that the former are intrusive into the latter. In general, however, the contacts between the Losee and the other gneisses are such as to leave the relations indeterminate. In the Raritan quadrangle the Losee gneiss grades into the other gneisses.

The relations between the Losee gneiss and the Franklin limestone have already been described (p. 6). At some places the gneiss appears to be intrusive into the Franklin limestone.

BYRAM GNEISS.

Name.—The Byram gneiss is named from the town of Byram, in Sussex County, where it is well exposed in the hills northeast of Roseville.

The rock exposed in the Van Nest tunnel of the Delaware, Lackawanna & Western Railroad at Oxford was called Oxford type by Nason.[a] This name was later[b] replaced by the term now used.

Distribution.—In the northeastern portion of the quadrangle the Byram gneiss occupies several broad belts separated by narrower belts of Losee gneiss, but in the western portion the Byram gneiss occupies the narrower belts and the Losee gneiss the broader ones. The most important areas of the Byram gneiss are two comparatively narrow strips on the slopes of Jenny Jump Mountain, a wide strip occupying nearly the entire extent of the Allamuchy-Pohatcong mountain range in the Raritan quadrangle, and a broad strip extending southwestward from the north border of the quadrangle near Lake Hopatcong and occupying the entire width of the Schooley Mountain mass to the line between Morris and Hunterdon counties, south of which it is separated into two belts by a wedge of Losee gneiss. In the mountain mass east of the German Valley the distribution of the Byram gneiss is more irregular. It occupies the greater portion of the ridge known as the Fox Hill Range, but elsewhere in this portion of the quadrangle it appears in small lenticular areas surrounded by Losee gneiss, in narrow strips separated by zones in which the Losee gneiss is the prevailing rock, and in one locality, from Califon northeast to Horton, by a belt of Pochuck gneiss. The strips generally trend northeast parallel to the trend of the Highlands ridges, but the area inclosing Mine Mountain has the shape of a horseshoe with the tip of its toe at Gladstone and Peapack and its shanks extending northeastward nearly to the east edge of the quadrangle. A lenticular area of Byram gneiss between the ends of the shanks covers about 1½ square miles, and two such areas between Pottersville and Mountainville occupy each about 1 square mile.

Character and varieties.—The several phases of the Byram gneiss differ greatly in appearance, but as seen in outcrop most of them resemble one another more than they do the Losee or Pochuck gneisses. Of the two principal varieties observed one is dark gray and moderately coarse grained and has a bronzy-brown tone on freshly fractured surfaces. It is composed essentially of microperthite, microcline, orthoclase, hornblende, quartz, magnetite, and in some places biotite. The dark minerals are ordinarily grouped into pencils arranged parallel to the strike of the rock bands. This grouping produces a gneissoid appearance on all fractured surfaces except that transverse to the axes of the pencils, where the structure appears evenly granular. The axes of the pencils pitch in the same direction as the axes of the ore bodies in the various magnetite mines throughout the region. This structure, which is characteristic of nearly all the gneisses in the district, is known as linear structure. Its strike is generally N. 15°–40° E.

The second variety of the rock is yellowish in outcrop, and pink, light gray, or nearly white on fresh fractures. It is ordinarily finer grained than the dark-gray variety, from which it differs mineralogically mainly in the subordination of dark components and thus the rock lacks the pencils of the darker variety and consequently the distinct pitch structure. It may possess a slight linear structure, but as a rule this is so obscure that the texture is practically granitic.

In the Raritan quadrangle both phases of the Byram occur, but not generally in distinct areas. The first or darker-colored phase is much more abundant than the lighter phase. It comprises the entire body of some of the belts, as that immediately west of Cranberry Reservoir, and the greater portion of all the others. The lighter phase is limited to narrow layers interlaminated with the darker variety and with layers of the Losee and Pochuck gneisses.

Intermediate phases between the Byram and the other gneisses have intermediate characteristics.

Mineral composition.—In mineral composition the Byram gneiss differs from the Losee gneiss in its larger proportion of potassic feldspars, particularly in the form of microperthite, and from the Pochuck gneiss in its smaller proportion of hornblendic and pyroxenic minerals. It commonly consists of quartz, microperthite, microcline, orthoclase, a little brown hornblende, magnetite, apatite, and sphene. Diopside and hypersthene occur in some phases but are not common. Biotite is generally present, in some specimens in large quantity. It is commonly associated with hornblende, but in a few specimens it is the only bisilicate found.

The Byram gneiss grades into the Losee gneiss by introduction of oligoclase and into the Pochuck by increase in oligoclase and bisilicates. The composition by weight of some of the varieties was determined as follows:

Mineral composition of various phases of the Byram gneiss.

	1	2	3	4	5	6
Quartz	24.27	27.12	28.06	30.89	35.54	35.29
Oligoclase				3.92		3.03
Orthoclase	31.75	12.07	.87	16.46	4.40	19.64
Microperthite	39.37	53.22	68.35	43.89	58.50	33.57
Hypersthene						3.03
Hornblende	2.31		.61	4.75	Trace.	
Magnetite	2.35		1.98		1.57	5.87
Biotite		7.68				
	100.05	100.09	99.87	99.91	100.01	99.93

1. Medium-grained bronzy variety. Ledge on southwest spur of hill northeast of Powerville, Passaic quadrangle.
2. Medium-grained light-colored variety. Ledge on New York, Susquehanna & Western Railroad, west of Riverdale, Greenwood Lake quadrangle.
3. Band of fine-grained light-colored variety in Losee gneiss, side of road crossing east ridge of Stony Brook Mountains, one-half mile from Brook Valley, Passaic quadrangle.
4. Very light colored fine-grained variety, top of southeast slope of 1169-foot hill southwest of Durham Pond, Passaic quadrangle.
5. Light-yellow medium-grained variety, south end of knoll on east side of road between Boonton and Taylortown, 1 mile south of Taylortown, Passaic quadrangle.
6. Coarse-grained gray variety, top of 1038-foot ridge, 1 mile east of Splitrock Pond, Passaic quadrangle.

Chemical composition.—The chemical composition of the Byram gneiss naturally changes as the rock approaches the Losee or the Pochuck type. The following table gives analyses of the Byram gneiss and of allied rocks:

Analyses of varieties of Byram gneiss and allied rocks.

	1	2	A	3	B
SiO_2	77.07	58.75	59.78	61.54	63.45
Al_2O_3	12.61	17.16	16.36	17.98	18.38
Fe_2O_3	.71	5.18	3.08	3.11	.42
FeO	.73	3.94	3.72	3.21	3.56
MgO	Trace.	.91	.69	.32	.35
CaO	.87	.62	2.96	2.29	2.93
Na_2O	3.43	5.72	5.39	5.85	5.06
K_2O	4.06	5.40	5.01	4.77	5.15
H_2O-	.23	.35	1.58	.09	.30
H_2O+	.62	.73		.78	
TiO_2	.12	.65			
CO_2	Trace.	.13	.75	.42	
P_2O_5	Trace?	.20		.18	Trace.
MnO	.09	.10		.08	
BaO					.13
	100.54	99.84	99.32	100.62	99.73

1. Light-colored Byram gneiss. Quarry a mile west of Hibernia. Analyst: W. T. Schaller. (Tehamose, I.3.2.3.)
2. Micaceous Byram gneiss. A moderately fine grained pinkish-gray variety. Van Nest tunnel, Delaware, Lackawanna & Western Railroad, near Oxford. Analyst: W. T. Schaller. (Ilmenose, II.5.1.3.)
A. Syenite, Silver Cliff, Colo. Analyst: L. G. Eakins. (Monzonose, II.5.2.3.) U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, p. 281, 1896.
3. Gneiss, intermediate between Byram and Losee types. A streaked gray variety. Van Nest tunnel, Delaware, Lackawanna & Western Railroad, near Oxford. (Laurvikose, I.5.2.4.)
B. Augite syenite (akerite), Loon Lake, N. Y. Analyst: E. W. Morley. (Pulaskose, I.5.2.3.) Geol. Soc. America Bull., vol. 10, p. 183, 1899.

Norms calculated from the above chemical analyses.

	1	2	A	3	B
Quartz	39.13	2.10	1.40	8.60	5.76
Orthoclase	24.46	31.69	30.00	28.36	30.02
Plagioclase:					
Albite	28.82	48.21	45.6	49.50	42.44
Anorthite	4.37	1.39	7.0	8.06	12.51
Other components	3.13	16.57	13.70	10.87	8.38
	99.91	99.96	97.70	100.39	99.11

In the usual nomenclature the rock from the Hibernia quarry (1) is a quartz monzonite, and the others (2 and 3) are monzonites. The close similarity of the latter to the syenite of Silver Cliff, Colo., and to the akerite of Loon Lake, N. Y., is plainly evident.

Structure.—The pencil structure characterizing the Byram gneiss has already been mentioned (p. 9). It is due partly to the parallel elongation of certain of the rock's components but more particularly to the occurrence of the dark constituents in cylindrical groups with their axes approximately parallel. On surfaces parallel to this direction the structure of the rock appears typically gneissic, and on cross sections it appears typically granitic. The cylindrical groups are composed of pyroxene, amphibole, and magnetite intercrystallized in the usual manner of those minerals in plutonic rocks. No crushing of the minerals is observable in them nor is any evidence discernible of distortion of the mineral particles by pressure. The structure of the rock appears to have directly resulted from the crystallization of its constituents from a magma.

In a few places near the faults that separate the gneiss from the Paleozoic and later strata the Byram gneiss is brecciated and crushed. It loses its ordinary character and much of it assumes the appearance of a pink or red microgranite. In thin sections all the constituents are seen to be crushed into small, sharp-edged fragments, which are embedded in a finer grained matrix of the same character. Many quartz fragments exhibit strain shadows and the feldspars show curved twinning bars. Here and there a few muscovite shreds are developed, and considerable chlorite is noticeable in the matrix.

Relations.—The relations of the Byram gneiss to the other rocks with which it is associated have been described. In brief, it is thought that the Byram gneiss is intrusive into the Franklin limestone and into some forms of the Pochuck gneiss, and that it is contemporaneous with some other forms of the Pochuck into which it passes by gradual transitions. Its relations to the Losee gneiss are not known, but it is probably practically contemporaneous with that rock, both gneisses possibly being differentiates from one magma.

ROCKS NOT MAPPED.

BANDED GNEISSES.

A small area immediately north and west of Pequest furnace is occupied by rocks that differ greatly from any others observed in the quadrangle. They consist of well-banded fine-grained gneisses, all containing much epidote and some apparently permeated with pegmatite material, and of fairly fine grained mica schists containing nodules of feldspar. Their general aspect is that of thinly bedded sedimentary schists. Some of the banding is due to alternate layers differing only in coarseness of grain and separated by thin seams of mica. More distinctly banded rocks consist of long flat lenses of fine-grained dark-green rock separated by narrow white layers that branch and fork. As a rule the bands are straight, but in some places the darker layers are bent and looped as though folded. With these banded gneisses are apparently interbedded dark-green schists resembling phases of the Pochuck gneiss.

Because of the distinct banding, which is much more definite than elsewhere in the region, it has been thought that these rocks might be metamorphosed sediments; but microscopic examination of their thin sections reveals nothing to substantiate this view. They are similar in general character to some forms of the Byram gneiss but are much more profoundly altered. Among the alteration products are great quantities of epidote and kaolin, both of which are apparently derived from feldspar, and in several places notable quantities of brown-buff tourmaline and a few garnets. Although there is no proof that the rocks are not metamorphosed sediments they have not been separated from the Byram gneiss in the mapping. If they are metamorphosed siliceous sediments they have been so thoroughly permeated with the Byram gneiss magma that they have assumed the general character of the Byram gneiss.

MAGNETITE.

Although small in quantity and restricted in area rocks composed mainly of magnetite nevertheless are rather widely distributed in parts of the Highlands. They are in many places associated with Pochuck gneiss or with pegmatite, forming long thin lenses or sheets in the Losee or the Byram gneiss or in the Franklin limestone and dipping conformably with the neighboring rocks. The rock consists mainly of magnetite, with hornblende, augite, feldspar, quartz, apatite, and in places biotite as accessories. Hornblende is the most abundant of the accessories and the most widely spread. Feldspar is also abundant in some specimens but is by no means so common as hornblende. Increase in feldspar is as a rule accompanied by increase in quartz and the magnetite grades into pegmatite. It grades into Pochuck gneiss by increase in the hornblende and augite, especially the former.

Most of the bands of magnetite exposed on the surface are short, but in places, as at Hibernia, in the Passaic quadrangle on the east, they measure several miles along the strike, and in the neighborhood of Ironia they form several belts over one-half mile long. Their widths, however, are rarely more than 20 feet, so that they are not represented on the areal-geology map.

[a] New Jersey Geol. Survey Ann. Rept. for 1889, p. 30.
[b] Spencer, A. C., U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (No. 161), and New Jersey Geol. Survey folio No. 2, p. 5, 1908.

A fuller discussion of the magnetites is given under "Economic geology" (p. 23).

PEGMATITE.

Character and distribution.—Pegmatite is found in large quantities associated with all the other rocks of the Highlands and in some places forms considerable masses unmixed with other rocks. Although commonly occurring in sheets or layers parallel to the associated limestone and gneisses, the pegmatite in some places forms veinlike bodies cutting across the structure of those rocks and penetrating them in such a way as to leave no doubt that it is distinctly later. In several localities pegmatite masses that are intercalated between gneiss bands and that run parallel with them for long distances send off branches, approximately at right angles, which traverse the gneiss nearly perpendicular to its strike. This feature is particularly well exhibited on the flat surface of a large ledge on the north side of the right of way of the Denville-Rockaway branch of the Delaware, Lackawanna & Western Railroad, about one-fourth mile east of the station at Rockaway.

No attempt has been made to map the pegmatite dikes in the Raritan quadrangle. They occur in all parts of the Highlands but commonly in bodies so small that they can not be represented on the scale of the map. In the Highlands some patches of considerable size are devoid of pegmatite, but throughout most of that area every square mile shows it to some extent.

Composition.—The principal minerals of the pegmatite are the same as those of the associated gneisses—quartz, microcline, microperthite, oligoclase, hornblende, pyroxene, biotite, and in many places magnetite and graphite. The hornblende and pyroxene vary greatly in amount, here and there comprising more than half of the rock mass. Hornblende is especially abundant in many dikes, especially those associated with the magnetite ores, and it occurs in large crystals, many of which measure 12 or 15 inches in length. Garnet is a common constituent of the rock, particularly where it has been sheared. Apatite, sphene, and zircon occur also at many localities, the zircon commonly in fine crystals. In some of the pegmatite bodies the amount of magnetite is so great that the rock has been mined as lean iron ore. The graphite is particularly interesting. It occurs in small flakes in most of the pegmatites, but in a few coarse-grained ones it appears in scattered plates one-half inch in diameter. One such occurrence is about 2 miles southwest of Mendham, on the road running west, at the stream crossing about three-fourths mile west of the road running south to Somersetin. Here, as at many other places, the pegmatite is not visibly associated with the Franklin limestone, so that it does not seem possible that its graphitic component can have originated in fragments torn from carbonaceous sediments and absorbed in the pegmatite material during intrusion. (See also p. 7.)

One phase of the pegmatite that has been used to some extent as a source of road material is remarkable for its content of blue vivianite. The rock, which is exposed in a quarry about a mile northwest of Mendham, is so close to the fault bounding the east side of the Mount Paul inset that all of its components have been crushed and very much altered. The vivianite occurs as blue earthy coatings in joint cracks and in the crevices between the particles of the broken quartzes and between the quartz and kaolinized feldspar. When crushed the resulting mass is light blue.

Relations.—The composition of the pegmatite bodies seems to suggest that genetically they are closely allied to the gneisses. Considerable force is added to this suggestion by the facts that their chief feldspar is, as a rule, like that of the associated gneiss; that in many places pegmatite and gneiss grade into each other without any sharp contact; and that in other places very coarse-grained patches in the gneiss are unquestionably identical in character with much of the pegmatite. As the dikelike or veinlike pegmatite is similar to the patches in the gneiss it is assumed that this also is a phase of the same magmas that produced the gneisses,[a] but as some of the pegmatites cut across the structure of the gneisses they must be later in age than the gneisses they traverse.

In order to bring these seemingly contradictory facts into accord, it is assumed that the pegmatites are portions of a magma, the earlier invasions of which formed the Losee and Byram gneisses. Here and there within the earlier intrusive masses the magmas solidified as coarse-grained patches. Elsewhere the earlier magma solidified in part and was later intruded by the underlying partly crystallized liquid magma, which found easiest movement parallel to the foliation of the overlying rocks, in which it formed intercalated layers. Where the intruded material was still viscous gradation occurred between the material of the pegmatite and that of the invaded mass. Where the latter rock had already solidified the invading material acted like a later intruding mass and made sharp contacts with the intruded gneisses. In a few places the pegmatitic material cut across the gneissic banding in irregular courses, but as a rule it insinuated itself between the layers and helped to emphasize the existing structure.

Reference has already been made to the fact that here and there the pegmatite has been crushed, and in consequence has assumed a gneissoid structure. At the same time considerable garnet and muscovite was developed, the latter in some places in large quantity. The resulting rock is a garnetiferous-micaceous gneiss which in many places contains a very considerable quantity of graphite.

[a] Compare S. H. Ball's discussion of origin of pegmatites in the Georgetown quadrangle, Colorado, in U. S. Geol. Survey Prof. Paper 63, pp. 61-64, 1908.

EPIDOTE-GRAPHITE ROCKS.

At several points in the quadrangle, principally in a zone extending from the northwest side of the conical hill (elevation, 531 feet above sea level) $1\frac{1}{2}$ miles northwest of Gladstone, to Burnett Brook, one-fourth mile west of the point where it crosses the road a mile north of Mount Paul, are small exposures and many fragments of a light-gray or light-green rather coarsely crystalline rock composed largely and in places exclusively of an aggregate of light-gray, nearly white epidote and small flakes of graphite, with here and there a few quartz grains and in some specimens a flake or two of a dark mica. The best exposures, however, are not in this belt. They occur about $2\frac{1}{2}$ miles farther southeast, alongside the road running northeast from Gladstone, near the point where it crosses North Branch of Raritan River, about $1\frac{1}{2}$ miles northeast of the village. Although the rock is better exposed at this place than anywhere else in the quadrangle its relation to the surrounding gneisses has not been made out. A coarse pegmatite occurs just north of the epidote rock, but the contact of the two was not seen. Both rocks are strongly graphitic. In the dump heap of the exploring pit on the east side of Peapack Brook at the road crossing west of Long Hill fragments of the rock were found intermingled with fragments of a fresh chondroditic limestone and with pieces of the Byram and the Pochuck gneiss. Nothing could be discovered that would throw light on the origin of the epidote rock, although its association with the crystalline Franklin limestone suggests that it may be a metamorphosed part of that formation.

CAMBRIAN SYSTEM.

GENERAL CHARACTER.

The Cambrian rocks of the Raritan quadrangle are part of a great belt of similar strata that extends without interruption from Canada to Alabama. In New Jersey and adjoining regions the strata are chiefly thick limestones but include much thinner beds of shale, sandstone, and quartzite at the base. Farther south the clastic rocks increase greatly in thickness and the limestones form proportionally less of the system. Along the entire length of the belt the Cambrian strata rest unconformably upon the eroded surfaces of the underlying rocks, and everywhere the materials of the basal beds were derived almost entirely from those rocks.

HARDYSTON QUARTZITE.

Character and distribution.—The Hardyston quartzite is not of uniform composition and thickness. Typically it is a quartzite, at many places conglomeratic and containing pebbles of quartz, feldspar, granite, gneiss, and hornblende schist. Most of the pebbles are less than an inch in diameter, but some measure 2 to 4 inches. In places the formation is a more or less friable calcareous sandstone, steel-blue when fresh, but weathering to a rusty-brown porous limonitic rock. It is generally but not invariably feldspathic. In some localities its arkose character is so strongly marked that it is not readily distinguishable from coarse granite. Its upper portion contains beds of slate.

It is the oldest fossiliferous rock in the quadrangle, forming the base of the Cambrian, and is found wherever the undisturbed contact between the pre-Cambrian and Cambrian rocks is exposed. As it is relatively thin and is now steeply inclined it appears at the surface in long, narrow bands flanking the pre-Cambrian areas. In many localities, owing to extensive accumulations of glacial material or subaerial wash, its presence can only be inferred, being indicated by scattered bowlders or by the structure of the Cambrian rocks near by, so that its distribution as shown on the map is much wider than that actually observed in the field.

Imperfect specimens of trilobites identified as *Olenellus thompsoni* have been found in considerable numbers in the weathered calcareous beds of its upper portion at widely separated localities in the Raritan quadrangle—at the foot of the mountain east of Tranquility, in the railroad cut north of Oxford, and in the railroad cut at Washington. No fossils have been observed in the unweathered portions of the calcareous beds nor in the coarser quartzitic phases, although they must be present in greater or less abundance in the former.

Thickness.—The formation ranges in thickness from a few feet to 200 feet or more, but as it passes into the overlying limestone through slaty or shaly layers, several of which are in places interbedded with limestone layers, its upper limits are indefinite.

Name and correlation.—The formation is named from Hardystonville, Sussex County, N. J., where it is well exposed. Its fossils indicate that it is Lower Cambrian in age. Its stratigraphic position is the same as that of the Poughquag quartzite of Dutchess County, N. Y., and the Chickies quartzite of Pennsylvania, and it should therefore probably be correlated with them.

Relations.—The Hardyston quartzite rests unconformably upon the deeply eroded uneven surface of the crystalline rocks, the contact being exposed a mile southwest of Long Bridge and in the railroad cut at Washington, as well as at other points outside the quadrangle. It becomes progressively more calcareous upward, showing local alternations of limestone and slate, and finally appears to grade into the overlying Kittatinny limestone.

Local details.—Southeast of the Highlands quartzite is exposed near Van Syckles, Annandale, Allerton, and Peapack. At Van Syckles scattered fragments and small outcrops of quartzite occupy a considerable area, incorrectly shown on the map as Kittatinny limestone, but the relations are obscure and afford no adequate knowledge of the structure. From Polktown a well-defined conglomeratic quartzite, 180 feet thick, can be traced almost to Annandale. Southeast of Annandale quartzite apparently occupies a rather large area, but owing to lack of exposures its boundaries are indefinite. A mile east of Allerton faults are numerous and the relations of the quartzite and gneiss are complicated. Just east of the millpond at Gladstone quartzite is well exposed, dipping westward and lying on gneiss. Similar beds are exposed southward to Peapack and northward along the Peapack-Mendham road for several miles.

In the German Valley quartzite is well exposed on the flanks of a small anticline at Califon and at several points along the northwestern base of the Fox Hill Range, but its presence northeast of Naughright can only be inferred, as exposures are lacking. In the Black River Valley north of Chester angular bowlders of quartzite are scattered about the fields, but the formation does not outcrop. Traces of it extend northward as far as Ironia, but its further continuation to Middle Forge as shown on the map is conjectural, as is the loop about the northeast end of the Fox Hill Range.

In the Musconetcong Valley there are traces of calcareous sandstone near Stephensburg and Changewater, but along most of the east side of the valley and also on the west side the formation is apparently cut out by faulting. In the Pohatcong Valley calcareous quartzite, steel-blue when fresh, is exposed in the railroad cut just northeast of the station at Washington and at Port Colden. Near the Karrsville schoolhouse numerous bowlders of conglomerate and of vitreous steel-blue quartzite strew the surface, and at many points for 2 miles north of Mount Bethel bowlders of reddish conglomeratic quartzite are scattered about. The beds are apparently nearly horizontal, so that they outcrop in a wide belt instead of a narrow band. The presence of the formation at other places in the Pohatcong Valley is inferred from the general structure.

In the Pequest Valley fossiliferous calcareous sandstone is exposed in the railroad cut north of Oxford station. For 10 miles northeast of Oxford the formation is not exposed and it is mapped along this belt by inference from the topography and the supposed structure. At the southwest end of Cat Swamp Mountain a massive arkose, dipping 15°–25° NW., is exposed in a small quarry by the roadside. In a small quarry near the Great Meadows schoolhouse quartzite rests upon the unevenly eroded surface of the gneiss, which it closely resembles. At Allamuchy the conglomeratic phase of the formation is well developed, with pebbles of quartz, feldspar, mica, granite, gneiss, and hornblende schist, some of which are 4 inches in diameter. Many of the feldspar pebbles preserve their crystalline form and some of the basal beds can with difficulty be distinguished from the underlying rock. Northeast of Tranquility weathered fragments of calcareous sandstone contain Olenellus. In ledges south of Decker Pond Olenellus-bearing sandstone overlies Franklin limestone cut by banded gneiss, and both limestone and gneiss are cut by pegmatite; but the sandstone is cut by neither. Just east of Decker Pond the upper slaty beds of the Hardyston are exposed.

South of Jenny Jump Mountain and northeast of Green Pond limy sandstone outcrops near an old limekiln. In the railroad cut 3 miles south of Green Pond limy sandstone, believed to be Hardyston, is exposed, but it does not outcrop at intervening points.

CAMBRIAN AND ORDOVICIAN ROCKS.

KITTATINNY LIMESTONE.

Character and distribution.—The Kittatinny limestone is generally blue or bluish gray, though it is in places drab, black, or rarely red. It has commonly been called the blue limestone in contradistinction to the white Franklin limestone. At several horizons it contains abundant layers or nodules of black chert, and some beds in its basal portion are oolitic. The formation consists chiefly of massive beds, in places 3 to 4 feet thick, but it includes, near the top, thin layers of limestone alternating with layers of shale or thin-bedded sandstone. In some places the rock shows distinct cleavage at right angles to the bedding. Chemically the rock is a magnesian limestone, a series of thirty or more analyses of samples from widely separated localities showing from 14 to 21 per cent of magnesia, but some beds near the top of the formation carry less than 3 per cent of magnesia.

In northern New Jersey the formation occupies part of the floor of the Kittatinny Valley and continues northeastward and southwestward into the adjoining States. In the Raritan quadrangle, the northwest corner of which embraces part of the Kittatinny Valley, it occupies a number of belts and isolated areas. It also underlies the greater part of the long, narrow valleys that intersect the Highlands. It occurs also southeast of the Highlands, where it is overlapped for the most part by

Triassic shale and sandstone, though it is rather extensively exposed near Clinton, Gladstone, and Peapack.

In some areas of the limestone its outcrops are numerous, but in others it is deeply buried beneath glacial deposits and its extent can only be inferred from the general topography and from the testimony of scattered deep borings.

Fossils.—The fauna of the Kittatinny limestone, so far as known, is not extensive, and fossils are found at but few localities, but it is sufficient to establish the Cambrian age of the greater part of the formation. Fossils were collected principally at O'Donnell & McManniman's quarry, at Newton, in the Franklin Furnace quadrangle, where Weller has identified the following species: *Obolus* (*Westonia*) *stoneana* (Whitfield) Walcott, *Eoorthis newtonensis* (Weller) Walcott, *Ptychoparia newtonensis* Weller, *Anomocare parvula* Weller, and *Dikellocephalus newtonensis* Weller; possible Foraminifera were also found. *Dikellocephalus newtonensis* is the most abundant member of the fauna, which shows a general similarity to some of the late Cambrian faunas of the upper Mississippi Valley. *Eoorthis newtonensis* is found also in an old quarry just north of Andover Junction in the extreme northern part of the Raritan quadrangle.

About half a mile north of Blairstown, in an abandoned quarry, a bed about a foot thick contains many fragments of trilobites, determined by Weller as *Agraulos saratogensis* Walcott, *Ptychoparia blairi* Weller, and *Ptychoparia calcifera* Walcott. These fossils are identical with species found in limestones near Saratoga, N. Y., which are classified as Upper Cambrian, and the beds containing them lie above the middle of the formation, but their exact position can not be fixed.

In the railroad cut at Columbia, a few miles southwest of Blairstown and outside the quadrangle, a fauna of early Ordovician (Beekmantown) age has been found in beds near the top of the Kittatinny limestone. This fauna, according to Weller, includes *Dalmanella? wemplei* Cleland, *Syntrophia lateralis* (Whitfield), *Raphistoma? columbiana* Weller, *Eccyliomphalus subellipticus* Weller, and *Isotelus? canalis* (Whitfield). So far as can be determined from the fauna, therefore, the formation is Upper Cambrian to early Ordovician in age.

Thickness.—The thickness of the formation is estimated at 2500 to 3000 feet, but as the structure is complicated by folds and faults it is not possible to measure the thickness accurately.

Name and correlation.—The formation is named from the Kittatinny Valley, of whose floor it forms a part.

As it seems to rest conformably upon the Hardyston quartzite, of Lower Cambrian age, and as it contains Beekmantown fossils near its top at one place and Upper Cambrian fossils in its body in other places, its deposition may have covered a period extending from the middle or later part of early Cambrian time to the early part of Ordovician time. It is not yet known whether the unfossiliferous lower part of the formation is of the same age as the unfossiliferous part above or older. No sedimentary break has been discovered between the Kittatinny and the Hardyston, and until such a break has been found the possibility remains that the lower part of the formation may be older than Upper Cambrian. It is equivalent also to the lower and greater part of the Shenandoah limestone where that formation is typically developed.

Relations.—The formation appears to rest conformably upon the Hardyston quartzite, and grades into it, the transition beds consisting of interbedded shale and limestone. It is limited above by an unconformity at the base of the Jacksonburg limestone. In places, as near Hope and Johnsonburg, the Kittatinny has been overthrust upon the Martinsburg shale, and southeast of the Highlands it is overlapped unconformably by Triassic beds.

Local details.—Southeast of the Highlands the formation outcrops near Gladstone, Pottersville, Annandale, Clinton, and Van Syckles. At Gladstone and Peapack its lower part is exposed in large quarries, in some of which the rock is distinctly reddish. The structure is irregular, the beds lying in all positions from horizontal to vertical. At Pottersville limestone is exposed in the east bank of Lamington River and has been found in wells, but owing to thick alluvial deposits its extent is unknown. East and south of Annandale it occupies several square miles, the beds dipping steeply westward. In the quarries along Prescott Brook the beds are much disturbed and in one quarry pre-Cambrian rocks are overthrust upon the limestone. In the large quarries at Clinton and for several miles north of that place the beds dip 30°–70° SW. Near Van Syckles limestone probably underlies a considerable area, but for the most part it is so deeply buried by alluvium that its relations can not be determined.

From large quarries between Califon and Middle Valley and from exposures and borings the limestone is known to underlie the German Valley as far north as Naughright, although in many localities it is buried by at least 100 feet of glacial drift and river deposits. At Middle Forge sheared and faulted beds of shaly limestone outcrop not far from Green Pond conglomerate. The limestone is probably continuous between Naughright and Middle Forge, but it does not underlie the whole valley, for northeast of Flanders hills of conglomeratic sandstone, probably Green Pond conglomerate, rise above the plain of glacial drift in the valley bottom.

In the Musconetcong Valley the formation is best exposed in the quarries near Changewater, Penwell, and Hackettstown, and along the railroad from Changewater to Washington. From Beatyestown northward outcrops are wanting on the east side of the river, but the topography indicates the presence of the formation beneath the wash from the higher slopes. North of Hackettstown the formation is believed to underlie the valley as far north as Waterloo, but all traces of it are concealed by the terminal moraine and the associated gravel deposits. In the Pohatcong Valley from Washington to Karrsville the limestone is generally so deeply buried by the Jerseyan glacial drift that bedrock is indicated only by traces.

The Pequest Valley from Oxford Furnace to Vienna is also deeply drift filled, rock exposures being limited to the Hardyston quartzite, as already noted, and to a few small outcrops of oolitic limestone between Pequest and Townsbury. The mapping of the limestone in the narrow valley northeast of Petersburg is conjectural and is based solely on the topography. North of Danville the formation outcrops on several of the islands that rise above the alluvium of the Great Meadows, but outcrops are not abundant south of Tranquility. West and southwest of Greensville three isolated limestone masses are overthrust upon Martinsburg shale, by which they are surrounded. A small mass of Byram gneiss 2 miles northwest of Huntsville has similarly been thrust upon the limestone. Other limestone areas which are similarly related to the Martinsburg shale lie north of Hope and south of Kerr Corners.

The limestone area near Blairstown is part of a long belt that enters New Jersey from Pennsylvania near Columbia, follows Paulins Kill valley, and ends near Branchville. Although the glacial deposits are thick in places, particularly in the terraces along Paulins Kill, limestone outcrops are numerous and much of the area has been left in timber on that account.

ORDOVICIAN SYSTEM.

GENERAL FEATURES.

In New Jersey the base of the Ordovician lies somewhere below the top of the Kittatinny limestone, but in the absence of extensive collections of fossils its exact position has not been accurately determined.

The rocks of the Ordovician system in New Jersey are chiefly shale, slate, and sandstone, although the lower part contains some limestone. They therefore present a marked contrast to the underlying Cambrian sediments, which consist chiefly of limestone. They are a part of the great area of Ordovician sediments—principally shale—which extends from Canada to Alabama and which, together with the Cambrian rocks, forms the floor of the Appalachian Valley.

JACKSONBURG LIMESTONE.

Character.—The Jacksonburg limestone, where most fully developed, has three distinct phases—a basal conglomerate of limestone pebbles, a dark-blue or black fossiliferous limestone, and a highly calcareous shale. The conglomerate is made up of slightly worn fragments of the underlying magnesian limestone, from a fraction of an inch to 8 or 9 inches in diameter, embedded in a relatively nonmagnesian matrix, and ranges in thickness from a few inches to 50 feet or more. Above this are two series, each 30 to 40 feet thick, of dark-blue highly fossiliferous limestone, some layers of which contain as much as 95 per cent of calcium carbonate. These two series of limestone are generally separated by about 30 feet of more shaly beds. Calcareous shale occurs also at the top of the formation. This sequence, though common, is not universal. At Jacksonburg, the type locality, in the northwestern part of the Raritan quadrangle, 20 feet of shale and thin-bedded shaly limestone forms the base of the section and is overlain by 102 feet of limestone, the top of the formation not being seen.

Fossils.—The limestone contains an abundant fauna, 98 forms having been described by Weller from outcrops within and adjoining the quadrangle. The most characteristic species are the following:

Solenopora compacta Bill.	Parastrophia hemiplicata (Hall).
Receptaculites occidentalis Salt.	Protowarthia cancellata (Hall).
Streptelasma corniculum Hall.	Bucania punctifrons (Emm.).
Prasopora simulatrix Ulrich.	Hormotoma salteri Ulrich.
Rafinesquina alternata (Emm.).	Leperditia fabulites.
Plectambonites sericeus (Sow.).	Isotelus gigas De Kay.
Strophomena incurvata (Shep.).	Bumastus trentonensis (Emm.).
Orthis tricenaria Con.	Calymene senaria Con.
Dalmanella testudinaria (Dal.).	Pterygometopus callicephalus (Hall).
Dalmanella subæquata (Con.).	
Zygospira recurvirostris (Hall).	

At Jacksonburg, where a trench was opened across the beds, the lower strata, for a thickness of 58 feet, contain a Lowville and a higher Black River fauna, and the higher beds contain a lower Trenton fauna. The other principal fossil localities are outside the Raritan quadrangle.

Distribution.—The Jacksonburg limestone in general outcrops as a narrow band between the Kittatinny limestone and the Martinsburg shale. In the shale belt south and east of Blairstown it has been faulted out at most localities. East of the Highlands its absence in most places is accounted for by faulting but may in part be due to overlap.

Thickness.—In the Raritan quadrangle the formation is 135 to 150 feet thick, but it becomes thicker southwestward, reaching a thickness of 300 feet or more. As it passes into the overlying shale and slate by a gradual decrease in its content of lime and an increase in silica its upper limit is not definitely fixed. Owing to weathering the transitional beds outcrop in few places.

Name and correlation.—The formation is named from Jacksonburg, northwest of Blairstown, where it is well exposed and where it has been most carefully studied. It is the stratigraphic equivalent of the upper part of the Shenandoah limestone where that formation is typically developed and is correlated with the Lowville, Black River, and the lower part of the Trenton limestone of the New York section. It has frequently been called "Trenton" limestone.

Relations.—The Jacksonburg limestone rests unconformably upon the eroded surface of the Kittatinny limestone. Its calcareous basal conglomerate in places attains considerable thickness and contains pebbles of limestone several inches in diameter. The contact is well shown at the Sarepta quarry, a few miles northeast of Belvidere, just west of the quadrangle, where the conglomerate rests on the beveled edges of Kittatinny strata. The formation grades upward into the Martinsburg shale, the beds becoming progressively less calcareous and more siliceous.

Local details.—Southeast of the Highlands the Jacksonburg limestone has been noted at only two points within the quadrangle—$1\frac{1}{3}$ miles south of Annandale, and $1\frac{2}{3}$ miles east of Van Syckles—and at a third point outside the quadrangle.

In the Musconetcong Valley a narrow belt of the formation is believed to occur everywhere between the Kittatinny limestone and the Martinsburg shale, but it is exposed only in the quarries at Penwell, 4 miles northeast of Washington, where a dark semicrystalline fossiliferous limestone with a few feet of basal conglomerate lies on the Kittatinny limestone. A few rods to the west, in a deep ravine, the higher calcareous shale appears, and beyond it lies the typical siliceous Martinsburg shale. The full thickness of the Jacksonburg here is probably at least 150 feet.

The Jacksonburg limestone can be traced by frequent exposures almost continuously from Swayze Mills nearly to Johnsonburg. Much of the Hope-Johnsonburg road lies on the formation, which has a width of outcrop of 100 to 500 yards. The conglomerate beds are best seen $1\frac{1}{2}$ miles northeast of Hope, where, probably owing to faulting, they seem to lie in the middle of the formation, and at the north end of Jenny Jump Mountain, along the road to Danville, where excellent exposures of the conglomerate lie less than 100 feet from pre-Cambrian rocks and dip 25° toward them. The pebbles are well rounded and average 2 to 4 inches in diameter, with a few at least 12 inches. All are of Kittatinny limestone, although ledges of the pre-Cambrian gneisses and limestone outcrop so near at hand. The absence of pebbles of the pre-Cambrian rocks from the conglomerate favors the hypothesis that the relation of the conglomerate to the gneiss is due to faulting and not to overlap. A mile southwest of the Danville road the Jacksonburg limestone disappears under the overthrust mass of Jenny Jump Mountain, and the underlying Kittatinny limestone adjoins the gneiss for several miles. South of Hope the conglomerate and higher beds of the Jacksonburg are again exposed in a prominent hill at the foot of the mountain and adjacent to the gneiss.

In the valley of Paulins Kill at Jacksonburg a continuous section from the base of the formation through a thickness of 122 feet was obtained by digging, but the upper 20 or 30 feet were not exposed. The basal conglomerate is absent, its place being taken by fine-grained shaly beds, the constituent material of which had apparently been derived from the underlying Kittatinny limestone.

Section of Jacksonburg limestone at Jacksonburg.

	Ft.	in.
Limestone, dark, fossiliferous, in beds 6 to 18 inches thick	42	8
Limestone, dark, thin bedded, highly fossiliferous	21	
Limestone, hard, bluish black	19	6
Limestone, soft, bluish gray	19	6
Limestone, shaly	19	4

As shown by Weller[a] the beds of the lower three divisions, comprising strata with a thickness of 58 feet 4 inches, contain a fauna quite distinct from those of the succeeding beds, the most characteristic species being *Dalmanella subæquata* and *Leperditia fabulites*. These beds are correlated with the Lowville and higher Black River limestones of the New York section. The upper two divisions, correlated with the lower Trenton of the New York section, are characterized by *Plectambonites sericeus*, *Dalmanella testudinaria*, *Zygospira recurvirostris*, and *Pterygometopus callicephalus*. In the dark thin-bedded limestone of the middle division *Plectambonites sericeus* is especially abundant and *Dalmanella testudinaria* is rare, but in the higher beds the conditions are reversed, *Plectambonites sericeus* being rare and *Dalmanella testudinaria* abundant. In the higher beds also the pelecypod, gastropod, and trilobite species are more conspicuous.

MARTINSBURG SHALE.

Character.—The Martinsburg shale ranges from the finest-grained shale and slate to fine sandstone. Most of the beds of shale and slate are black, though some of them are red, and they are more abundant in the lower part of the formation; whereas the sandstone beds, many of which are calcareous, are dark bluish gray and occur more commonly higher in the formation. The fine-grained rocks constitute a larger part of the formation than do the gritty beds. The two types, however, are not restricted to the lower and upper portions respectively but occur interbedded and with numerous and abrupt changes from one to the other. The coarser beds form layers from a few inches to 1, 2, or even 3 feet thick. Owing to their greater resistance, the thicker beds form outcropping ledges, but the finer beds are more commonly broken down by the frost and covered with their own débris. In places the coarser beds have been quarried for flagstones.

Slaty cleavage is everywhere strongly developed in the finer-grained beds, in which it is the predominant structure, so that the true bedding planes are in many places difficult to determine. Generally but not exclusively the cleavage dips eastward at high angles to the dip of the strata. In disintegrating, the finer-grained rock breaks chiefly along the cleavage planes

[a] New Jersey Geol. Survey, Paleontology, vol. 3, p. 37, 1907.

and also along joint planes, and much more rarely along bedding planes. At some horizons in the lower part of the formation the cleavage planes are so straight and parallel and the rock is so even textured that commercial slate has been obtained from it in considerable quantities. For the most part, however, the cleavage planes are slightly curved or not quite parallel, so that the rock splits irregularly. As slaty cleavage is the characteristic structural feature of the finer-grained beds and as these beds predominate in amount over the sandstones or gritty layers, the formation might very properly be called a slate.

Distribution.—The formation occupies the surface of a large part of the Kittatinny Valley, forming the higher belt along the northwestern side of the valley as well as the subordinate ridges that separate the main drainage lines within the valley. It outcrops also in the Musconetcong Valley within the Highlands belt and at a number of points southeast of the Highlands. The small area in the extreme northwest corner of the quadrangle is a part of a wide belt that crosses the State from Pennsylvania to New York. The larger shale area south of Blairstown is part of another belt that extends northeastward from the Delaware north of Belvidere. They unite near Branchville, 5 miles north of the quadrangle. The shale hills near Greensville are the central portions of a faulted syncline that extends northeastward nearly to Franklin Furnace. In the Musconetcong Valley a synclinal belt of shale extends southwest from Hackettstown nearly to Washington, for two-thirds of which distance it is bordered on the northwest by pre-Cambrian rocks against which it has been faulted. Southeast of the Highlands the shale occupies areas west of Clinton, south of Annandale, and north of Gladstone. Much of the rock in these areas is bright red, a color presenting a striking contrast to the unbroken somber hues of the larger belts that lie northwest of the Highlands and suggesting a difference in the conditions of sedimentation and possibly indicating a difference in age.

Thickness.—The whole formation is so crumpled and cleaved that no accurate estimate of its thickness can be made, but it is probably at least 3000 feet thick and may be more.

Name and correlation.—The formation has generally been known as the "Hudson River slate," but as this name has lost much of its significance as a definite geologic term, and as the formation is the same as the Martinsburg shale of West Virginia, the latter name is used here.

Fossils. — Four species of graptolites — *Diplograptus* cf. *amplexicaulis*, *Diplograptus* sp., *Lasiograptus* cf. *eucharis*, and *Corynoides calycularis* — have been collected from a small quarry three-fourths of a mile east of Branchville in the Franklin Furnace quadrangle. These graptolites are characteristic fossils of the basal part of the Martinsburg shale in southern Pennsylvania, Maryland, and Virginia, and, according to Ulrich, are of Trenton age. In the southern localities they are found associated with many other fossils including a variety of *Dalmanella testudinaria*, which is also found with the graptolites at Branchville.

Five other species of graptolites—*Climacograptus parvus*, *C. modestus?*, *Dicranograptus parvangulus*, *Nemagraptus gracilis*, *Reteograptus geinitzianus*—which are characteristic of the Normanskill fauna, have been collected by Weller from the shale in the cut 340 yards east of Jutland on the Lehigh Valley Railroad. This fauna is considered by Ruedemann to be of Chazy age. It appears, therefore, that beds which are older have been provisionally mapped with the Martinsburg shale near Jutland. In New Jersey no fossils have been found by which the age of the upper part of the formation can be definitely fixed, but at Otisville, N. Y., a few miles north of the New Jersey State line, *Schizocrania filosa* and graptolites characteristic of the Utica shale of the Mohawk Valley have been found in beds close to the overlying Shawangunk conglomerate.

Relations.—Where the succession is normal the Martinsburg shale overlies conformably the Jacksonburg limestone, the pure limestone of the middle Jacksonburg grading rather abruptly through more and more earthy limestone and calcareous shale into the siliceous shale of the Martinsburg. However, owing to faulting and in some places perhaps to overlap, the normal succession is in places interrupted and the Martinsburg rests upon Kittatinny limestone.

In adjoining regions north and northwest the Martinsburg is overlain by the massive Shawangunk conglomerate. The latter is regarded as Silurian in age, so that there was a long interval between its deposition and that of the preceding Martinsburg shale, although in New Jersey they show no marked discordance in attitude. Silurian strata also occur in the Raritan quadrangle, but so far as can be determined the lowest of these rests unconformably upon Kittatinny limestone or the pre-Cambrian gneiss and not upon Martinsburg shale. Near Clinton the Martinsburg is overlapped by the shales of the Newark group, and in places, owing to an overthrust fault, it is overlain by masses of Kittatinny limestone and even by pre-Cambrian gneiss. The limestone areas north of Hope, south of Kerr Corners, and southwest of Greensville are believed to be remnants of such overthrust strata. Two small areas of gneiss, which likewise rest upon the shale, one a mile northeast of Hope and the other one-half mile northeast of Silver Lake, are similar remnants.

Local details.—In the areas southeast of the Highlands the formation is best seen in artificial exposures such as the railroad cuts east of Jutland, for weathering and erosion have almost everywhere produced smooth slopes deeply covered with residual material. In the Musconetcong Valley much the same condition prevails, but the rock is well exposed in deep railroad cuts near Port Murray, in several small abandoned slate quarries between Port Murray and Stephensburg, and in places along the steeper hillsides. The railroad cuts show that weathering has penetrated to considerable depths and has changed the shale from black to yellow. In the Kittatinny Valley, which lies wholly within the region covered by the ice of the Wisconsin stage, outcrops of hard sandstone layers are common, but the finer-grained shale and slate, where not covered with glacial drift, are mantled with a thin coating of their own débris. The formation is best exposed in this valley in the deep cuts along the new line of the Delaware, Lackawanna & Western Railroad south of Vail, Blairstown, and Kerr Corners, and north of Johnsonburg. An area of Martinsburg shale south of Johnsonburg, east of Glover Pond, is incorrectly colored on the map as Byram gneiss.

SILURIAN SYSTEM.

GENERAL FEATURES.

The rocks here referred to the Silurian form apparently only the middle or upper part of that system as elsewhere developed. The absence of the lower or Medina part from New Jersey and adjoining regions is indicative of somewhat widespread earth movements which closed the period of deposition indicated by the Martinsburg sediments and raised the region above the zone of sedimentation. When deposition began again later in Silurian time beds of coarse conglomerate were laid down, followed by sandstones, shales, and limestones. These conditions of deposition prevailed into Devonian time with but slight changes of altitude.

In the Raritan quadrangle the Silurian and Devonian rocks are restricted to the northeastern portion, where they form the southern ends of Green Pond and Copperas mountains and detached hills from Flanders northeastward.

GREEN POND CONGLOMERATE.

Character and distribution.—A coarse siliceous conglomerate, occurring in Green Pond and Copperas mountains, interbedded with and grading upward into quartzite and sandstone, is known as the Green Pond conglomerate. Its pebbles range in diameter from one-half inch to 3 inches; almost all of them are of white quartz, but a few are of pink quartz, black, white, yellow, and red chert, red and purple quartzite, and a very few of red shale and pink jasper. The surfaces of many of the white quartz pebbles have a pink tinge. The quartz pebbles were probably derived from the pre-Cambrian crystalline rocks; some at least of the cherts came from the Kittatinny limestone; and some of the quartzites may have come from the Hardyston; but the sources of the pebbles of red and purple quartzite, red shale, pink jasper, and white. yellow, and red chert are unknown.

The matrix is composed of vitreous, generally dull-red quartz sandstone, but white, gray, and greenish strata are abundant, particularly in the basal portion, so that the formation is not so exclusively red as some descriptions imply.

The beds are almost uniformly quartzitic and on account of their hardness form the long, narrow, steep-sided ridges that characterize the Green Pond Mountain region. Here and there, however, the basal portion of the conglomerate is friable and disintegrates readily, owing probably to its containing more or less calcareous material derived from the Kittatinny limestone upon which it locally rests. The quartzite, which in part is interbedded in the upper portion of the conglomerate and in part overlies it, is in general purple-red, though some layers are of various shades of pink, yellow, brown, and gray. Some of the beds are massive and show no laminæ, but others plainly disclose thin stratification planes. The conglomerate beds are in many places very thick and show slight traces of bedding.

In the isolated hills southwest of Rockaway River the rock is much softer, being friable sandstone rather than quartzite; some of the beds are so completely disintegrated that they have been dug for sand and gravel for many years.

In the Raritan quadrangle the Green Pond conglomerate forms the main mass of Copperas and Green Pond mountains, the latter of which terminates southward at Rockaway River. The formation appears again in a series of long narrow ridges southwest of Rockaway River near Rustic, Kenvil, Succasunna, and Carey. Whether it extends southwest of Flanders is unknown, owing to lack of all rock exposures for several miles.

Thickness.—West of Green Pond the conglomerate beds dip 45°-78° NW., indicating a probable thickness of 1500 feet. The average of measurements elsewhere is about 1200 feet.

Relations.—Along Green Pond Brook and west of Green Pond the formation rests unconformably on pre-Cambrian rocks, although the actual contact has nowhere been observed. The same relation holds along the east side of Copperas Mountain, where, opposite Denmark Pond, conglomerate ledges are seen overlying although not in contact with gneiss that forms the lower mountain slopes. In adjoining regions it apparently rests upon eroded Kittatinny limestone and less certainly upon Martinsburg shale. Southwest of Rockaway River isolated hills of Green Pond conglomerate rise above glacial sand and gravel plains. The structural and stratigraphic relations of the conglomerate to the buried strata are unknown, but these lowlands are supposed to be underlain by Kittatinny limestone, on which the conglomerate probably rests. So far as known it is overlain conformably by the red Longwood shale, but nowhere in New Jersey have the two been seen in actual contact.

Name and correlation.—As organic remains are unknown in the conglomerate, inferences as to its age are based on its stratigraphic position and lithologic character. On these grounds it is correlated with the Shawangunk conglomerate of Kittatinny Mountain, New Jersey, and Shawangunk Mountain, New York. The Salina age of the latter seems well established by the occurrence in it near Otisville, N. Y., of a eurypterid fauna that ranges through a thickness of 650 feet. However, recent studies by Van Ingen tend to show that the lower part of the Shawangunk may be of Clinton age.

Owing to the fine exposures in the cliffs overlooking Green Pond, the formation has long been known as the Green Pond conglomerate. The earlier writers, however, included under this term another somewhat similar conglomerate, now known to be of Devonian age.

Local details.—In the German Valley near Carey, numerous sand pits have been opened in a white and pink disintegrated conglomeratic sandstone, which is notably cross-bedded, fissile, and nonarkosic. The beds are referred without question to the Green Pond conglomerate. Northeastward for a distance of 4 miles long narrow detached ridges of quartzite and conglomerate rise like islands above the plain of glacial drift that forms the valley floor near Kenvil and Succasunna. Outcrops of the fresh rock are not abundant, but its character can be inferred from the surface fragments. The best exposure is in the "white rock cut" on the Delaware, Lackawanna & Western Railroad, where 185 feet of white and flesh-colored sandstones, some thinly laminated, some massive, dips steeply southeast. West of Kenvil and one-half mile southwest of Mount Arlington station ledges of gray quartz conglomerate dip steeply toward the gneiss, which outcrops 200 yards to the west. Fragments of white and pink sandstone occur higher on the hill and nearer the gneiss. The beds unquestionably belong to the Green Pond conglomerate, but their structural relation to the Kenvil-Succasunna ridges, from which they are separated by a low swampy plain without rock exposures, is unknown.

Northeast of Rockaway River the conglomerate forms the main mass of Green Pond Mountain. Ledges of purple and white quartzite with overturned dips to the southeast are exposed along the road south of Berkshire Valley, and similar beds with steep normal dips to the northwest outcrop along the road crossing Green Pond Mountain east of Berkshire Valley. The best exposures, however, are in the high cliffs above the southern end of Middle Forge Pond, along the wild and narrow gorge of Green Pond Brook, and in the cliffs overlooking Green Pond.

LONGWOOD SHALE.

Immediately overlying the Green Pond conglomerate, and so far as known conformable with it, is a soft red shale, in which an irregular cleavage is generally so highly developed that the bedding planes can be determined only with difficulty. The rock, however, does not have a slaty structure. The formation, which is named from the Longwood Valley, forms a narrow belt at the northwest foot of Green Pond Mountain, exposures occurring at intervals from Lower Longwood northward. South of that place thick drift deposits conceal the rock of the valley bottom. Accurate determination of the thickness, which may be about 200 feet, is not possible. The formation is not known to contain fossils, but as it rests directly upon the Green Pond conglomerate and is overlain by limestone carrying a Salina fauna it is regarded as being of Salina age. Its stratigraphic position is in general the same as that of the red shale on the northwest slope of Kittatinny Mountain—the High Falls formation — but the two may not be exactly synchronous.

DECKER LIMESTONE.

Character and distribution.—A dark-gray impure siliceous and shaly limestone overlies the Longwood shale but is nowhere seen in contact with it. It is not more than 50 feet thick, but no single exposure shows its entire thickness.

At Upper Longwood there are good exposures in an old quarry 300 yards southeast of the forge ruins. The limestone beds dip 80° W. and overlie the Longwood shale, which outcrops a few rods to the east. Just below the dam at Woodstock forge ledges of green shale and siliceous limestone with steep eastward (overturned) dips are found adjacent to the Longwood shale. Between this point and Upper Longwood there are other exposures of the same calcareous beds.

Relations.—Of the formations referred to the Silurian system the Decker limestone is the highest recognized in the Raritan quadrangle. Still higher Silurian beds (the Rondout and Manlius limestones) may be represented in the covered interval which everywhere separates the Decker limestone outcrops from the adjoining Devonian formation, as they are present under similar conditions at Cornwall, N. Y.

Name and correlation.—At the Upper Longwood quarry Weller collected *Monotrypa corrugata* Weller, *Stropheodonta bipartita* (Hall), *Chonetes jerseyensis* Weller, *Orthis flabellites* Foerste, *Rhynchonella deckerensis* Weller, *Rhynchonella agglomerata* Weller, and *Atrypa reticularis* (Linné.). On the basis of these fossils the beds are correlated with the lower portion of the Decker ("Decker Ferry") limestone on Delaware River and with the Wilbur limestone member of the upper part of the Salina formation of eastern New York. The exact relations of the Decker limestone to the upper formations of the Cayuga group of central New York or to the basal part of the Helderberg group of the Lower Devonian have not been fully determined.

DEVONIAN SYSTEM.

GENERAL FEATURES.

The Devonian strata in the isolated belt of Paleozoic rocks near Green Pond Mountain are chiefly sandstone and shale of great thickness, grading upward into a thick-bedded massive conglomerate which is very similar in lithologic character to the Green Pond conglomerate. Only the lower formations outcrop in the Raritan quadrangle. These Devonian sediments present a marked lithologic contrast to the highly fossiliferous Devonian limestone and calcareous shale along Delaware River northwest of Kittatinny Mountain. So different are they that it is a question whether the Devonian sediments of the Green Pond region are the shoreward representatives of the calcareous formations found along the Delaware or whether they were deposited in a somewhat isolated basin.

KANOUSE SANDSTONE.

The Kanouse sandstone, the lowest known Devonian formation in this area, has an estimated thickness of 215 feet. It is a thick-bedded fine-grained conglomerate below and a greenish sandstone above; the basal portion is composed of white quartz pebbles from one-fourth to one-half inch in diameter, most of them set somewhat loosely in a siliceous matrix, so that the rock is of open texture and friable. In places, however, the interstices are filled with siliceous cement and the rock is decidedly quartzitic. The coarser beds grade upward into hard, greenish, thin-bedded sandstone, which in turn passes into black argillaceous shale (Cornwall shale) carrying a Hamilton fauna. The sandstone occupies a narrow belt parallel to the outcrops of the Longwood shale but is separated from it by the Decker limestone. It is the Newfoundland grit of the New Jersey Geological Survey reports.

Outcrops are wanting in this area, but good exposures occur northeast and east of Petersburg just north of the quadrangle, at Newfoundland, and in the valley west of Kanouse Mountain still farther northeast, from which the formation is named. Although fossils are not rare, as a rule they are obscure and many of them are so greatly distorted that identification is difficult. At the two localities outside the quadrangle where recognizable forms have been found in the formation, an Onondaga fauna has been recognized, but it may be questioned whether the whole thickness of the beds is referable to the Onondaga, particularly in view of the fact that at Highland Mills and Cornwall, N. Y., there are exposures of many of the formations which normally occur between the Decker limestone and the Onondaga limestone. It may be, therefore, that the beds here included in the Kanouse sandstone, together with those in the adjoining concealed area, include representatives of a number of Devonian formations below the Onondaga horizon; exposures are not numerous enough to determine this positively.

CORNWALL ("PEQUANAC") SHALE.

The rocks forming the Cornwall shale are black to dark-gray, somewhat slaty, thick-bedded shales which are more sandy in their upper portion. They are nearly everywhere strongly cleaved, so that in many places where the rock is of uniform texture the bedding planes are not readily discernible. They overlie the Kanouse sandstone with apparent conformity, but their contact with it has nowhere been observed. They are the youngest Paleozoic rocks in the quadrangle.

They are well exposed at Upper Longwood and northward beyond the limits of the quadrangle. South of Upper Longwood they probably underlie the greater part of the Longwood Valley and, with the underlying Kanouse, Decker, and Longwood formations, may extend across Rockaway River, as for 15 miles or more in that direction the only rock exposures are the isolated hills of Green Pond conglomerate that rise above the valley filling. The thickness of the formation is unknown but is estimated to be as much as 1000 feet in some places. Fossils found elsewhere fix its age as Hamilton.

Darton proposed the name Monroe for this shale, and it has been so designated in some reports of the New Jersey Geological Survey, but owing to the prior use of the term for a formation in Michigan of a different age, Pequanac was substituted in the Passaic folio. The term Cornwall used by Hartnagel[a] has priority, however, and is a better name owing to the extensive development of the shale in Cornwall, N. Y.

[a] New York State Museum Bull. 107, p. 41, 1907.

TRIASSIC ROCKS.

NEWARK GROUP.

NEWARK GROUP IN GENERAL.

Extent.—The Triassic rocks of the Raritan quadrangle are a part of the Newark group, which extends from the Hudson southwestward through New Jersey, Pennsylvania, and Maryland into Virginia and which appears in detached areas in Nova Scotia, Massachusetts and Connecticut, Virginia, and North Carolina. The belt in which they occur is therefore over 1000 miles long, but the Triassic areas are now widely separated and may never have been directly connected.

In New Jersey the Newark group occupies a broad belt that crosses the north-central part of the State from the Delaware to the Hudson, narrowing from a width of 32 miles on the Delaware to 16 miles on the New York State line. It is bordered on the northwest by the Highlands, on the northeast by the Hudson and the serpentine of Staten Island, and on the southeast by low plains made of Cretaceous and Tertiary strata.

Character.—The Newark rocks in general are remarkably uniform in character. They comprise great thicknesses of alternating sandstone and shale, chiefly reddish brown, which in places along the margin of the group pass into coarse conglomerate. In some places the conglomerate is composed chiefly of limestone pebbles; in others it is mainly of quartzite pebbles. Gneiss and granite pebbles are on the whole conspicuously absent, although broad areas of those rocks now form the adjoining highlands. Intercalated sheets of extrusive igneous rocks are known in New Jersey as the Watchung basalt. Dikes and intrusive sheets of diabase and basalt associated with the Newark group are later in age than the strata with which they are in immediate contact but were intruded previous to the faulting and tilting which closed the deposition of the group. The diabase and basalt, both extrusive and intrusive, are commonly known as "trap" or "trap rock."

Structure.—The structure of the Newark group is monoclinal throughout wide areas, with faults having the downthrow on the up-dip side. From New Jersey southward the beds in greater part dip 10°–15° W., whereas in New England and Nova Scotia and at some of the easternmost outcrops in Virginia and North Carolina the dip is in the opposite direction.

The thickness of the group is great but as yet has been determined only approximately and only in parts of the area. The great width of the belt in which the dip is in the same direction would indicate a thick succession of strata, but the apparent thickness is certainly too great, as many longitudinal faults repeat the outcrops of the series.

In New Jersey the dip is mainly westward or northwestward, but in the Watchung Mountain region the strata form a low syncline having various minor flexures. The abrupt margin on the northwest is defined chiefly by faults, along which the generally westward dipping strata abut against the old crystalline rocks, which nearly everywhere rise in high slopes. The northeastern boundary may also be defined by a fault along the Hudson, but of this there is less definite indication. From the southern part of Staten Island southwestward to Trenton, however, the Triassic rocks are unconformably overlapped by the Raritan formation of Cretaceous age, which for some miles lies across the lower beds of the Newark group.

Fossils and correlation.—Few fossils have been found in the Newark group in the Raritan quadrangle, but a sparse fauna and flora have been collected in adjacent parts of the State.[a] Perhaps nine or ten species of plants have been identified, including a fucoid, a fern, two equiseta, a cycad, and several conifers. The cycads are the most abundant and are represented chiefly by leaves.

No mollusks or insects have been found in the Newark group in New Jersey, although one or two have been reported from localities in other States. Abundant remains of bivalve crustaceans are preserved in fine dark shale at several places. The most characteristic fossils of the group in the State are the remains of fishes. Excavations for the storage reservoir of the Jersey City water system, at Boonton, in the Passaic quadrangle, revealed great numbers of fish remains in the fine dark shale of the Brunswick formation. They were studied by Dr. C. R. Eastman, who identified the following species:[b]

Semionotus ovatus Redfield.	Semionotus elegans Newberry.
Semionotus robustus Newberry.	Semionotus brauni Newberry.
Semionotus agassizii Redfield.	Catopterus gracilis Redfield.
Semionotus gigas Newberry.	Catopterus redfieldi Egerton.
Semionotus fultus Agassiz.	Diplurus longicaudatus Newberry.
Semionotus tenuiceps Agassiz.	

At several localities in the State tracks of reptiles, and perhaps of batrachians as well, similar to those at the well-known localities in the Connecticut Valley, are preserved on the surfaces of beds, and remains of a small dinosaur were found a few years ago in the sandstone at the base of the Palisades. No traces of birds or mammals have been discovered in the Newark rocks in New Jersey.

[a] For summary of the fauna and flora of the Newark group see Russell, I. C., Correlation papers—the Newark system: U. S. Geol. Survey Bull. 85, pp. 123–132, 1892.

[b] New Jersey Geol. Survey Ann. Rept. for 1904, p. 72, 1905.

The fossils of the Newark group are insufficient to establish with certainty its equivalence with any part of the Triassic system in Europe, but both its fauna and its flora seem to be most nearly equivalent to those of the upper part of the Tirolic series, or Keuper, and the Bajuvaric series, or Rhætic beds. The Newark group is therefore probably uppermost Triassic. Indeed, in view of the fact that many stratigraphers regard the Rhætic as the base of the Jurassic system, it is not impossible that the upper part of the Newark group may be of Jurassic age. In the absence of definite evidence to confirm this supposition, however, the whole group is customarily assigned to the Triassic.

Subdivisions in New Jersey.—The sedimentary rocks of the Newark group in the New Jersey region comprise three formations, the Stockton, Lockatong, and Brunswick, the last named being the latest. These subdivisions are distinct along the Delaware and farther northeast, beyond the Raritan, but are less easily traceable across the northeastern part of the State, where the surface is in large part covered by glacial drift and the upper two formations lose their distinctive characters. Along their northwestern border all three formations contain beds of coarse conglomerate, which is so striking in character that it has been discriminated on the map by a separate symbol and pattern.

The igneous rocks of the extrusive flows are comprised under the name Watchung basalt.

NEWARK GROUP IN THE RARITAN QUADRANGLE.

CHARACTER AND RELATIONS.

In the Raritan quadrangle rocks of the Newark group occupy most of the area south of a somewhat irregular line extending from Bernardsville to Clinton. The sedimentary rocks are comparatively soft sandstone and shale which are worn to a low level, forming an undulating lowland. The igneous rocks, both those belonging to the group and those associated with it, occur mainly in thick sheets, and owing to their hardness they form high ridges, of which Cushetunk, Round, First Watchung, and Second Watchung mountains, and Long Hill are the most conspicuous. These rise several hundred feet above the plains or rolling lowlands of the softer sedimentary beds, and generally have even crest lines and steep slopes in directions opposite to the dip.

In the vicinity of Jutland, Clinton, Pottersville, and Gladstone the Newark strata rest on Paleozoic limestone and shale, and the same relations may prevail in areas farther northeast, but the data in these areas are less decisive. A short distance southeast of the boundary the deepest borings have nowhere passed through the Newark beds, and the underlying formations may be either Paleozoic strata or pre-Cambrian crystalline rocks.

SEDIMENTARY ROCKS.

STOCKTON FORMATION.

Character.—The Stockton formation consists of coarse, more or less disintegrated arkosic conglomerate, yellow micaceous feldspathic sandstone, brown-red sandstone or freestone, and soft red argillaceous shale. These are interbedded in no regular order and are many times repeated, a fact that indicates rapidly changing and recurrent conditions of sedimentation. Although the formation includes many layers of red shale its characteristic rocks are the arkosic conglomerate and sandstone, the latter affording valuable building stone.

Much of the sandstone shows not only cross-bedding but ripple marks, mud cracks, and impressions of raindrops. The rapid alternation from conglomerate to shale and vice versa, the changes in composition in individual beds, and the cross-bedding and ripple marks indicate clearly that the beds were deposited in shallow water. The bulk of the material of which they are composed was derived from older rocks on the south and southeast.

Arkosic conglomerate and yellow sandstone prevail near the bottom of the Stockton formation and brown-red sandstone near the top, but the lower beds are not all coarse grained, for at some localities red shale and fine sandstone are interbedded with the conglomerate. Layers of soft argillaceous red shale also separate the brownstone beds near the top of the formation. Here and there thin layers of green, purple, and black shale occur at different horizons, but they are inconspicuous. The conglomerate consists chiefly of quartz pebbles, the largest 4 inches in diameter, and fragments of feldspar crystals, some of which measure an inch or more across. The cleavage faces of the feldspar generally show little weathering. The rock contains some mica and a few pebbles of sandstone and slate. The yellow and gray sandstones are composed of essentially the same materials as the conglomerate but are finer and contain some mica in addition to the quartz and feldspar that form the chief constituents. The sandstone shows minute rust-colored specks, probably due to the disintegration of the mineral pyrite, and it contains scattered pebbles of various kinds, most of them quartz but some of red shale, rather irregular in shape, which seem more like masses of clay deposited with the sand and afterward hardened than waterworn pebbles of shale. Cross-bedding is common in the sandstone. The shale is composed of fine red mud containing more or less minute flakes of mica. In some places it forms thick beds, which appear firm and massive when freshly exposed in a quarry but which split readily on exposure to the weather.

Thickness.—The thickness of the Stockton formation is estimated to range from 2300 to 3100 feet, allowance being made for repetition of beds by faulting, but owing to the monotonous character of the beds and the possibility of undiscovered faults the precise thickness is very uncertain.

Local details.—The Stockton beds are brought to the surface by a great fault 1¼ miles north of Flemington, and extend northward to the limits of the formation near Clinton in a gradually widening area, which attains a maximum breadth of 3 miles in the latitude of Lansdowne. Within this area the beds change in texture and composition as they approach their northwestern boundary. Near Flemington they consist of coarse arkose sandstone, as a rule much disintegrated and interbedded with soft red shale. Northward the typical arkose beds decrease in number and thickness and are replaced by coarser beds, made up largely of thin bits of Martinsburg shale and small quartzite pebbles. Farther north conglomerate beds of white, gray, and reddish quartzite in a red mud matrix appear and are well developed in a considerable area south of Clinton, where they have disintegrated into a rather heavy dark-red soil full of innumerable fragments of light-colored quartzite pebbles.

LOCKATONG FORMATION.

General character.—Above the Stockton formation lies the Lockatong formation, which consists of a succession of dark-gray to black shale that splits readily along the bedding planes into thin layers but has no slaty cleavage; hard, massive, black and bluish-purple argillite; dark-gray and green flagstone; dark-red shale resembling flagstone; and some thin layers of highly calcareous shale. Between these types occur almost countless gradations. Some of the argillites are specked with minute crystals of calcite, and many faces of joint planes and cavities are covered with deposits of the same mineral. Minute crystals of pyrite are abundant in some layers, constituting, with the calcite, the only secondary minerals. It was formerly supposed that the dark Lockatong beds owe their hardness and dark color to baking by the igneous rocks. The transition between the Stockton and the Lockatong formations is through a few hundred feet of intermediate beds which might be classed with either formation. Along the northwestern boundary of the Triassic area the Lockatong formation contains thick beds of coarse conglomerates that are indistinguishable from those in the Stockton and Brunswick formations.

Both ripple marks and mud cracks occur at all horizons in the Lockatong formation, showing that shallow-water conditions prevailed throughout the time of deposition. On the other hand, the absence of strong currents is indicated by the extreme fineness of the material.

Thickness.—The Lockatong formation may be as much as 3600 feet thick in the Sourland Mountain and Hunterdon plateau areas, if that region is not traversed by faults. Near Ewingville and Princeton it is apparently only 1800 feet thick if the beds of predominantly dark material are alone included.

Soil.—The Lockatong beds give rise to a rather heavy wet clay soil. The surface is thickly strewn with slabs of argillite and flagstone and is generally rocky on slopes. Except in places favorable to the accumulation of wash the depth of the soil and subsoil is generally less than 6 feet.

Local details.—Northwest of Flemington the Lockatong formation occurs on the Hunterdon Plateau in a curved belt 3 to 4 miles wide, only the northern portion of which is within the Raritan quadrangle. At the margin of the plateau, along the deeply incised courses of Lockatong and Wickecheoke creeks, massive black argillite and fine-grained green-black sandstone are finely exposed.

Near the southern margin of the quadrangle the Lockatong beds begin to lose their typical character, the departure from the normal increasing northward. The change is mainly one of increasing coarseness, accompanied by change in color, in manner of weathering, and in the soil formed by decomposition. The hard, black, dark-green and dark-red shales and argillites grade into drab, red-brown, green, and yellow shaly sandstones, some of which are slightly arkosic, resembling closely some members of the Stockton formation. This change occurs along the strike and increases in amount as the northwestern boundary of the formation is approached, being first noted in the upper beds and gradually extending to the lower. Along Cakepoulin Creek there are good exposures of thick red and gray sandstone which contains some pebble-bearing layers that resemble strongly those of the Stockton formation, though generally rather harder. For 2 miles southeast of Sidney the separation of the beds into the two formations, Lockatong and Stockton, is almost entirely arbitrary.

Northwest of Cakepoulin Creek pebble-bearing layers increase rapidly in thickness and number, and within 1½ miles the formation becomes chiefly massive beds of heavy quartzitic conglomerate, which continue for several miles, forming the elevated wooded belt known locally as the "Barrens."

BRUNSWICK SHALE.

Character.—The Brunswick formation consists of soft shale with local sandstone layers. The rocks are predominantly red but contain a few purple, green, yellow, and black layers. In general they present a monotonous succession of soft argillaceous red shale that crumbles readily to minute fragments or splits into thin flakes and weathers to a red, more or less sandy clay soil. Much of the shale is porous, many of the minute irregular cavities being partly filled with a calcareous powder. Calcite veins and crystals are common in some layers. The formation contains some lenticular masses of green shale, ranging in shape from thin layers to nearly spherical bodies, the largest a foot or two in diameter. Much of the shale contains mica, and where it is very micaceous the layers separate evenly along bedding planes. More commonly, however, the rock breaks up into small, more or less rectangular fragments. Although the formation consists in greater part of soft red shale, it contains, chiefly near the base, some hard layers of fine-grained sandstone and flagstones and locally some thick beds of conglomerate.

Abundant ripple marks, mud cracks, and raindrop impressions occur at many horizons. In some quarries imprints of leaves and of tree stems, or the stems themselves, are found. The numerous reptile tracks which have made the Newark group famous occur chiefly in this formation.

As compared with the adjoining formations the Brunswick shale is soft and easily eroded, so that the region it underlies is distinctly lower and more nearly level than those occupied by the other formations.

At places along the northwestern boundary pebbly sandstone and massive conglomerate beds occur in the Brunswick shale, as they do in the Stockton and Lockatong formations. The areas of conglomerate, particularly those of quartzite conglomerate, rise notably above the red-shale lowland and are covered with much thicker soil and subsoil. The shale disintegrates into particles so fine that they wash away, even on the gentle slopes that characterize the shale areas, almost as rapidly as they are formed, leaving the rock continually exposed to further erosion. Even in the broad, almost flat areas that prevail along the southern margin of the quadrangle, the soil on the Brunswick shale is thin. The disintegration of the conglomerate, however, yields an exceedingly stony clay, the largest pebbles having a diameter of 12 inches. These pebbles accumulate at the surface, forming a protective covering and preventing further denudation. The disintegration of the conglomerate beneath this covering goes on at a constantly decreasing rate, but as transportation is much retarded by the coarse material on the surface the quartzite conglomerate areas are higher and are covered by a much thicker mantle of rock débris than the areas of the softer and more easily eroded shale.

Thickness.—The thickness of the formation is uncertain, for it is impossible to determine to what extent the succession of exactly similar beds has been repeated by faulting. Only a small part of the formation lies in the quadrangle, and its entire thickness may be about 12,000 feet.

Distribution.—In the Raritan quadrangle the Brunswick shale underlies a small area on the Hunterdon Plateau and a broad undulating lowland east and northeast of Flemington. It also occupies the narrow valley between the two Watchung mountains and underlies the thick alluvial deposits of the upper Passaic Valley east of the town of Basking Ridge. In much of this region the soil is thin, and soft dark-red shales are typically exposed in numerous shallow road cuts and along watercourses.

Local details.—Sandstone belonging to the Brunswick shale is exposed in quarries at Pluckemin and Martinsville. The shale appears in the deep gorge of Passaic River at Millington and in hundreds of shallow cuts along highways and streams. Northeast of Basking Ridge exposures of thin black carbonaceous layers in red and green shales have led to some fruitless search for coal. Hills of quartzitic conglomerate lie along the borders of the formation near Pottersville and Peapack. Mount Paul, 4 miles north of Peapack, is capped by an outlier of similar conglomerate resting on Paleozoic red shale, much compressed and folded, which is correlated with the crumpled Martinsburg shale between Clinton and Jutland. The quartzitic conglomerate also outcrops on the hill 3 miles northeast of Logansville and 1 mile northwest of New Vernon. An area of calcareous conglomerate begins a mile north of Lebanon and extends within 1½ miles of Pottersville, a distance of 6 miles. Most of the limestone pebbles are of various shades of blue and gray, though some are red, and they are set in a red mud matrix, so that the rock has a variegated appearance. In the more massive conglomerate the rock consists of large pebbles surrounded by smaller fragments of the same material, in other layers it is composed of pebbles set in a red mud matrix, and toward the margin of the area it is a shale containing scattered limestone pebbles. Many of the pebbles in the conglomerate are 6 to 8 inches in diameter, and in some localities limestone bowlders 3 feet or more in diameter occur. The majority of the fragments less than 2 inches across are sharply angular or subangular, but those of larger size are generally worn and rounded. At a number of points this conglomerate is so pure a limestone that it has been quarried and burned for lime for local use. In general appearance it is identical with the well-known "Potomac marble" quarried at Point of Rocks, Md.

IGNEOUS ROCKS.

WATCHUNG BASALT.

Distribution.—In the western part of the Triassic area in northern New Jersey are two prominent ridges known as the Watchung or Orange Mountains, north of which (chiefly in the Passaic quadrangle) lies a line of lower disconnected ridges, made up of Packanack and Hook mountains and Riker and Long hills. The southwestern parts of the two Watchung mountains and the tip of Long Hill extend into the Raritan quadrangle north of Somerville and Bound Brook. The three ridges are the present edges of three thick and extensive sheets of basalt which were erupted successively during the deposition of the Triassic sediments, deeply buried under subsequent deposits, later uplifted and flexed, and finally exposed and truncated by erosion.

In the Passaic quadrangle the flows seem to be contemporaneous extrusive sheets. They lie conformably upon unaltered or very slightly altered strata and as a rule are vesicular; they appear to be successive flows, in part lying on tuff deposits; their upper portions are vesicular to a considerable depth; and they are overlain by unaltered strata, which in some localities rest upon an intervening breccia containing fragments of the igneous rock. Not all these features are equally well shown in the Raritan quadrangle.

The precise stratigraphic position in the Newark group of these basalt flows is not determined, but they are known to lie in its upper part.

First and Second Watchung mountains are long, parallel, and in places double-crested ridges, which trend south-southwest in the Passaic quadrangle but which swing around to the northwest north of Bound Brook, in the Raritan quadrangle. Near Far Hills, Second Watchung Mountain recurves to the northeast and ends near Bernardsville. Owing to the hardness of the basalt and the dip of the beds, the ridges present, on the outer margin of the crescent, high escarpments above slopes of the sandstone and shale upon which the lava sheets lie. The inner sides of the ridges are gentle slopes in which the basalt extends down to the overlying strata in the valley or plain below.

The outcropping edge of the third Watchung basalt sheet forms a line of single-crested ridges which rises a short distance west of the inner slope of Second Watchung Mountain. Only its southwestern end (Long Hill) extends into the Raritan quadrangle. This line of ridges is topographically similar to the Watchung Mountains, but is much less prominent and rugged. Through much of its course it has a steep eastern or southern slope, but its escarpments are few, low, and irregular, and the line of contact between the basalt and the underlying sandstone is generally not far below the crest. Its inner slopes are rocky but gentle. Owing to the comparative thinness of this sheet, slight differences in its thickness, extent, or structure cause breaks in the continuity of its outcrops or considerable deflections in its course, such as are not found in the larger Watchung masses. The outline of the sheet south of Basking Ridge illustrates this irregularity.

Succession of flows.—Each of the Watchung basalt sheets appears to be made up of successive flows, as indicated by vesicular surfaces overlain by compact basalt, by differences in color and other physical characters, and by corresponding differences in chemical composition.

The red shale lying between the two ridges of Second Watchung Mountain north of Bound Brook probably indicates that the mountain consists of two flows or series of flows separated by a thin local body of sediments. Other facts that strengthen this supposition have been observed in the adjoining Passaic quadrangle.[a]

Lewis has pointed out that the other sheets of Watchung basalt also probably consist of three flows each. In First Watchung Mountain the basal division or flow is a bluish-gray rock 50 feet or less thick, which is distinctly marked farther northeast but is indistinct or absent in the Raritan quadrangle. In places its upper surface is vesicular or ropy. The middle division, which is the most important, is a dark-gray to black rock, ordinarily showing well-developed columnar structure, with columns from 6 to 12 inches in diameter, in places arranged in clusters radiating downward. Its surface ranges from vesicular to ropy in many places. The third and uppermost division, which is exposed in quarries east of the quadrangle, is fine grained and grayish, and in the thicker portions its upper part is highly vesicular.

The third Watchung basalt sheet exhibits evidence of three successive flows at the Millington quarry, where an eroded upper gray layer 10 to 20 feet thick is separated from the nearly black rock beneath by an undulating surface well marked by rusty ferruginous alteration products. In the bottom of the quarry gray rock again appears, separated from the black by one of the numerous horizontal divisional planes that give a bedded or stratified appearance to the rock.

Thickness.—The thickness of the Watchung lava flows is known only approximately and different observers have made somewhat different estimates. At Millington the Long Hill sheet is about 300 feet thick. North of Bound Brook the double flow of the Second Watchung Mountain sheet is perhaps not less than 1200 feet thick, the upper of the two flows having a thickness probably not less than 800 feet. The First Watchung Mountain sheet is about 580 feet thick at Chimney Rock but is much thinner at its termination near Pluckemin.

[a] U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), and New Jersey Geol. Survey folio No. 1, p. 10, 1908.

Structure of flows.—Columnar structure is generally well developed in the first and second Watchung basalt sheets, dividing the rock into columns that are mostly hexagonal. The best examples of this feature are exhibited in the adjoining Passaic quadrangle at Orange, Paterson, and Little Falls, and at Green Brook on the slope of Second Watchung Mountain southwest of Little Falls.

The third Watchung basalt sheet is a fine-grained rock, similar in every respect to that of the other Watchung ridges. Its structure is columnar in only a few places, however, and ordinarily it breaks down into wedge-shaped masses of small size. Although the upper surface of the sheet is deeply eroded at the south, some vesicular rock remains.

Lewis[a] has pointed out that horizontal sheeting or platy jointing is distinctly developed in all the basalt sheets, most prominently near their upper and lower surfaces. The thinnest layers are as a rule near the bottom, where some of them are only 1 to 2 feet thick, but the layered structure extends only a short distance upward toward the central massive part of the sheets.

Both joints and faults are common. They strike prevailingly north-south, or within 15° of that direction, and stand approximately at right angles to the upper and lower surfaces of the sheets. Some joints strike N. 40° E.; others N. 70° E. Joints at right angles to the prevailing direction, though prominent in places, are much less numerous and in many places are lacking altogether. Irregular jointing is so well developed in some localities as to break the rock into small wedge-shaped pieces. Many of the north-south joints have developed into faults and contain from an inch to more than a foot of crushed and slickensided material.

Petrography.—Lewis[b] has recently described the basalt essentially as follows: The extrusive rocks are all fine textured, ranging from dense flinty looking or aphanitic and rare glassy phases to varieties with fine granular texture. In all grades of texture phenocrysts of augite and here and there of feldspar are not uncommon. All varieties are dark colored, ranging from dark greenish-gray to brown-black and almost black. Some of the more altered portions, especially in much-faulted and sheared areas, are bright green to greenish black from the development of large amounts of secondary chlorite. Weathered surfaces assume various tints of brown and yellow, as the iron of the dark silicates is converted into limonite, and soil resulting from the decay of the basalt, unless well supplied with vegetable matter, is distinctly yellowish.

Augite and plagioclase are the chief constituents, with small amounts of magnetite and sparse olivine, and here and there considerable amounts of glass. The texture ranges from intersertal to ophitic. In places it is porphyritic with phenocrysts of augite and feldspar. Some of the phenocrysts are sprinkled with poikilitic inclusions of the other minerals and of glass, and scattered stellate aggregates of augite and feldspar indicate simultaneous crystallization.

Near the bottom of the various sheets and their constituent flows and near their vesicular or ropy upper surfaces grayish and brownish glass, in places highly spherulitic, is abundant. It is commonly thickly crowded with dustlike and minute dendritic magnetite crystals and unindividualized microlites. With great increase of glass augite disappears, and minute feathery feldspar, generally curved or in radiate and sheaf-like clusters, is the only crystallized mineral present. In many places, as at West Paterson and Feltville in the Passaic quadrangle, the outer surfaces of the parts having the ropy flow structure are composed of glass, which has a maximum thickness of 25 millimeters. Among the feldspars orthoclase is rarely recognizable. Scattered olivine crystals are sparingly present, though rarely abundant, and are commonly altered wholly or in part to greenish or yellowish serpentine. Generally much of the glassy base is also altered to greenish or yellowish serpentine, in many places with some chlorite, and here and there it has been entirely replaced by granular calcite.

The augite is altered in part to fibrous uralitic hornblende, to chlorite, or to dirty brownish serpentine and granular magnetite, and in places to a mixture of all three. At some localities, especially at Chimney Rock near Bound Brook, parallel, narrow, bright-red bands in the trap are found to be due to minute flakes of hematite, probably from augite, along several zones near the joint planes. The feldspars commonly show more advanced alteration than the augite, being clouded with kaolin-like material or partly replaced by calcite and analcite. In places the feldspars and here and there the olivine crystals as well as the glassy base are entirely replaced by calcite.

Amygdules, filling the bubble cavities in the cellular varieties of the basalt, are composed of radial or banded concentric calcite or of serpentine, chlorite, and zeolites. Some cavities are lined with films of quartz, calcite, or feldspar, or in parts of First Watchung Mountain with metallic copper, the rest of the space being filled with serpentine. Veinlets of calcite, chlorite, serpentine, and in places a little hematite traverse a few of the sections.

Chemical composition.—The chemical composition of the Watchung basalt is relatively uniform and does not differ much from that of the Palisade diabase. There are, however, certain differences in the proportions of the constituents in the different flows of each sheet and some local variations in each flow. The rocks of the third Watchung flow, compared with those of the first Watchung flow, are lower in alumina, magnesia, and lime but higher in soda and titanium oxide and much richer in iron oxide. The following analyses, most of them taken from a report by Lewis,[c] illustrate the principal features.

[a] Lewis, J. V., New Jersey Geol. Survey Ann. Rept. for 1907, p. 148, 1908.

[b] Idem, pp. 155 et seq.

[c] Idem, p. 159.

Analyses of Watchung basalt.[a]

	First Watchung sheet.						Third Watchung sheet			Second Watchung sheet.
	1	2	3	4	5	6	7	8	9	10
SiO_2	50.19	51.09	51.77	51.82	51.84	51.86	49.68	49.17	49.71	50.81
Al_2O_3	14.65	14.23	14.59	14.18	15.11	16.25	14.02	13.80	13.66	13.25
Fe_2O_3	3.41	2.56	3.62	.57	1.78	2.14	4.97	4.90	5.49	14.66
FeO	6.96	7.74	6.90	9.07	8.31	8.24	9.52	10.01	9.51	
MgO	7.95	7.56	7.18	8.39	7.27	7.97	5.80	5.04	6.18	6.97
CaO	9.83	10.35	7.79	8.60	10.47	10.27	6.50	9.87	5.85	10.96
Na_2O	2.64	1.92	3.92	2.79	1.87	1.54	3.49	2.21	4.51	.76
K_2O	.75	.42	.64	1.26	.34	1.06	1.41	.54	.37	1.71
H_2O+	2.38	1.01	1.85	1.40	1.33	1.38	1.89	.73	2.66	.88
H_2O-	.66	1.66	.46	.30	.56		.54	1.04	.48	
TiO_2	1.13	1.30	1.13	1.17	1.22		1.39	1.50	1.53	
NiO						.03				
P_2O_5	.18	.16	.18	.17	.13		.21	.24	.10	
MnO	.07	.25	.05	.13	.09	.09	.18	.07	.18	
SrO							Trace	.03		
	100.30	100.25	100.08	99.85	100.32	100.28	99.60	99.75	100.13	100.00
Specific gravity	2.92	2.936	2.91	2.95	2.93		2.949	2.997	2.91	

[a] Analyses by R. B. Gage, except No. 6 by L. G. Eakins and No. 10 by W. C. Day.

1. Lower gray layer, Hartshorn's quarry, near Springfield, Passaic quadrangle.
2. Middle black layer, Hartshorn's quarry, near Springfield, Passaic quadrangle.
3. Upper gray layer, Hartshorn's quarry, near Springfield, Passaic quadrangle.
4. Lower gray layer, Hatfield & Weldon's quarry, Scotch Plains, Passaic quadrangle.
5. Middle black layer, Hatfield & Weldon's quarry, Scotch Plains, Passaic quadrangle.
6. Large columns near the bottom, O'Rourke's quarry, West Orange, Passaic quadrangle.
7. Lower gray layer, quarry at Millington, Raritan quadrangle.
8. Middle black layer, quarry at Millington, Raritan quadrangle.
9. Upper gray layer, quarry at Millington, Raritan quadrangle.
10. Francisco's quarry, Little Falls, Passaic quadrangle.

In the ordinary nomenclature these rocks are called basalt, or, in some of the porphyritic phases, where olivine crystals are abundant, olivine basalt. In the quantitative system all the norms fall into class III, order 5. Nos. 5 and 7 are camptonose (III.5.3.4), Nos. 3 and 9 are ornose (III.5.3.5), and the others are auvergnose (III.5.4.4–5).

Local details.—The relations of the first Watchung lava flow to the underlying strata are best shown at the copper mine 3 miles north of Somerville, where the contact is exposed along the main drift for 1200 feet down the dip and along many side drifts. The lower surface of the lava sheet is gently wavy but is strictly conformable to the shale, which dips 10°–15° NE. The basalt near the shale is in part firm, fine grained and dense, but in places it is vesicular, the cavities for 6 inches or so above the contact being filled with quartz, manganocalcite, and zeolites, and numerous lumps and stringers of native copper. Small irregular masses of shale are included in the base of the lava sheet. At its immediate contact with the lava the shale is dark red, in places even brownish black, but this color penetrates only 2 to 3 millimeters and the rest of the inclusion has the customary brownish-red color of the Brunswick shale. Calcite in relatively large crystals has commonly been formed in the shale, and in places some crystalline quartz is present. The ropy structure characteristic of some surface lava occurs in some places.

The underlying shale is normally a relatively soft, dark, reddish-brown rock, but the upper 2 to 3 feet, next the basalt, is a harder and more massive purple rock, which has been partly bleached in irregular patches by the leaching of the iron coloring, and rendered porous by the solution and removal of numerous small crystals of calcite. In the spaces so left copper and chalcocite have been deposited. These conditions have been observed at intervals for 15 miles along the mountain to the southeast and east, but nothing at all comparable to them is known in any other part of the First Watchung Mountain sheet nor in any other extrusive sheet, although the rocks of all are practically identical. Hence it is not believed that these effects are attributable to the overlying lava flows, but to ascending ore-bearing solutions.[a] In the gorge north of Bound Brook, opposite Chimney Rock, workings made in exploring for copper once exposed the contact but are now for the most part inaccessible. Other exposures of the basal contact have been found along the base of the mountain northeast of Bound Brook, in the Passaic quadrangle.

The sedimentary rocks overlying the first Watchung lava flow are exposed at many places in the valley between the two ridges, but the contact relations are shown only at Feltville, several miles to the east, in the Passaic quadrangle. The upper part of the sheet is commonly slaglike or ropy and its surface is in part billowy, like the pahoehoe of the Hawaiian Islands. Much of the basalt is deeply vesicular, the abundant vesicles being either empty or filled with shotlike masses of calcite.

Along Mine Brook, southwest of Bernardsville, the shale underlying the second Watchung basalt sheet is exposed in many places not far from the basalt and at Compton's quarry, in Pluckemin, in actual contact with it. The lava flow is perfectly conformable to the shale, which is only slightly altered in color at the contact. The basal portion of the basalt is somewhat vesicular.

From Pluckemin southward Second Watchung Mountain is characterized by a double crest, with a distinct and continuous depression between the ridges, the outer of which is as a rule slightly higher than the inner. The depression is conspicuous in the vicinity of Mount Horeb and for several miles to the northeast. At various places along it red shale fragments have been noted in the soil and the shale itself outcrops along the road east of Mount Bethel at the very margin of the quadrangle. There seems to be good reason for believing that an intercalated bed of easily eroded shale, whose position can not be accurately mapped because of the uniform mantle of "trap wash," is the cause of the depression.

The upper surface of the lava flow, like that forming First Watchung Mountain, is vesicular and in many places is ropy and billowy in form, like pahoehoe. Its contact with the overlying beds has not been observed, the shale in the upper Passaic and Dead River valleys having been eroded below the level of the alluvial deposits of those streams.

The visible lower contacts of the third sheet are precisely like those of the other Watchung sheets. At many localities the underlying strata near the basalt are entirely unaltered and are conformably overlain by the sheet, the course of which is determined by the flexures. In the gorge at Millington the contact is finely exhibited for about 20 yards.

[a] Lewis, J. V., The Newark (Triassic) copper ores of New Jersey: New Jersey Geol. Survey Ann. Rept. for 1906, pp. 156-164, 1907.

No contacts with overlying strata are known, and in most places the nearest outcrops on the inner slopes are at a considerable distance from the basalt. A mile north of Millington, on the road to Basking Ridge, some very argillaceous shale, which at one point outcrops within 5 or 6 feet of the surface of the sheet, shows not the slightest sign of alteration.

New Vernon sheet.—A broad area of basalt, commonly known as the "New Vernon trap," forms the western end of a semicircular ridge a mile northeast of Logansville. It is the edge of a lava sheet that outcrops along the sides of an irregular dome-shaped uplift and may be either the attenuated northwestern extension of the third Watchung sheet brought to the surface by flexure or, less probably, a local extrusion. The outcrop of the sheet is marked by a ridge, averaging one-half mile in width and rising about 200 feet above the surrounding plain, except where cut by three narrow drainage gaps. In contour it is not so steep and rugged as the Watchung Mountains and its steep inner slope is not marked by escarpments. The rock is fine-grained basalt, very much decomposed superficially but notably vesicular and surficially slaglike in places and similar on the whole to the rock of the Watchung ridges. The thickness of the sheet is between 150 and 250 feet. There are indications that it is perfectly conformable to the sedimentary rocks, although actual contacts have not been seen. The underlying sandstone and shale flank the inner side of the ridge and their strike is closely parallel to its trend. Outcrops of sedimentary rock near the basalt are few, but those observed showed no trace of alteration. Petrographically the rock probably does not differ materially from the Watchung basalt.

New Germantown sheet.—Near New Germantown a small horseshoe-shaped basalt ridge incloses between its ends two small isolated masses. The rock is fine grained, dense, and black, quite unlike the coarse-grained diabase of Cushetunk Mountain. Locally it is slightly vesicular and is discernibly ropy. No contacts are known, but the dip of the associated shale indicates that the ridge is formed by the outcropping edge of a synclinal sheet, the axis of which pitches northwestward. The dips of the beds within the crescent are steep, ranging from 34° to 60°. From these the least thickness of the trap is computed to be about 400 feet.

The adjoining shale is not metamorphosed so far as observed and the sheet is undoubtedly extrusive. Lewis[a] has regarded it as the western portion of the first Watchung flow, in which case the two small masses between the horns of the crescent are thin erosion remnants of the second Watchung sheet. The structure of the intervening shale is such that this correlation is entirely possible.

Prospect Hill sheet.—West of Flemington a small mass of basalt forms the crest and upper slope of Prospect Hill. Presumably it is a flow, although its relations to the surrounding beds are indeterminable. However, unaltered shale is exposed along the road on the east and in the banks of a small brook on the west and not far from the basalt, and vesicular rock occurs on the crest of the hill. The rock is fine grained and considerably decomposed, individual crystals not being recognizable macroscopically. Under the microscope a fine-grained diabasic texture is recognizable.

INTRUSIVE ROCKS ASSOCIATED WITH THE NEWARK GROUP.

TYPICAL FORMS.

The intrusive igneous rocks associated with the Newark group comprise sheets and dikes of diabase and basalt. The principal diabase masses are intrusive sheets or sills, which range in thickness from a few inches to over a thousand feet, and which, although approximately conformable to the inclosing strata for greater or less distances, cut across them in places. The dikes are of various thicknesses but are relatively thin.

Both sheets and dikes are later than the beds into which they have intruded, but their intrusion may have been going on deep underground at the same time with the effusion of the Watchung basalt on the surface. In the adjoining region on the south Lower Cretaceous sediments overlap the beveled edges of the intrusive sheets and the inclosing strata, hence the intrusive rocks must be much older than Cretaceous. That all are of approximately the same age is a fair but not a necessary conclusion.

SHEETS.

Occurrence and character.—The four irregular masses of diabase south of Lebanon (Cushetunk and Round mountains and two masses without names) are probably parts of one intrusion which may be the same as that which formed the Palisades sill and the large irregular sheets in the Trenton quadrangle on the south. Near the Hudson the horizon of intrusion of the Palisade diabase is low in the Newark group, but southwestward it rises at intervals and finally reaches the middle part of the Brunswick shale. Owing to faults, to erosion insufficient to expose the diabase in some intervals

[a] Lewis, J. V., New Jersey Geol. Survey Ann. Rept. for 1906, pp. 115-117, 1907.

between outcrops, and to excessive erosion in other intervals, it is not possible fully to ascertain the structural relations of the various diabase masses, but it is not improbable that all are parts of one general intrusion. Doubtless they were fed by great dikes, but no signs of such feeders appear at the surface. In adjoining regions the larger masses have a general trend parallel to the strike of the sedimentary rocks, but such does not seem to be the case in this area.

The strata close to the large diabase intrusions are extensively altered, especially where they consist of shale, as they generally do in this region.

Cushetunk Mountain.—Cushetunk Mountain is a prominent horseshoe-shaped ridge lying south of Lebanon and inclosing within its curves the picturesque Round Valley. The toe of the horseshoe is toward the southeast and the heels abut against a fault along the border of the Highlands. A small low hill of diabase adjoins the fault line about midway between the heels. Near the diabase the shale is uniformly dark colored and greatly indurated, but its actual contact with the former has not been found. Both in Round Valley and in the cuts along the railroad west of White House the strata strike nearly east and west and dip 20°–45° N., so that except near Lebanon and at the toe of the shoe there is marked divergence in the trend of the strata and of the diabase ridges. The unconformity of the diabase sheet to the shale is clearly apparent.

Half a mile west of the broad southern lobe of the Cushetunk sheet black indurated shale dips westward on both sides of a narrow diabase ridge. The diabase seems to dip westward with the inclosing shale.

Round Mountain.—Round Mountain rises to an altitude of 608 feet above sea level, with moderately steep slopes on all sides, and is separated from Cushetunk by a valley which has been cut down to 345 feet above sea level. The trap sheet seems to lie in a syncline or spoon and to have been separated from Cushetunk by erosion. The surrounding shale, so far as it can be seen, is somewhat indurated and altered.

DIKES.

A number of dikes cut the strata of the Newark group. Few of them can be traced for long distances, and several of them are recognizable only by a line of yellow soil, the product of their disintegration. Where fresh they are dense black or dark-green crystalline rocks, rusty brown on their weathered surfaces, the constituent minerals being unrecognizable to the naked eye. They are best classed as basalts but are commonly spoken of as "trap." They have been noted west and south of Flemington, near Oak Grove, west of Stanton station, northeast of Three Bridges, southwest of South Branch, in the railroad cut west of Neshanic station, north of Woodfern, southwest of Pottersville, and south of Peapack station.

A very coarse-grained diabase of somewhat unusual macroscopic appearance forms a steep-sided hill one-half mile southeast of Peapack, adjacent to the gneiss. Along its southern face a fault separates it from the shale of the Newark group.

The rocks of the Highlands are cut by a few narrow dikes of diabase and allied rocks that are believed to be of Triassic age. The largest dike is about a mile southwest of Middle Valley, in the gneisses a few score rods from their contact with the Paleozoic limestone of the valley. This dike, which is quarried for road metal and crushed rock in general, is 60 feet thick, dips about 45° SE., and is bordered on both sides by Byram gneiss, which is slightly slickensided along the contact. The dike can be traced for about a quarter of a mile along its strike, which, where the rock is being quarried, is approximately northeast. Farther south, near the road, the trend changes to N. 70° E.

Other rather large diabase dikes cut the Losee gneiss on Jenny Jump Mountain, and smaller ones outcrop alongside the High Bridge branch of the Central Railroad of New Jersey 2 miles north of High Bridge.

MINERAL COMPOSITION.

The rock of most of the intrusive masses is quartz diabase of exactly the same character as that of the great intrusive sill which forms the Palisades and associated ridges, and which has been described in detail by Lewis,[a] from whose paper the following condensed statement is taken:

The diabase is everywhere a heavy dark-green or nearly black rock and is in the main coarse grained, many individual minerals being more than one-eighth inch in diameter. The color changes to brighter shades of green as the dark-green or nearly black augite, the most abundant constituent, becomes more hydrated. Near the contacts with the inclosing sedimentary rocks the texture is fine grained in many places, with porphyritic crystals of augite and more sparingly of feldspar embedded in a groundmass of feldspar rods and augite and magnetite grains, the rock in those places being much like the dense extrusive basalt of the Watchung Mountains.

The rock everywhere contains augite, plagioclase, magnetite, and a little apatite; almost everywhere it contains some quartz and orthoclase in micrographic intergrowths, and in places those minerals constitute as much as one-half of its bulk. Less commonly, olivine, biotite, and, rarely, scattered grains of pyrite and chalcopyrite and slender needles of rutile are present.

The augite fills the interstices between the interlacing lath-shaped feldspars or where greatly in excess forms the groundmass in which the feldspars are embedded. In some of the coarser-grained phases, however, a granitoid texture is developed with the two principal minerals of approximately equal size, the rock thus becoming a gabbro.

From the prevailing intersertal or ophitic texture of the diabase it is evident that the crystallization of the plagioclase was very generally completed before that of the augite. In the granitoid portions of the rock, however, plagioclase and augite formed more nearly simultaneously, each interfering with the crystal outlines of the other. Moreover, numerous plates of porphyritic augite in the fine-grained contact facies of the rock, with only rarely a large feldspar, indicate that crystallization had begun before intrusion and under conditions that would have led to the formation of the minerals in their usual order in igneous rocks, namely, the augite before the feldspar.

CHEMICAL COMPOSITION.

The composition of the diabase is shown by the following analyses of specimens from four places in the Passaic quadrangle and one in the Trenton quadrangle:

Analyses of diabase from the Passaic and Trenton quadrangles, N. J.[a]

	1	2	3	4	5
SiO_2	60.05	51.34	51.88	49.62	56.78
Al_2O_3	11.88	12.71	14.53	10.51	14.33
Fe_2O_3	3.22	2.65	1.35	.64	5.76
FeO	10.21	14.14	9.14	12.02	9.27
MgO	.85	3.66	7.78	15.98	1.58
CaO	4.76	7.44	9.98	7.86	5.26
Na_2O	4.04	2.43	2.06	1.40	3.48
K_2O	2.10	1.44	.93	.55	1.75
H_2O+	.66	.69	.97	.49	.10
H_2O-	.21	.18	.12	.38	.33
TiO_2	1.74	3.47	1.35	1.01	1.44
P_2O_5	.52	.20	.14	.16	.36
MnO	.28	.36	.10	.09	.25
	100.52	100.71	100.33	100.71	100.64
Specific gravity	2.872	3.089	2.98	3.118	-------

[a] Nos. 1, 2, 3, 4 by R. B. Gage; No. 5 by A. H. Phillips.

1. Quartz diabase, Pennsylvania Railroad tunnel, Homestead, 400 feet from western portal. (Dacose, II.4.2.4.)
2. Quartz diabase. Pennsylvania Railroad cut, near Marion station. (Camptonose, II.5.3.4.)
3. Basaltic diabase, Weehawken, lower contact in Pennsylvania Railroad tunnels. (Auvergnose, III.5.4.4–5.)
4. Olivine diabase, Weehawken, road to west shore ferry. (Palisadose, IV.1^2.1^2.2.)
5. Quartz diabase (?), Rocky Hill, old quarry near the railroad station, about 400 feet from the upper contact. (Tonalose, II 4.3.4.)

QUATERNARY SYSTEM.

The Quaternary system comprises the unconsolidated surficial deposits which mantle the bedrock surface throughout a large part of the quadrangle. These deposits are as a rule of local distribution and consist of clay, sand, gravel, and bowlders, in many places without systematic arrangement. Some are glacial, some lacustrine, and some fluviatile or estuarine in origin. They belong in part to the Pleistocene and in part to the Recent series.

PLEISTOCENE SERIES.

SUBDIVISIONS.

The deposits of Pleistocene age represent two or possibly three of the stages into which the Pleistocene of North America has been subdivided. They are chiefly of glacial origin but include also fluviatile or estuarine deposits that are believed to be contemporaneous with one of the glacial invasions. They form an almost continuous mantle over the northern third of the quadrangle and occur in patches over much of the rest of it.

PENSAUKEN FORMATION.

The nonglacial deposits of early Pleistocene age consist of a few small isolated patches of gravel and sand in the southeastern part of the quadrangle. Many traces of gravel which lie at lower altitudes are interpreted as remnants of the same formation, some of them near their original position and others transported and redeposited. Similar sand and gravel occur at a few other localities but are not shown on the map, as they are concealed by a thin layer of Jerseyan drift. Sand thus covered is found just north of Raritan and has been seen in excavations made at several points east of White House Station and near Peapack.

Some of these deposits of sand and gravel are on divides or low hills; others are near high ridges; and most of them lie in places where there has manifestly been considerable erosion since they were deposited. They are regarded as remnants of a formation that once covered all the lands of this region that stand at altitudes below 200 feet above sea level and possibly some higher lands in the northern part of the quadrangle. They are regarded as parts of the Pensauken formation, but some of them may be parts of an older formation, the Bridgeton. The Pensauken formation is perhaps the equivalent of a portion of the Columbia group of regions farther south. In the Raritan quadrangle the evidence for this correlation is not very clear.

JERSEYAN DRIFT.

Distribution.—South of the terminal moraine of the last (Wisconsin) glacial stage lie many patches of much older glacial till, the age of which can not be determined with certainty but which belong to one or more of the earlier glacial stages and which are mapped as Jerseyan.

The greater part of these deposits lie in two irregular belts that run generally east-west across the quadrangle. The northern belt, which extends from Washington to Rockaway, lies just south of the terminal moraine of the Wisconsin stage. It is made up of detached irregular patches lying on the plateau surface and on the slopes, with long tongues extending southwestward down the Pohatcong, Musconetcong, and German valleys. The southern belt, which is less continuous and more irregular, lies along the inner margin of the Piedmont belt, at the southeastern base of the Highlands, and extends southward through the valley of North Branch of Raritan River to Milltown and Raritan. Between the two belts lie an isolated area near Mendham and two smaller patches near Newport.

Scattered bowlders transported from a distance, presumably by glacial action, are found in the same general region at many places outside of the areas mapped as Jerseyan. They are especially abundant just south of the Highlands near the western margin of the quadrangle and are perhaps not entirely absent from a single square mile of the Highlands area.

Situation.—The Jerseyan drift in the southern belt generally lies on divides or on the upper parts of gentle slopes, where also the scattered bowlders in this part of the quadrangle are found. Like the Pensauken formation these deposits have evidently been subjected to extensive erosion and are believed to be remnants of a once nearly continuous deposit that mantled this part of the Piedmont Plateau.

The deposits of Jerseyan drift in the northern belt are generally larger and more continuous and are possibly younger. Some of them lie on the plateau or on the slopes of the Highlands ridges, but the larger ones lie in the main interhighland valleys. Although they have undergone some erosion they have not been eroded to any such degree as the deposits of the southern belt.

Character and thickness.—The Jerseyan drift of the southern belt, of the Highland areas, and in large part that of the valleys in the northern belt is till consisting of pebbles and bowlders, the largest as much as 15 feet in diameter, embedded in a matrix ranging from fine sand to rather tough clay. The matrix is everywhere thoroughly oxidized, and the stony material is greatly disintegrated. The stony material has in large part been transported from a distance. In the southern areas it consists chiefly of pebbles and bowlders of gneiss and quartzite; in the northern areas it includes much material derived from the Paleozoic formations lying farther northwest, although it includes very little limestone. Little or no calcareous or other soluble material is found anywhere in the till.

The stony material is largely angular and includes striated pebbles and bowlders, which, though abundant only in certain of the deposits, may be found in nearly all of them. South of the Wisconsin terminal moraine striations on bedrock have been observed only at a point about a mile west of High Bridge, where well-defined striæ on the surface of a ledge of Hardyston quartzite trend S. 33° W.

Stratified deposits of sand and gravel a few feet thick are interbedded with the Jerseyan drift of the northern belt at several places in the valleys.

The Jerseyan drift is generally thin, but in some places it has a thickness of 30 feet. Ordinarily it is not well exposed, and it has been penetrated by wells and other excavations in but few places. Good exposures containing glacially striated pebbles have been observed at High Bridge, Washington, and Bernardsville.

Interpretation.—Although not all the incoherent surficial material mapped as Jerseyan drift is of glacial origin most of it certainly is, especially that in the southern belt. The physical heterogeneity of the deposits, the till-like admixture of coarse and fine material, the preponderance of material transported from a distance, and the presence of striated pebbles and bowlders, furnish adequate warrant for such a conclusion.

In some of the northern areas, where exposures are few and poor, the character of the drift itself furnishes little warrant for its definitive classification as till, and it is possible that at least a part of the Jerseyan drift mapped in those areas may be of fluviatile origin. However, as there is abundant proof that the Jerseyan glacier extended well south of these northern areas, and as much of the material is similar in character and in composition to the undoubted till farther south, it

[a] Lewis, J. V., Petrography of the Newark igneous rocks of New Jersey: New Jersey Geol. Survey Ann. Rept. for 1907, pp. 105 et seq., 1908.

seems reasonable to regard the deposits of the northern belt as also of glacial origin.

Some of the drift that lies just outside of the Wisconsin terminal moraine and that resembles slightly the till of the moraine but is apparently not so highly weathered as the ordinary Jerseyan drift may possibly be a fringe of extra-morainic drift of Wisconsin age. If so, it has had incorporated in it much of the older till and is inseparably connected with remnants of old drift in the same area.

Scattered bowlders of rock transported from a distance, many of them from original positions at lower altitudes, are found throughout the area covered by the Jerseyan ice sheet and are additional evidence of glacial action. Their present position relative to the areas occupied by drift deposits leads to the conclusion that most of them are erosion remnants of former deposits of till, from which the matrix and the finer stony material have been washed away.

Age and correlation.—The oxidation and deep coloration of the matrix of the Jerseyan drift, the deep disintegration of most of the stony material, the absence of calcareous and other soluble material, and the fragmentary and much-eroded character of the deposits themselves, all indicate that the formation is much older than the last or Wisconsin drift. Deposits of the same general character and presumably of the same age extend for some distance westward into Pennsylvania, and although they can not be traced continuously into the Mississippi Valley nor definitely correlated with one of the earlier drift sheets of that region, there is little doubt that they are equivalent in age to one of the earlier drift sheets of the Mississippi basin, not improbably to the pre-Kansan (sub-Aftonian) or possibly to both that and the Kansan.

INTERGLACIAL DEPOSITS (OLDER ALLUVIUM).

Distribution.—The valleys of both North and South Branch of Raritan River and their tributaries contain considerable deposits of alluvium at levels higher than the recent flood plain. Along South Branch the older alluvium forms a nearly continuous deposit from Lansdowne to Three Bridges, though with considerable interruption near Stanton station. Below Three Bridges it occurs in patches only. It reaches a maximum altitude of 35 feet above the stream at Flemington Junction, where it has a known thickness of 20 feet. In some places, as at Flemington Junction, Woodfern, and South Branch, it forms more or less clearly defined terraces. Along North Branch it forms a low and nearly continuous plain, 15 to 20 feet above the river, from Bedminster nearly to South Branch village. In several places, as at North Branch village and north of Burnt Mill, it forms more or less well defined terraces. Similar deposits exist along the valleys of Lamington River and Rockaway Creek.

Along the east side of the valley of Black River from Ironia southward to the mouth of Tanner Brook there is more or less fine yellowish sand, which in places forms an indistinct terrace about 40 feet above the stream and in other places mantles the valley slopes to a maximum height of 180 feet above the river.

Composition.—Much of the alluvium may be described as clayey gravel, the stony constituents of which are mainly gneiss, with some sandstone, quartzite, and shale pebbles with a maximum diameter of 6 to 8 inches. Along Lamington River and Rockaway Creek the gravel is on the whole more clayey than along North Branch. West of Bound Brook a deposit composed chiefly of basalt gravel forms a wide plain opposite Chimney Rock gap in First Watchung Mountain. At Pottersville another deposit similarly situated as regards the deep gorge of Black River is composed essentially of gneiss gravel. The sand along Black River is in part at least stratified and contains some poorly rounded rock fragments, chiefly gneiss. It reaches higher altitudes, and is more highly oxidized, as shown by its color, than the sand of the near-by outwash plain of Wisconsin age.

Age and origin.—The alluvium in the valleys of North and South Branch of the Raritan and their tributaries is regarded as younger than the Jerseyan but older than the Wisconsin drift, and in this sense it is interglacial. It is believed to be made up in part of Jerseyan drift brought down to the valleys and deposited in them after they had been excavated essentially to their present level. As the patches of Jerseyan drift on the Triassic lowland occur only on hilltops and divides 40 to 100 feet above the level of the alluvium terraces, the erosion was very considerable, and the alluvium is appreciably younger than the Jerseyan drift. The scattered bowlders lying on the intervening slopes seem to connect the drift remnants with the valley alluvium and to corroborate this conclusion concerning the origin of the alluvium.

The sand along Black River is of uncertain origin and age. It may be, in part at least, of eolian origin, but in some areas it does not seem to be eolian, and no certain criteria were found for discriminating these areas from those adjoining. Its classification as "older alluvium" is not wholly satisfactory but seems less open to objection than any other that has been proposed.

WISCONSIN DRIFT.

Distribution and character.—Glacial drift of Wisconsin age covers nearly the northern fourth of the quadrangle and several irregular areas near the middle of the eastern side. The material is till, sand, gravel, and lacustrine silt and clay. The deposits fall into three general classes—terminal moraine, ground moraine or till, and stratified drift, which is of several sorts, including lacustrine and fluviatile deposits.

Terminal moraine.—The terminal moraine extends irregularly from east to west across the northern part of the quadrangle from Rockaway to Pequest. (See fig. 12, p. 23.) Rockaway, Mount Hope, Dover, Wharton, Port Morris, Netcong, Stanhope, Hackettstown, Vienna, Danville, Townsbury, and Pequest lie upon it or close to its borders. It is from half a mile to about 2 miles wide, averaging $1\frac{1}{2}$ miles.

In places—as a mile west of Townsbury—the outer margin of the moraine is sharply marked by an abrupt change, easily discernible across plowed fields, from the reddish-brown residual soil of the gneiss to the lighter-colored till. As a rule, however, the moraine is bordered by other forms of drift and its outer margin is indistinct.

The moraine ranges in height from 420 feet at Townsbury to 1208 feet above sea level at its highest point, $1\frac{1}{2}$ miles east of Lake Hopatcong. The maximum difference in the height of the inner and outer borders of the moraine on any one meridian is about 400 feet, seen at Rustic, where the outer border has an altitude of 800 feet and the inner border an altitude of 1200 feet. Although the range in the altitude of the moraine is considerable its range from north to south is comparatively slight, owing to the absence of broad valleys down which ice tongues could extend for long distances.

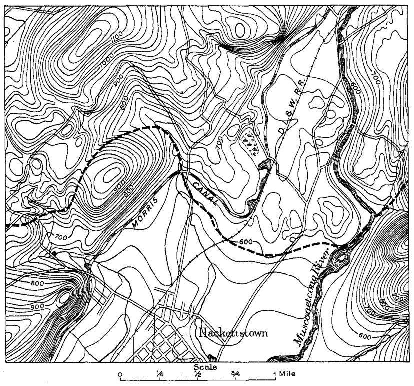


FIGURE 4.—Map of area near Hackettstown, showing bend in the terminal moraine around hill northwest of the town.
The broken line indicates the outer (southern) margin of the moraine.

Nevertheless, the outer margin of the moraine shows irregularities that are definitely connected with the form of the surface against which the edge of the ice lay or over which it had come. The sharp reentrant in the moraine at Rockaway, for example, was caused by the high hill just northeast of Dover, which held the ice back. Other reentrants due to similar causes lie northwest of Hackettstown (fig. 4) and west of Townsbury (fig. 5). On the other hand the valleys of the

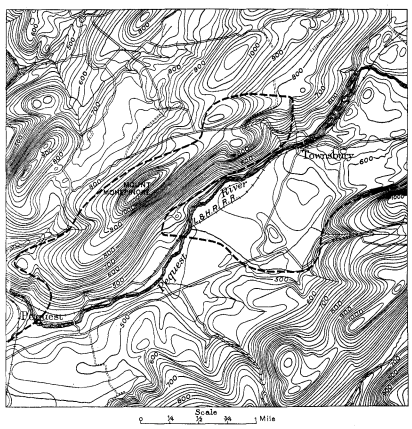


FIGURE 5.—Map of the region near Townsbury, showing bend in the outer margin of the terminal moraine at Mount Mohepinoke.
The broken line indicates the outer (southern) margin of the moraine.

Musconetcong and the Pequest allowed the ice to advance farther south than it could advance on the adjacent highlands; however, Allamuchy and Brookland mountains, over which it passed before reaching those valleys, prevented its movement as far down them as it would have gone had its course been unobstructed.

Though distinct, the terminal moraine is not conspicuous topographically, largely because of the great relief of the surface on which it lies. On a plain it would stand out, but amid the mountainous or semimountainous topography of the quadrangle its height and irregularity of surface are dwarfed. From the south or outer face it is conspicuous at a few points, as south of Shippenport, south of Stanhope, in the vicinity of Budd Lake, and north of Hackettstown. At Hackettstown it is conspicuous in contrast with the plain of the Musconetcong (see fig. 6) but is insignificant in contrast with the high hills of crystalline rock that border the valley. It is again conspicuous in the valley of the Pequest, which it crosses as a great irregular dam, cut through by the narrow gorge of the river.

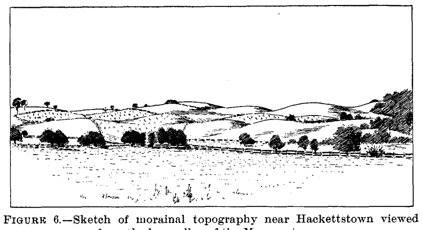


FIGURE 6.—Sketch of morainal topography near Hackettstown viewed from the low valley of the Musconetcong.
From a photograph.

The irregular knob and kettle topography characteristic of terminal moraines is well developed in some places in the Raritan quadrangle but is feebly marked in others. It is rather pronounced north of Dover, south of Wharton, about Hopatcong Junction and Shippenport, a mile northeast of Saxton Falls, a mile northeast of Hackettstown, and in the vicinity of

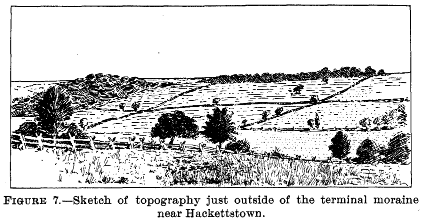


FIGURE 7.—Sketch of topography just outside of the terminal moraine near Hackettstown.
From a photograph.

Townsbury. Where best developed the difference in altitude between the tops of the knobs and the bottoms of the kettles is 35 to 45 feet. The contrast in relief between the moraine and the area south of it is well shown $1\frac{1}{2}$ miles northwest of Hackettstown, on the Petersburg-Hackettstown road. (See figs. 7 and 8.)

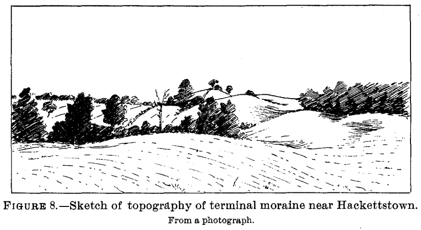


FIGURE 8.—Sketch of topography of terminal moraine near Hackettstown.
From a photograph.

In composition the moraine is dependent on the character of the rock over which the ice had come. East of Budd Lake the ice had moved for a long distance over the Highlands, the rocks of which are predominantly gneiss and schist, with quartzite, conglomerate, and slate in the Green Pond Mountain belt. West of Budd Lake it had moved along the Kittatinny Valley and thence onto the Highlands, thus passing from areas of sandstone, slate, and limestone, to those of gneiss and schist. Accordingly, from Rockaway westward nearly to Hackettstown, the stony material of the moraine consists of gneiss and schist with minor amounts of Green Pond Mountain material. The moraine is exceedingly stony, 50 per cent of it being composed of bowlders, many of which are abundantly striated and conspicuously worn. Wide differences in size of material, in relative amounts of till and stratified material, and in compactness are visible.

As the moraine descends from the Highlands to the Musconetcong Valley its lithologic character changes. In the valley 60 to 70 per cent of the stony material is limestone derived from the underlying rocks. West of the Musconetcong its character again changes, in keeping with the change in the underlying rock, and gneiss and other crystalline bowlders again become dominant, though limestone continues abundant. In the Pequest Valley and in other places where the moraine lies at a relatively low altitude much stratified drift is associated with the unstratified.

The greatest known depth of drift in the terminal moraine is at Mount Arlington, where a well is reported to have penetrated it for 260 feet without reaching bedrock. Its average depth is probably less than 75 feet.

Ground moraine.—The ground moraine of the region was derived chiefly from the underlying rock, but a small part of it came from a greater distance. The till of the Highlands is therefore different in composition from that of the Kittatinny Valley, its stony material being made up chiefly of gneiss, whereas that of the latter is of shale, sandstone, and limestone. Till covers most of the surface of the quadrangle north of the terminal moraine except where rock crops out, as it does in places on almost every slope, and except in the larger valleys, where stratified drift and recent alluvium predominate. The thickness of the ground moraine is not great, averaging outside of the valleys probably not more than 10 feet. Striæ are most numerous in the belts of Martinsburg shale; the gneiss and schist of the Highlands were not well adapted to receive them, and the Kittatinny limestone, although it readily received them, was not well adapted to retain them. Since the till was deposited its surface has been weathered and leached of soluble constituents to a depth of 2 feet or more and in a few places to depths twice as great.

The till of Jenny Jump and Allamuchy mountains, which form the western Highlands, is composed largely of gneissic and granitic material but contains also material brought in from the Kittatinny Valley and deposited in places on the Highlands, particularly on the slope facing the valley. On the broad summits and gentle slopes the till is clayey and locally compact, and beneath the zone of weathering it is foliated. In places it is decidedly arkosic, the matrix being largely disintegrated gneiss. Its maximum depth, so far as known, is 40 feet, but this may be exceeded in a few places. That the till in many localities rests on the eroded and polished bedrock is fairly inferred from the number of firm roches moutonnées that project through it. In other places a thin layer of till rests on loose and disintegrated gneiss, which retains its characteristic banding. The observed relations indicate that the disintegration of the rock was preglacial, and that the disintegrated material was not disturbed by the ice. Many of the bowlders are 10 or 15 feet in diameter and some are even larger. A limestone bowlder northwest of Danville measures 50 by 25 by 15 feet, and must have been transported at least 2 miles and carried over an intervening ridge 200 to 400 feet higher than its source.

East of Allamuchy Mountain the gneissic type of till is more common than farther west. Foreign material probably constitutes less than 5 per cent of its bulk, except in the vicinity of Green Pond and Copperas mountains, where bowlders of Green Pond conglomerate are common. Such bowlders are also abundant in the till on the Highlands farther east. Striæ on bedrock are rare, the few observed being on freshly exposed surfaces and ranging in trend from S. 25° W. to S. 55° W.

In the limestone belts of the Kittatinny Valley the till is confined chiefly to the higher parts of the areas underlain by that rock, the stratified drift filling the lower depressions. Where thin the till commonly ranges in color from reddish brown to orange and chocolate; its stony material consists largely of angular blocks of limestone; it contains few glaciated stones; and its earthy part is not notably calcareous. Where it is thick its color is lighter, indicating less perfect oxidation; it is calcareous at depths of 2 to 4 feet from the surface; it contains many glaciated stones and many foreign bowlders, chiefly of shale, sandstone, and conglomerate. Owing to the great unevenness of the rock surface the thickness of the till differs greatly within short distances, rough, weather-beaten ledges of limestone outcropping close to till at least 60 feet deep. Its average thickness, however, in the limestone belts, is probably between 5 and 10 feet.

In the shale belts of the valley the till, where thick, generally consists of a compact, clayey matrix closely set with stones of all sizes and not commonly foliated. Except near the borders of the limestone belts it is not notably calcareous. Where the till is thin it is composed essentially of the preglacial residual soil of the shale and a little additional foreign material. Its average thickness is probably between 8 and 12 feet.

Stratified drift.—Stratified drift of the Wisconsin stage is widely distributed in the valleys of the quadrangle, chiefly in those of the northern part but also in those in the southeast corner. South of the terminal moraine, near Dover, Kenvil, Hackettstown, Pequest, and Bound Brook, considerable areas of stratified drift form outwash plains or valley trains. North of the moraine such drift, mostly in the form of low terraces, forms narrow belts in the valleys. At several places, however, it forms distinct kames, and between the kames and the terraces it occurs in gradations known as kame areas and kame terraces, the latter term being applied to terraces whose surfaces and slopes have kamelike (moraine-like) undulations. A few short, distinct ridges have the form of eskers. Much of the stratified drift north of the moraine is so disposed in the valleys and so shaped topographically as to indicate that it was deposited against irregular bodies of stagnant ice rather than along lines of free drainage.

The lithologic character of the stratified drift, like that of the till, differs from place to place with differences in the character of the underlying rock, but not to so marked a degree. That of the Kittatinny Valley is composed chiefly of fragments of shale, sandstone, conglomerate, and limestone, and that of the Highlands consists predominantly of gneiss. Much of it is poorly assorted, although the stones are generally fairly well rounded and worn. Its thickness is not readily estimated, for wells rarely reach its base. Its depth is perhaps on the average two or three times that of the till.

South of the moraine, at Dover and along the valley of Rockaway River for 2 miles east of Dover, stratified drift is abundant. In Dover it forms an outwash plain, but farther east, where it does not rest against the moraine, the form disappears. On Succasunna Plains, for about 3 miles along the front of the moraine, the stratified drift slopes southward, its material becoming noticeably finer with distance from the moraine. The plain is interrupted by several rock hills and by swampy depressions. A well about a mile southeast of Ledgewood is reported to have penetrated 60 feet of gravel and sand and 60 feet of clay containing no pebbles without reaching rock. A feeble valley train of gravel starts at the moraine at Hackettstown, where it is a mile wide, but within 3 miles its width narrows to a quarter of a mile or less. It is present in large quantity nowhere below Beatyestown, although it occurs in interrupted narrow belts to the Delaware. At the moraine its altitude is 600 feet but it declines 40 feet in the first quarter of a mile and 20 feet in the next quarter, beyond which for several miles it falls 15 to 16 feet to the mile. Stratified drift occurs also in the Pequest Valley south of the terminal moraine. Some of it forms kames or high terraces, the shape of which indicates that they were built between the ice and the valley wall before the moraine was formed. At lower levels coarse gravel deposits, slightly younger than the kames and kame terraces, head in the moraine.

Extensive areas of gravel along the Raritan and its branches near Bound Brook and Somerville are the dissevered remnants of an outwash plain which spread southwestward from the moraine east of Plainfield, in the Passaic quadrangle.

Stratified drift extends northeastward from the Pequest Meadows for several miles, the main belt lying along Pequest River and subordinate belts along Trout Brook and Bear Creek. The main area is low near the meadows, is in places swampy, and is composed of fine sand and silt. Its depth has not been determined but is more than 20 feet. The plain rises gradually toward the northeast and the material is coarser, the fine sand being replaced by gravel at an altitude of about 550 feet, which is the height of the moraine at Danville and the maximum height of a possible glacial lake held by the moraine in the low country on the north. The plain is interrupted by knolls of limestone and by small kames, few of which are more than 10 or 20 feet high, and which are of much coarser material than the plain in which they appear to be partly buried.

The valley of the Musconetcong north of the moraine contains only small stratified deposits, which generally consist of coarse gravel that forms an undulating plain extending nearly to the present river level and showing slight postglacial erosion in the valley. Along the valley of Lubber Run gravel occurs at intervals in the form of semi-isolated plains having somewhat irregular surfaces and bordering swampy flood plains, conditions which are interpreted to indicate deposition in a valley somewhat obstructed by blocks of stagnant ice. Somewhat similar deposits occur in the Longwood Valley west of Green Pond Mountain.

All the kames and kame terraces lie north of the moraine except a few that occur where the ice front temporarily pushed a short distance south of it, the most prominent being the kames in the Pequest Valley south of Townsbury. Prominent kames and kame terraces north of the moraine occur at Andover, west of Stanhope, and northeast of Johnsonburg. Two of the so-called islands of the Pequest Meadows are kames, and knolls of coarse gravel (half-buried kames) rise above the level of the gravel plain north of the meadows. Most of the gravel along Paulins Kill in the quadrangle is in the form of kames or kame terraces, indicating deposition in a valley obstructed by ice rather than in one affording free drainage.

The kames and kame terraces consist predominantly of coarse and poorly assorted material. Some of them are bowlder strewn and most of them contain abundant cobbles.

Few typical eskers occur in the Raritan quadrangle. The best one is $1\frac{1}{2}$ miles south of Hurd, west of the road to Berkshire Valley. Another is north of Jenny Jump Mountain near Southtown.

Lacustrine deposits.—Deposits laid down in a body of water known as Lake Passaic, which for a time occupied the upper Passaic Valley, occur in the basin between the Highlands and Second Watchung Mountain. During its maximum stage this lake stood at an elevation of about 360 feet. Faint traces of its shore lines, formed while it stood at this height and slightly lower, have been detected on the slopes of the Watchung Mountains and between the higher parts of Long Hill, which once rose above it as islands. Small deposits of local gravel, chiefly trap, in the form of beaches and spits, are the most conspicuous shore features. Thick deposits of calcareous laminated clay and silt that lie along Dead and Passaic rivers in the Great Swamp are also believed to be of lacustrine origin. Their thickness near Long Hill village exceeds 30 feet and their maximum thickness is probably much greater. As these clays lie chiefly in the lowest portions of the basin, which were the last to be drained, they may be, in part at least, postglacial.

The clay and sand underlying the recent alluvium of the Pequest Meadows should probably be regarded as deposits in a temporary lake formed behind the morainal dam that crossed the valley between Danville and Townsbury. The height of this dam was 550 feet, which is the elevation at which fine sand gives place to coarser deposits along the northern margin of the assumed lake.

The stratified drift of Succasunna Plains may represent delta-like accumulations that encroached upon and practically filled a shallow temporary lake that may have existed in front of the moraine in a northward-draining valley.

RECENT SERIES.

Humus (swamp muck).—Deposits of humus occur at many places in the quadrangle, the largest lying in the valley of the Pequest north of Danville, though smaller patches abound in the Highlands north of the terminal moraine. A similar deposit lies in the valley of Black River southwest of Ironia, where the drainage was obstructed by drift. Still other deposits lie east of Basking Ridge, in the basin of Lake Passaic.

Skeletons of six mastodons are reported to have been found many years ago in a small bog in the terminal moraine between Vienna and Hackettstown. Most of the bones crumbled to pieces on exposure to the air. A small pond, known as Mastodon Pond, now occupies the site of the bog. Remains of other mastodons have been reported near Vienna, Hope, Greensville, and in the Morris & Essex Canal "near Schooley Mountain."

Alluvium.—Many alluvial deposits are not separable from humus deposits, humus and alluvium being generally intermingled. The most continuous deposits are along Raritan River and its two main branches, the recent alluvium being limited practically to the present flood plains.

STRUCTURE.

GENERAL FEATURES.

The main structural features of the quadrangle—those that determine the general distribution of the rocks—are, first and most important, a series of northeast-southwest folds parallel to the general Appalachian structure; second, two series of great faults trending in the same direction; and third, a series of shallow cross folds, the axes of which trend northwest and southeast. The principal features are shown in the sections on the structure-section sheet.

The great folds involve the Paleozoic and pre-Paleozoic rocks. The folds are unsymmetrical, their axial planes being inclined to the southeast. The great faults break all the rocks into a series of huge elongated blocks. The northwestern side of each block is relatively depressed, the tilting ranging from 10° to 20°. The precise attitude of the fault planes has not been determined, but they are not far from vertical, and they cut abruptly across the formations. The cross folds consist of shallow basins and domes, whose dips are ordinarily less than 10° and whose strata in consequence have curved outcrops, as prominently shown by the Watchung basalt sheets. The deformation thus expressed is of much less magnitude than the general folding, tilting, and faulting.

STRUCTURE OF THE HIGHLANDS.

FOLDING.

The general structure of the Highlands is monoclinal. Straight or gently curved structural features are the rule, but in many places individual layers or sets of layers, if followed along the bedding, exhibit at intervals sharp troughlike corrugations, ranging in size from mere wrinkles to folds of considerable span. As a rule these folds are very minor features compared with the notably great, nearly straight structures which they modify, but in a few places they are important because they determine the areal distribution of the different varieties of gneiss. Also, in some of the mines of the region, the ore bodies have the forms of pitching troughs.

FAULTING.

Major faulting.—A great fault bounds each of the Highlands ridges on its southeast side, separating the pre-Cambrian from the later rocks. These faults are well shown in all the sections on the structure-section sheet. They divide the Highlands into a series of elongated blocks, corresponding to topographic ranges. (See p. 2.) As the rocks on the northwest sides of the faults are upthrown the blocks are tilted northwestward. The gneisses close to the fault lines are more or less sheared, especially near the southeastern border of the Highlands, where in many places the rocks are so much crushed and mashed as to have lost all semblance to the normal gneisses and to resemble fine-grained granites.

Where the faults separate pre-Cambrian from later rocks they are easily traced, but where they cut only pre-Cambrian formations it is difficult if not impossible to locate them. In some places crushed zones can be traced from the distinct faults separating the later rocks from the gneiss into areas occupied by gneiss exclusively, but as a rule they can not be followed beyond the contacts of the different sorts of rocks.

The portion of the Highlands that lies in the Raritan quadrangle comprises a part of the "Passaic block," the western boundary of which extends along the east side of Green Pond and Copperas mountains and along the west side of the German Valley; a part of the "Central Highlands block," which lies between the Passaic block and the west side of the Musconetcong Valley; and a part of the "Western Highlands block," which lies west of the Musconetcong.

No large cross faults have been discovered in the Raritan quadrangle. An offset in the ridge at Junction suggests a fault, and the lower valley of Spruce Run cuts nearly across Musconetcong Mountain approximately along its probable course, but no direct proof of the existence of a fault at this place can be found.

Minor faulting.—Minor faults occur within the structural blocks defined by the major faulting. They may be classed as longitudinal or as cross faults, their classification according with their trend — whether with or across the structure of the gneisses.

Longitudinal faults are not easily recognized. Some of them in the later beds surrounding the gneisses have been traced to the contact but could not be followed into the pre-Cambrian rocks because of the impossibility of identifying individual layers. Shear zones observed at a few places on the prolongations of the fault lines may possibly indicate that the faults cross the contact into the gneisses, but at a few other places shear zones noted are not prolongations of visible faults in the sedimentary rocks, though they may possibly be the continuation of faults that are not otherwise revealed. The shear zones of both kinds die out within short distances, so that the faulting, if it exists, is not of great magnitude. One such fault may account for the Fox Hill Range, which is sharply separated from the main mass of the Passaic Range by a deep, narrow valley, the rocks along the bottom of which are much sheared and metamorphosed. A few faults that strike nearly parallel to ore beds have been observed in mines, but information concerning them is very indefinite.

Cross faults are more easily recognized. Those which intersect well-banded gneisses that are well exposed at the surface may be readily detected by the visible displacement of the beds. As a rule the downthrow is on the southwest side of the fault, the consequent displacement on the surface being to the right, but displacements in the opposite direction are common. The fault planes ordinarily trend about N. 30° W. and dip at high angles, some of them with hade to the northeast, but about as many with hade to the southwest. There seems to be no uniform relation between the hade and the downthrown side, the faults being as commonly reverse as normal. These faults are important only as they affect ore bodies, for, though the displacement they have caused is in general comparatively slight, yet in places it amounts to several hundred feet—a distance of considerable importance to the miner. One of the largest cross faults passes between Mount Hope and Hickory Hill, north of Dover, where the displacement on the surface is 160 feet, as measured between the ends of five ore veins occurring on opposite sides of the fault trace. Another cross fault is reported to pass along Black River at Hacklebarney and to shift the ore bodies horizontally about 200 feet to the right. Many other smaller cross faults occur in the district, most of them having been disclosed in underground workings of mines.

STRUCTURE OF THE PALEOZOIC ROCKS.

GENERAL FEATURES.

The Paleozoic rocks of the quadrangle have the northeast-southwest structural trend that is characteristic of the Appalachian province and that is due primarily to a system of folds and faults trending northeast and southwest. Although the major structure is simple the details are complex, minor folds, some of them closely compressed and in places overturned, occurring within the larger folds. The small folds are more common in the slate and shale of the Martinsburg than in the massive Kittatinny limestone and are more abundant in the lower layers of the slate, which was formed of finer sediments, than in the upper coarse-grained thick layers of sandstone. In other words, the thinner-bedded less resistant sediments have yielded by crumpling and by the development of cleavage, and the more massive layers have accommodated themselves to the pressure by forming folds of much greater radius.

CLEAVAGE.

Most of the Paleozoic sedimentary beds possess, in different degrees, a definite cleavage, which is best developed in the finest-grained, even-textured members of the Martinsburg shale but is absent from the massive sandstone beds of the same formation and from the heavy conglomerate layers of the Green Pond conglomerate. At best only faint traces of it are found in the thick beds of the Kittatinny limestone, but it occurs also in the more shaly layers, although not to so great a degree as in the Martinsburg shale. The extent to which the coarseness of material has affected the cleavage is clearly shown in the Martinsburg formation, where the sediments range from the finest-grained slate to sandstone and alternate repeatedly. In the coarser beds the cleavage is imperfect, the tendency to fracture being indicated by joints nearly at right angles to the bedding rather than by true slaty cleavage. In the finest, most even-textured beds the cleavage is in flat parallel planes, along which the rock splits with great regularity. Although the coarser layers show little or no signs of cleavage, intervening beds of slate an inch or less in thickness are sharply cleaved. Between the two extremes occur all degrees of cleavability.

The cleavage is almost everywhere inclined to the southeast at angles greater than 20° and averaging about 60°. In a few localities, however, it is inclined to the northwest. No constant relation exists between the angle of dip and the angle of cleavage; the cleavage generally dips to the southeast, whereas the beds dip both northwest and southeast at all angles.

FOLDS.

The folds are rarely symmetrical; as a rule one limb is much steeper than the other. In general the beds that dip southeastward dip less steeply than those that dip northwestward; that is, the southeastern limbs of the synclines and the northwestern limbs of the anticlines have the steeper dips, so that the axial planes are inclined to the southeast, following in this respect the common Appalachian type of folds that are not overturned. In some places, however, the reverse relation is noted, the steeper limb of the syncline being on the northwest. Southeast of the Highlands, in the small areas of Paleozoic rocks between the gneiss and the Newark sedimentary rocks, overturned folds with essentially parallel sides prevail, and the dips are uniformly in one direction. The strata are also affected by cross folds of great length and low amplitude, which manifest themselves in a slight pitch of the axes of the northeast-southwest folds.

FAULTS.

Both thrust (reverse) and normal faults cut the Paleozoic rocks. Along the thrust faults extensive movement took place on nearly horizontal or slightly inclined fracture planes, and the rocks involved were afterward sharply folded. The chief overthrust has been from the southeast (see fig. 10, p. 20), but along some lines of faulting it has been from the northwest. The major movements were accompanied by crushing, minor faulting (fig. 9), and crumpling of the finer beds. These relations

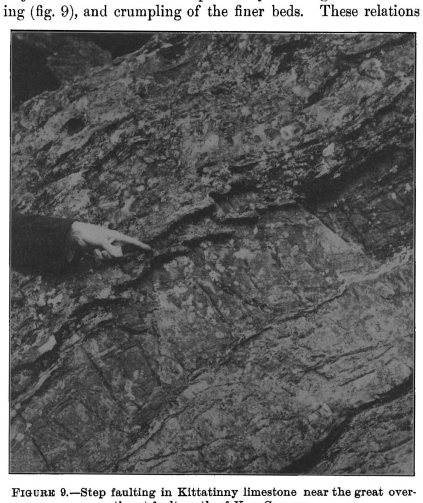


FIGURE 9.—Step faulting in Kittatinny limestone near the great overthrust fault south of Kerr Corners.
The thin hard layer is broken by joint planes at nearly uniform intervals and is offset 2 or 3 inches by small thrust faults.

indicate that the thrust faulting probably accompanied the earlier stages of folding and was a result of the same forces of compression.

The normal faults, almost without exception, show uplift on the northwest and depression on the southeast side. So far as they depart from verticality the large faults seem to hade slightly to the southeast or downthrown side. The dislocation ranges from a few feet to probably several hundred or even a thousand feet or more but can not be accurately determined for the larger faults. Along the northwest side of the Musconetcong Valley the gneiss has been uplifted against the Martinsburg shale, and in the extreme northeast corner of the quadrangle pre-Cambrian gneiss is faulted against Devonian shale. The latter dislocation, however, is not so great as would appear, for neither Cambrian nor Ordovician strata are present. In the region northwest of Jenny Jump Mountain later normal faults intersect and displace the warped thrust fault.

AGE OF FOLDS AND FAULTS.

The folding is probably to be referred to the general movement that affected the Appalachian region at the close of the Paleozoic era. Some faulting seems to have accompanied the folding, resulting in overthrusts along fault planes which are now sharply curved. The great faults, however, which break the region into long narrow blocks, are not so positively connected with these movements but resemble in many respects the normal faults in the Newark group in the southern part of the quadrangle, where the movements occurred in post-Newark time. The prevalence of extensive and profound normal faulting in that region in post-Newark time makes it extremely probable that this adjoining area of Paleozoic and pre-Paleozoic rocks was similarly affected, particularly as one or two of the faults in the Newark beds measure several thousand feet. The facts therefore seem to be best explained on the assumption that two periods of faulting occurred at widely separated times, the first during the folding at the close of the Paleozoic, the second in post-Newark time. The former caused overthrust faults and the latter normal faults.

LOCAL DETAILS.

Kittatinny Valley.—The limestone north of Blairstown lies in an anticline that dips 15°–20° along the northern and 35°–50° along the southern flank. A fault with hade parallel to the dip of the adjoining strata has cut out the Jacksonburg limestone on the southern flank.

The Martinsburg shale belt south of Blairstown lies in a syncline, within which many minor folds can be made out by careful plotting of outcrops. Several areas of Kittatinny limestone have been overthrust on the shale of this belt and, with the thrust plane, have been involved in later folding and faulting, so that the limestone now occupies troughs in the shale. (See fig. 10, p. 20.) The largest of these areas lies north of Hope and has the most complicated structure. The southern end of another area is cut by section C–C of the structure-section sheet.

The limestone belt northeast of Johnsonburg forms an anticline with gentle dips, somewhat complicated by faults and having its axis well exposed in the high bluff just southeast of the village. A reverse fault along its northern flank has thrust the Martinsburg shale upon the Kittatinny limestone and has cut out most of the Jacksonburg limestone. The fault plane, dipping 45°–50° N., is exposed in the railroad cut at Johnsonburg.

Southeast of the Johnsonburg anticline a syncline of Martinsburg shale bears several overthrust and infolded areas of Kittatinny limestone along its axis, shown in figure 10 (p. 20). East of Greensville this syncline is crossed obliquely by a fault with uplift on the east, causing marked offsets and overlaps in the outcrop of the Jacksonburg limestone. Owing to the absence of exposures at critical localities there is some uncertainty as to the exact relations, and the definiteness implied by the map is not wholly warranted. The broad limestone belt east of this syncline and extending northeast from Pequest Meadows shows a low anticline and syncline. (See section B–B, structure-section sheet.)

Jenny Jump Mountain is a great mass of gneiss overthrust from the southeast upon a faulted anticline of Kittatinny limestone. At the northern and southern ends of the mountain the Jacksonburg limestone and Martinsburg shale adjoin the gneiss, but for most of the distance along the southeastern flank of the anticline they have been completely overridden. Northeast of Silver Lake and 2 miles north of Greensville two small masses of gneiss, both outliers of the overthrust gneiss mass, overlie, respectively, the Martinsburg shale and the Kittatinny limestone. (See section B–B.) Northeast of Jenny Jump Mountain the course of the overthrust is difficult to trace, but it is tentatively correlated with the fault which cuts the shale syncline east of Greensville. The masses of limestone which seemingly overlie the Martinsburg shale north of Hope and southwest of Greensville are believed to be portions of the Jenny Jump thrust mass preserved in synclines by the later folding of the thrust plane itself. South of Johnsonburg and east of Glover Pond a narrow area of Martinsburg shale is erroneously represented on the map as Byram gneiss.

Interhighland valleys.—The Pequest Valley northeast of Oxford and Pohatcong Valley north of Washington are apparently normal synclines. In the Musconetcong Valley, the Paleozoic strata form a closely folded syncline with Martinsburg shale in the center. A great fault has cut off part of the western limb of the fold and has brought the gneiss against the Martinsburg shale between Rockport and Port Colden. The northward extension of this fault and fold, with remnants of the Paleozoic strata preserved in its deepest portions, is seen in the valley of Lubber Run. (See sections B–B, C–C, D–D.) Along the eastern side of the Musconetcong Valley the strata are nearly vertical and in places are overturned, so as to dip steeply eastward. The discontinuity of the band of Hardyston quartzite and the generally sheared condition of beds along the contact of Cambrian and pre-Cambrian strata indicate a thrust fault along the eastern side of the valley. The German Valley is a synclinal fold, faulted along its northwest flank. Just north of Califon a quaquaversal anticline of gneiss surrounded by Hardyston quartzite projects into the valley and is separated from the main mass on the east by a fault.

Green Pond Mountain, the southern termination of which lies in the northeastern part of the area, is a westward-dipping monocline of Silurian conglomerate overlying the gneiss (as shown along the gorge southwest of Green Pond) and underlying Devonian shale, which outcrops in the Longwood Valley along its western flank. A small but sharp syncline occurs in the high bluff just west of Middle Forge Pond. On the east the mountain is separated by a normal fault from Copperas Mountain, which is a syncline of conglomerate resting upon gneiss. (See section A-A.) Farther south, near Berkshire Valley, the strata of Green Pond Mountain are overturned and dip steeply southeast, but in the isolated ridges southwest of Rockaway River the structure is synclinal.

Southeast of the Highlands.—The structure of the Paleozoic areas southeast of the Highlands is exceedingly complex. Faults are numerous and the rocks, particularly the shales, are closely crumpled. The railroad cuts east of Jutland show recumbent folds and many faults—eighteen of the latter at all angles from horizontal to vertical were found within 100 yards. In the limestone belt north of Clinton steep westward dips prevail, but the width of outcrop indicates a series of close overturned folds rather than a simple monocline.

South of Annandale closely compressed and nearly vertical folds of Kittatinny limestone are separated by faults from the Martinsburg shale on the west and from the gneiss on the north, sheared hornblendic gneiss above crushed dolomitic limestone being exposed in the stream bank east of Annandale. East of Allerton[a] the structure is complicated and the lack in many places of any but disintegrated material renders impossible anything but general conclusions. At Sharp's quarry near Prescott Brook a mass of pegmatite has been overthrust on the limestone, both rocks being much broken near the fault plane. At Pottersville the Kittatinny limestone, except along the river, is covered by alluvium and its boundaries are unknown. At Peapack and Gladstone east-west faults offset the quartzite-gneiss contact and in many of the quarries the rock shows evidence of displacement. North of Gladstone the Jacksonburg limestone is cut out by faulting, the Martinsburg shale and Kittatinny limestone being in juxtaposition with diverse structures. As all these faults apparently pass beneath the Triassic sediments and do not offset those beds, so far as determinable, they are believed to antedate the post-Newark disturbance.

STRUCTURE OF THE TRIASSIC ROCKS.

GENERAL FEATURES.

The Newark rocks in New Jersey exhibit an extensive monoclinal structure and low northwestward dips, modified by local flexures, especially in the Passaic Valley west of the Watchung Mountains and farther south, near the western margin of the Newark area. The monocline is also traversed by faults with throws of several thousand feet and by many minor dislocations. The diabase intrusions have caused local disturbances of the strata, partly by flexure and partly by dislocation, especially where the igneous rock increases in thickness or changes from one horizon to another.

The Stockton and Lockatong beds are most constant in dip and strike, and the monoclinal structure is most marked in the areas they occupy. The Brunswick shale has been thrown into shallow folds, some of them covering several square miles.

In the Raritan quadrangle the Triassic strata lie in a number of broad low flexures, and the northwest-dipping monoclinal structure characteristic of the Newark beds is less marked than it is in some other areas. The curved outline of the Watchung mountains forms the southwestern border of a broad, shallow, basin-like fold, and the neighboring strata strike and dip in conformity with the trend of the basalt sheets. Another broad, low synclinal flexure, prominently marked by the curved outcrop of the New Germantown sheet of basalt, with which the inclosing shale beds are conformable, occupies the area between New Germantown, Lamington, White House, and Pottersville. Between the New Germantown sheet and the Watchung Mountain sheets the structure is anticlinal.

For several miles northwest of Neshanic the beds dip 10°–20° N. 15°–30° W. Toward South Branch the dip veers to north and east of north, and toward Flemington to west and south of west and becomes somewhat steeper. In Round Valley the shale does not conform to the diabase of Cushetunk Mountain but dips 20°–35° N. 15°–20° W. West of White House and along the northern flank of Cushetunk Mountain the shale beds dip 40° N. or NNE. and do not strike parallel to the strike of the diabase. Meager exposures indicate the existence of a low anticline between Cushetunk and Round mountains and of a syncline in the shale around Round Mountain. Between Lansdowne and Pittstown the dip is 12°–15° S. 60°–65° W., but it becomes more westerly toward Cherryville and Klinesville and is N. 30°–40° W. at Croton.

[a]On the map two areas of limestone, the larger along Prescott Brook, and the smaller south of Allerton, are wrongly represented by the Byram gneiss pattern and color.

FAULTS.

The Newark rocks in the Raritan quadrangle are traversed by a great fault which has a throw of several thousand feet and by numerous minor dislocations. Great faults also mark the contact of the Newark with the older rocks along much of the northwest boundary of the quadrangle. These faults are not connected with flexures and are later than the igneous intrusions and flows. In general they strike northeast and southwest, their courses being more or less oblique to the strike of the strata. In all except a few of the minor faults the downthrow is on the southeast side. The larger faults are probably almost vertical. In general the dislocations appear to lie along

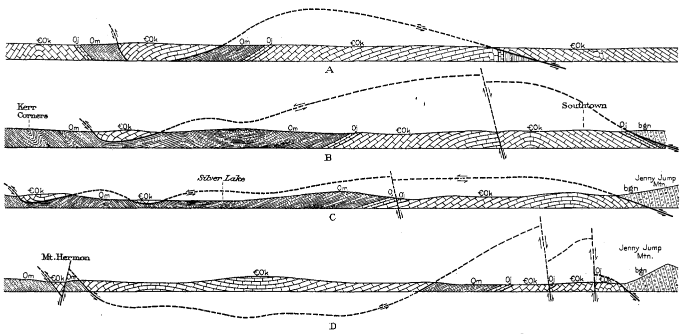


FIGURE 10.—Northwest-southeast structure sections across the great overthrust fault in the northwestern part of the Raritan quadrangle.

A, Along Sussex-Warren county line, northwest of Tranquility.
B, Through Kerr Corners and Southtown.
C, Through Silver Lake to Jenny Jump Mountain.
D, From Mount Hermon to Jenny Jump Mountain.
bgn, Pre-Cambrian Byram gneiss; €Ok, Kittatinny limestone; Oj, Jacksonburg limestone; Om, Martinsburg shale.
Scale, 1 inch = approximately 2¼ miles.

single planes, but in some places narrow zones of shattered rock may be noted. In other places the strata are crumpled along the fault.

The greatest dislocation enters the quadrangle at its southern margin and passes northward just west of Flemington. It reaches the gneiss near Cushetunk Mountain, and its northward continuation is uncertain. It may pass into the crystalline rocks or, with a much more irregular course, it may form the northwest boundary of the Newark area from Lebanon northeastward. North of Flemington it brings the sandstones of the Stockton formation into contact with strata high in the Brunswick shale, both formations, much crushed, being exposed at the intersection of the roads 2 miles north of Flemington. Along Prescott Brook, just southeast of the limestone quarries, red shale outcrops, dipping westward toward the Kittatinny limestone, from which it is separated by a fault, which is perhaps the continuation of the Flemington fault.

Portions of the northwestern boundary of the Triassic area are marked by faults. One is exposed in the railroad cut just east of Jutland station, where the fault plane dips steeply westward and slickensided surfaces indicate a horizontal north-south movement. From Cushetunk Mountain northeast to Mendham the border is slightly irregular and is probably marked by a great dislocation, perhaps the continuation of the Flemington fault. Between the horns of Cushetunk Mountain shale of the Newark group either dips directly toward the older rocks or strikes at right angles to the contact. The sharp synclinal fold which is indicated by the curved outline of the New Germantown sheet of basalt terminates against the pre-Cambrian rocks as if faulted off.

From a point a little southeast of Peapack to the New York State line, nearly 40 miles away, the border is remarkably straight and is undoubtedly determined by a large fault. The strongest evidence in favor of this conclusion is the way in which the western part of the Watchung syncline is cut off, because the shale along Mine Brook, near Bernardsville, lies at the same horizon as that between First and Second Watchung mountains, back of Plainfield. West of Liberty Corner, Second Watchung Mountain recurves northeastward, decreasing in height and width as the fault line cuts it obliquely. At Bernardsville an outcrop of trap close to the gneiss is crushed into what is practically a friction breccia. In areas northeast of Bernardsville beds of shale strike at right angles to the contact with the gneiss, and in other localities they dip directly toward the gneiss.

Small faults have been noted at a number of places in railroad cuts, road sections, and stream banks, the most important being in the Lehigh Valley Railroad cuts west of Flagtown station, in the bluff at the head of the Raritan Water Power Co.'s raceway west of Raritan, in the railroad cut west of Raritan, in Bartle's sandstone quarry at Martinsville, along the road a short half-mile west of Bedminster, along the same road a few rods east of Greater Crossroads, and in the Philadelphia & Reading Railway cut a mile east of Bound Brook. At most of these places the fault planes are nearly vertical, but in the quarry at Martinsville they are almost horizontal.

GEOLOGIC HISTORY.

PRE-CAMBRIAN TIME.

The earliest event recorded in the rocks of the Raritan quadrangle was the deposition of the sediments now forming the Franklin limestone and the associated strata and perhaps of others represented by part of the Pochuck gneiss. As some of the rocks are composed of fragmental material the existence at that time of land from which this material was derived may be safely inferred, but nothing is known of the position of the land nor of the extent of the sea in which the deposits were formed. After the strata were deposited the region was uplifted and the rocks were compressed, folded, and considerably metamorphosed. They were then extensively invaded by igneous masses. Possibly the intrusions occurred before the close of the period of deformation. At any rate the form and position of the intrusive masses was largely controlled by the folded structure of the stratified rocks, and as a rule they were intruded in more or less parallel sheets. The intrusions took place at great depths, and the igneous masses were evidently solidified under considerable pressure and consequently acquired a gneissic structure during crystallization. After the deformation of the strata and the intrusion of the magma that formed gneisses the complex was subjected to long erosion and the surface was so greatly reduced that portions of the igneous masses that had cooled at great depths were exposed. Possibly the surface was reduced to a peneplain, but more probably it still retained many irregularities, as the overlying Cambrian sediments are far from uniform in thickness and lithologic character.

PALEOZOIC ERA.

EARLY PALEOZOIC TIME.

At the beginning of the Paleozoic era the region was submerged in a narrow sea that extended from Alabama northeastward into Canada. Although this sea did not long retain any one definite form or place, the position of its southeastern shore throughout a large part of the era is closely represented by the present western margin of the Piedmont Plateau. East and south of this shore lay a land of unknown extent, called Appalachia. The position of the northern and western shores of the sea varied through wide limits and at times the sea covered nearly the whole of the Appalachian province and the upper Mississippi basin.

The earliest deposit formed in the Paleozoic sea in New Jersey was the sand and gravel now constituting the Hardyston quartzite. The manifold differences in the lithologic character of the formation and its great variation in thickness within narrow geographic limits indicate a wide range of sedimentary conditions, such as would prevail close to a shore presenting somewhat contrasted topographic features. During Lower Cambrian time, while sedimentation was in progress, the sea encroached southeastward upon the land, and the shore ultimately lay far southeast of the present Highlands, as is shown by outcrops of the quartzite at Trenton, N. J., and in the Harlem quadrangle, in New York. That the land was low and that the migration of the shore line was relatively rapid may be inferred from the thinness of the quartzite and from its somewhat abrupt passage into interbedded shale and limestone.

The thick Kittatinny limestone, which overlies the Hardyston quartzite, represents a long period of time, during which, so far as can be ascertained, there was in northern New Jersey no break in sedimentation. While the calcareous mud that now forms the limestone was being accumulated, comparatively little land-derived material was deposited in the area, but inasmuch as wave marks occur at several horizons the sea must have been rather shallow and probably the adjoining land was low and the shore even farther distant than during Hardyston deposition. The thin shales and scattered layers of sandstone interbedded with the limestone, however, show an influx of land-derived sediment at recurrent intervals. That the sea withdrew for a time at the beginning or during the early part of the Kittatinny epoch is possible, and such withdrawal would account for the possible absence from the Kittatinny limestone of beds known to be of Middle Cambrian age.

So far as has been determined from the record of the rocks in northern New Jersey the conditions remained approximately the same and sedimentation was apparently continuous from Cambrian into Ordovician time. Some geologists, however, believe that the sea withdrew for a short time at the close of Cambrian time and then returned, to cover only a small part of the region, during a period in which the beds containing Beekmantown fossils were deposited. At any rate the sea withdrew at the end of Beekmantown deposition and the region was land for a time sufficiently long to permit the upper part of the recently deposited calcareous mud to be removed from some areas by erosion and to allow the formation elsewhere to be consolidated into limestone. This interval is shown by the absence of the upper portion of the Kittatinny from part of the region, by the unconformity between it and the Jacksonburg limestone, and by the limestone conglomerate in places at the base of the latter formation.

With the return of the sea in Jacksonburg time and the resumption of the deposition of calcareous mud, low islands and reefs at first existed, around which the conglomerate was deposited, generally without marked structural unconformity, but the faunal change at that horizon indicates that the break in the record was long enough to permit the incursion of a new and abundant fauna of different facies from the preceding one. This period of erosion appears to have been much shorter in the Kittatinny Valley than in the Green Pond Mountain region, where the Jacksonburg limestone is not found, the Kittatinny limestone has only a fraction of the thickness that it has elsewhere, and there are only doubtful occurrences of the Martinsburg shale. Apparently in that region the interval of erosion was so long that most of the Kittatinny limestone was removed and the Jacksonburg limestone and the larger part of the Martinsburg shale were not deposited.

The changes which closed the deposition of the calcareous mud and brought about that of the material now forming the Martinsburg shale were gradual and gentle but widespread, since from Vermont to Alabama limestone is succeeded conformably by shale. A recession of the shore line far to the southeast, a probable shoaling of the water, and an uplift of the adjoining land brought about the deposition of siliceous silt and sand in place of calcareous sediment. The change in sedimentation seems to have begun earlier in this region than in the typical Trenton area in New York.

MIDDLE AND LATE PALEOZOIC TIME.

At the close of Ordovician time extensive crustal movements in New England and Canada affected the New Jersey region also and raised it above sea level for a long period, as is shown by the lack of deposits between the Martinsburg shale and the Shawangunk conglomerate, the formation next overlying the shale a few miles northwest of the quadrangle. In central New York and elsewhere this interval is represented by Upper Ordovician and earlier Silurian strata. During this time or a large part of it northern New Jersey was land undergoing erosion. If it was invaded by the sea, the deposits formed then were so thin and the subsequent erosion so great that all traces of them were removed.

The Green Pond Mountain region may have been land continuously from the close of the Kittatinny limestone deposition, although there is some evidence that, for a short time at least, shale supposed to be Martinsburg was deposited. If the Green Pond and Shawangunk conglomerates are equivalent, as seems almost certain, erosion continued well into the Silurian period, probably until Salina time. These conglomerates were formed either as great deltas on the shores or in an estuary of a Salina sea that gradually advanced southeastward, or, as suggested by some geologists, as an alluvial fan or series of fans on the lowland adjoining the sea. In either case the material was derived from land southeast of the area of deposition.

Still later in Silurian time, the water in the region being deeper, the red sand and mud of the Longwood shale succeeded the sand and gravel of the Green Pond conglomerate. The Decker limestone, Kanouse sandstone, and Cornwall shale indicate a brief period of still deeper water and comparative freedom from land-derived sediment, followed by recurrent periods of silts and sands as the sea grew shallower and the adjoining land was again raised. This change culminated in the accumulation of the thick beds of sand and coarse gravel, which formed the sandstone and conglomerate that overlie the Cornwall shale in Bearfort Mountain, northeast of the Raritan quadrangle, and that are the youngest Paleozoic sediments in New Jersey.

In the upper Delaware Valley, northwest of the Raritan quadrangle, a somewhat similar but more complicated series of limestones and shales, overlain by grits and conglomerates, indicates similar physical conditions. Although none of the higher Silurian and Devonian beds now remain in the region between Kittatinny Mountain and the Green Pond Mountain belt, such beds, together with some that lay still higher, may once have covered it and have been eroded away in post-Paleozoic time.

The later Paleozoic history of the region can not be read from the record of the strata. The region seems to have become land late in Devonian time and never to have been submerged since. In closely adjoining portions of Pennsylvania a great thickness of conglomerate, sandstone, and shale, with beds of coal, was accumulated in the interior sea in Carboniferous time. In the northern anthracite coal field, the nearest part of which is but 45 miles northwest of the Raritan quadrangle, the Carboniferous strata now remaining are 3200 feet thick. The character of the strata, particularly those containing coal beds, shows that that part of the Carboniferous period was a time of oscillation of sea and land and of wide advance and retreat of the shore line, when shallow seas were succeeded by low-lying, poorly drained lands with widespread peat bogs, some remote from the sea and some along the shores, and these again were succeeded by marine estuaries. With the great oscillations of shore line that occurred during the period marine waters may have invaded for a time the adjacent parts of New Jersey, but if so all traces of sediments that would indicate such encroachment have been eroded away.

POST-CARBONIFEROUS DEFORMATION.

During all of Paleozoic time the region of the interior sea, particularly the eastern part of it, had been on the whole a region of subsidence, in which many thousand feet of sediment had been accumulated. After the deposition of the Pennsylvanian strata subsidence was followed by uplift which raised the surface of the entire region above sea level. This uplift was the result of compression of the earth's crust, probably exerted from the east and southeast, by which the Paleozoic strata in this and adjoining regions, as well as the pre-Cambrian floor upon which they rested, were bent into great mountain-making folds. Along lines of structural weakness the strata were closely folded and were fractured and overthrust on great fault planes, which were themselves in some places involved in the later movements and sharply folded. Cleavage was developed in the finer-grained rocks. The disturbances were greatest at the southeast, for the Paleozoic rocks are more distorted in their small areas southeast of the Highlands than in the Kittatinny Valley. Farther northwest the compression was much less; in northern Pennsylvania the strata were merely uplifted and more or less wrinkled.

MESOZOIC ERA.

TRIASSIC PERIOD.

PRE-NEWARK EROSION.

The recorded history of the quadrangle during the early part of the Triassic period is almost a blank, but it is known in outline from the study of neighboring areas. During and after the great deformation near the close of the Paleozoic era, and probably throughout the greater part of the Triassic period, the whole region must have been land and the surface must have been greatly reduced by prolonged erosion, as the Newark strata overlap the beveled edges of the folded and faulted Paleozoic and older rocks. Presumably the region was worn down approximately to a peneplain. The evidence of such planation is meager in New Jersey, but in Connecticut and in the southwestward extension of the New Jersey Triassic belt the surface upon which the Newark strata were deposited appears to have been one of moderate relief, as has been pointed out by Davis.[a]

If northern New Jersey was land during Carboniferous time, as is probable, the streams draining the region probably flowed westward into the dwindling remnant of the interior Paleozoic sea. It seems likely that they continued to flow in that direction during the early part of the Triassic period, although the detailed drainage pattern of that time must have been highly complicated as the result of the great deformation through which the region had just passed. So far as known, no traces of that early drainage pattern nor any remnants of the surface on which the streams flowed now remain, except such as may be preserved in the rock surface beneath the Triassic beds.

NEWARK SEDIMENTATION.

Later in the Triassic period long, narrow basins or low plains were formed in the regions now occupied by Newark sediments from Nova Scotia to North Carolina. They are thought to have been formed by local warping or faulting of the worn-down upland accompanied by slow uplift of the adjoining regions—in New Jersey the areas on both the northwest and the southeast. In the depressed areas fluviatile, lacustrine, and perhaps estuarine beds were deposited at different places and times. Many short and vigorous streams brought down rock waste from the uplands and deposited it in coalescing alluvial fans on the bordering lowland and along the flood plains of meandering rivers, some of which probably lost themselves in the sand, as do many rivers on alluvial fans in semiarid regions to-day. In places finer sediments were laid down in temporary shallow lakes or brackish-water estuaries. The strata at all horizons show ripple marks, raindrop impressions, footprints of reptiles, and other evidences of alluvial and shallow-water deposits. In some areas, especially in Virginia and North Carolina, vegetal deposits, now represented by coal beds, were formed in extensive marshes. Here and there along the northwest border of the basin coarse gravel composed of quartzite and limestone accumulated where swift streams came down from the adjoining highlands. Occasional downward movements, due to warping or faulting, gave opportunity for great local thickening of deposits along the belts affected, whereas, in adjoining regions not so depressed, sediments of the same period may never have attained great thickness.

Reptiles, some of gigantic size, wandered along the shores of shallow lakes and across the soft mud flats of broad, many-branched streams, leaving numerous footprints as the record of their existence. The complete or partial drying up of the shallow lakes caused great mortality among their finny inhabitants and entombed in the mud at certain horizons great numbers of fish which, however, belonged to comparatively few species.

[a] Davis, W. M., The Triassic formation of Connecticut: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 20–26, 1898.

During the later part of the epoch in the New Jersey region three, perhaps four, successive outbursts of volcanic activity resulted in the effusion of thick and extensive lava sheets upon the sediments. After each eruption sedimentation proceeded as before and buried the lava flows more or less deeply. A part of the lava that failed to reach the surface was forced between the strata as an extensive sheet having a somewhat irregular outline. The strata were also cut by thin vertical dikes, many of which are offshoots of the intrusive sheet. The flows and the intrusive sheet are restricted to the areas of Newark strata, but a few small dikes of similar rock which cut the adjoining gneisses probably belong to this period of igneous activity.

The deformation that formed the basin in which the Newark sediments were deposited also caused great changes in the drainage of the region. While the basin was being formed the land on the northwest was uplifted and the old erosion surface so warped as to give a considerable part of it a southeastward slope, on which a new drainage system was established. Short and vigorous streams, flowing southeastward and debouching upon the lowland, rapidly cut headward into the new upland and are believed to have pushed back the divide between themselves and the northwestward-flowing drainage approximately to the position of the present Allegheny Front. The material brought down by these streams probably formed the greater part of the Newark sediments.

JURASSIC AND CRETACEOUS PERIODS.

POST-NEWARK DEFORMATION.

The Newark deposition was brought to a close by renewed uplift and the newly formed strata were thrown into low flexures. Fractures having a general northeast-southwest trend were formed and were developed into normal faults by the northwestward tilting of the blocks or slices of rock between them, some of the displacements thus caused amounting to several thousand feet. The faulting and tilting was not restricted to the area now occupied by the Newark group but extended also to the adjoining region on the northwest, where the folds and overthrust faults in the pre-Triassic rocks are cut by normal faults of probably post-Triassic age.

The effect of the movements was to develop asymmetric ridges having steep, eastward-facing scarps along the faults and broad, gentle western slopes on the backs of the tilted blocks. Five or six such ridges crossed the Raritan quadrangle, four of them corresponding in trend and approximately in position to the ranges of the Highlands. Another, possibly two others, traversed the Kittatinny Valley. Most of the Triassic area within the quadrangle appears to have been only gently if at all tilted and may be divided into two blocks, separated by an eastward-facing scarp west of Flemington.

The fault-block ranges of the upland area northwest of the Triassic basin were probably not fairly straight flat-topped ridges but rather rough and notched, as that area must have been dissected by the streams of the Newark epoch. The result of the post-Newark deformation of such a dissected upland must have been to throw the drainage system established in Newark time into great confusion, and the new drainage pattern developed must have been largely original, and the streams consequent. Probably no traces of it have been preserved.

FORMATION OF SCHOOLEY PENEPLAIN.

For a long time after the uplift and deformation that closed the Newark sedimentation the region was undergoing erosion, which continued into late Cretaceous time. The streams draining it flowed southeastward into the Atlantic and deposited along the coast the waste they carried away. The post-Triassic uplift had been considerable, and throughout the Jurassic period the land remained fairly high and the coast was some distance to the southeast. In fact, no Jurassic sediments are known along the Atlantic coast, and whatever beds were deposited during that period must have been completely overlapped by later strata, of Cretaceous and Tertiary age.

Early in the Cretaceous period the part of the region nearest the coast had been reduced to a flat plain, which stood practically at base-level. A slight subsidence allowed the sea to encroach upon this plain for some distance and diminished the velocity of the streams, which began to deposit alluvial material in their valleys and on the seaward margin of the plain, constituting the Raritan formation. Renewed uplift caused the streams to cut away the inner margin of the recently deposited beds, no traces of which now remain in the Raritan quadrangle, although when deposited they probably covered its southeast corner.

These later movements left no decipherable record in the topography of inland New Jersey, where erosion continued uninterruptedly to the close of the Cretaceous period, before which time the surface of the entire region had been reduced by stream erosion to a peneplain having rather slight relief and probably a gentle southeastward slope. The even crest of Kittatinny Mountain, the broad, flat-topped summits of the Highlands, the even crest of Green Pond Mountain, the crests of the higher trap ridges, and the general surface of the

Hunterdon plateau are believed to be remnants of this peneplain. It has been called the Cretaceous peneplain, from the name of the geologic period in which it was completed, and the Kittatinny peneplain, from Kittatinny Mountain, but it is more generally known as the Schooley peneplain, from Schooley Mountain, on whose broad, flat top it is well preserved. It appears to have been widely developed in the northern Appalachian region, and dissected plateaus believed to be remnants of it are found in southern New England and throughout extensive areas in the Middle Atlantic States.

LATE CRETACEOUS DEPOSITION.

In the later part of the Cretaceous period much of the region had been reduced so nearly to base-level that a subsidence allowed the Atlantic to encroach a long way upon the seaward margin of the plain. Erosion continued in the unsubmerged part of the region, and parts of the peneplain were reduced still further, the material carried away by the streams being spread out upon the sea floor along the submerged belt in beds of clay, sand, and marl. No such Upper Cretaceous sediments remain in the Raritan quadrangle, but their distribution in adjacent areas indicates that they must have once covered much of its southeastern part. Reasoning from certain peculiarities of the streams Davis[a] has concluded that their courses are in part superposed from a cover of strata now removed and that at one time Upper Cretaceous beds probably extended across the Triassic area and overlapped a little upon the Highlands. This conclusion seems to be supported by the composition of the Cretaceous strata, which contain almost no material derived from the Triassic rocks but are made up of sand, clay, and other material that was clearly derived from the rocks of pre-Triassic age.

CENOZOIC ERA.

TERTIARY PERIOD.

EARLY TERTIARY EROSION.

At the close of the Cretaceous period the region was uplifted several hundred feet. The Schooley peneplain became a plateau, along whose southeastern border a broad belt of the recently deposited Cretaceous strata emerged from the sea and formed a coastal plain. The uplift was accompanied by doming or warping of the peneplain, the inland portion being elevated more than the coastal margin, so that the seaward slope of the surface was somewhat increased. Parts of the new coastal plain were uplifted more than others, and in southern New Jersey a small area was warped down at the same time, allowing the deposition of Eocene sediments.

The erosion cycle during which the Schooley peneplain was formed had lasted so long and the surface had been reduced so nearly to base-level that the principal streams had become thoroughly adjusted to structure and rock hardness. Paulins Kill, Pohatcong Creek, Pequest and Musconetcong rivers, and the part of the South Branch of the Raritan between Flanders and High Bridge probably flowed in nearly the same courses as at present, along shallow limestone valleys separated by low divides. By the uplift that closed the cycle these adjusted streams were rejuvenated, and they began to deepen their valleys in the newly elevated plateau without essentially shifting their courses. The southeast margin of the plateau was drained by streams that flowed to and across the new coastal plain. Some geologists who have studied the region hold that all the drainage of the North Branch of the Raritan and that of the South Branch below Round Mountain was once carried southward and southwestward to the Delaware through Millstone River, which then flowed southward instead of northward.

As the reduction of the surface proceeded, the thin inner margin of the Cretaceous strata was stripped away, uncovering the older rocks, across which the streams of that part of the area then flowed in superposed courses independent of the structure. This erosion cycle lasted long enough to permit the removal of all the Cretaceous beds from the Raritan quadrangle and the formation of an extensive lowland plain on the Triassic rocks. The crests of the two Watchung mountains and of Cushetunk Mountain and the higher part of the Hunterdon plateau remain as evidence of the former continuity of the Schooley peneplain over the region. Most of the superposed streams that formerly flowed across the ridges had been diverted through capture by other streams that were working headward on the softer rocks. The beheaded remnants of the streams that had drained the area within the curve of the Watchung Mountains remained as short streams draining the inner slope of the crest of Second Watchung Mountain. One stream, however, the North Branch of the Raritan, remained in its superposed course across the southwest end of Mine Mountain, where it intrenched itself in a deep gorge in the old rocks.

During this cycle the rejuvenated streams of the plateau intrenched themselves several hundred feet in their limestone valleys, which they broadened to the full width of the belts of Paleozoic rock. The Kittatinny, Pequest, Musconetcong, German, and Longwood valleys were formed at this time and were eroded practically to their present breadth and nearly to their present depth. Thus a new peneplain was developed on the Paleozoic and Triassic rocks. Rather imperfect remnants of this peneplain are still preserved in the tops of the Martinsburg shale ridges of the Kittatinny and Musconetcong valleys. No definite traces of it remain in the area of Triassic rocks, though possibly it is marked by the tops of the higher hills of Triassic strata about Potterstown and New Germantown and west of Gladstone.

[a]Davis, W. M., and Wood, J. W., The geographic development of northern New Jersey: Boston Soc. Nat. Hist. Proc., vol. 24, pp. 399 et seq., 1889.

MIOCENE SUBMERGENCE.

In the Miocene epoch the region was depressed, at least along its seaward margin, and the sea transgressed for some distance across the Cretaceous and Triassic strata, over which a new formation was laid down. The amount of subsidence and the extent of the area—if any—in the Raritan quadrangle that was covered by Miocene strata is uncertain, as subsequent erosion has removed all traces of sediments of that age from the quadrangle. Some geologists believe that the subsidence of the region and the transgression of the sea was as great as or greater than that in late Cretaceous time and that Miocene strata once covered the present Triassic area and overlapped upon the Highlands, but the evidence is not conclusive.

The Miocene subsidence apparently left no record in the topography of the Raritan quadrangle, the evidence of it being found in the central and southern parts of the State.

LATE TERTIARY EROSION.

At the close of the Miocene epoch a moderate uplift of the region ended the early Tertiary erosion cycle and caused another to begin. The sea withdrew approximately to the position of the present coast line, again uncovering the Coastal Plain, the surface of at least a part of which was then formed by Miocene strata. The rejuvenated streams again began to lower the surface. In the Kittatinny and Musconetcong valleys they further intrenched themselves along the limestone belts, wearing down the surface 100 to 200 feet below the tops of the shale ridges. In the Triassic area in the quadrangle all Miocene sediments, if indeed any had been deposited, were removed, and the general surface was so much lowered as to leave no certain remnants of the early Tertiary peneplain. A new peneplain, called the Somerville peneplain because of its preservation on the divides near Somerville, was developed on the less resistant rocks. It is represented in the quadrangle by the flat divides of the region between Somerville on the southeast, Flemington on the southwest, and Bedminster on the north, by the low plain in the extreme southeast corner of the quadrangle, and by the general surface of the limestone belts in Kittatinny Valley and the interhighland valleys.

QUATERNARY PERIOD.

PLEISTOCENE EPOCH.

PENSAUKEN DEPOSITION.

After the Somerville peneplain was formed its lower portion was covered with thin deposits of sand and gravel, probably largely fluviatile but perhaps in part estuarine. The meager remnants of these deposits are correlated with the Pensauken formation, although possibly some of them may be part of the older Bridgeton formation. In southern New Jersey the pre-Pensauken erosion cycle was interrupted by the deposition of the Bridgeton formation, which was followed by erosion. No traces of this interruption have been noted in the Raritan quadrangle. Patches of the gravel remain on divides and isolated hills and, together with the pebbles that are scattered widely over the Triassic lowland, afford evidence of the considerable erosion that the region has suffered since early Quaternary time.

Just what changed the streams from degrading to aggrading agents is not clear. Possibly the widespread aggradation was merely the last stage of the normal erosion cycle, when the streams, having reduced the land to base-level, were meandering widely on broad flood plains. The coarseness of the sediment, however, seems opposed to this explanation. More probably a slight warping of the surface drowned the lower courses of the streams and caused the deposition therein of sand and gravel, which eventually spread in a practically continuous thin blanket over the seaward margin of the peneplain. The reversal of the Millstone and the diversion of the Raritan drainage to New York Bay probably occurred in the erosion cycle which followed this deposition.

GLACIATION.

GENERAL CONDITIONS.

After the deposition of all or a part of the Pensauken deposits the region was invaded from the north by an ice sheet. This sheet, which was part of the great continental glacier that overspread much of northeastern North America (see fig. 11), was of slow growth. It probably began with the accumulation of snow east and west of Hudson Bay. With increasing rigor of climate, the cause of which is not known, the snow became deeper and more widespread. Pressure converted all except the surface part of it into ice, changing the snow fields into great ice fields thinly covered with snow. In time the ice attained sufficient thickness to move under its own weight, and the ice sheet became a continental glacier.

A great mass of evidence shows that the ice sheet did not develop once for all and then melt from the face of the land. On the contrary, one ice sheet formed and then melted partly or wholly, to be succeeded by another, which in turn was wholly or partly dissipated before the return of glacial conditions caused the advance of a third. In the United States the pronounced advances of the ice number at least four and

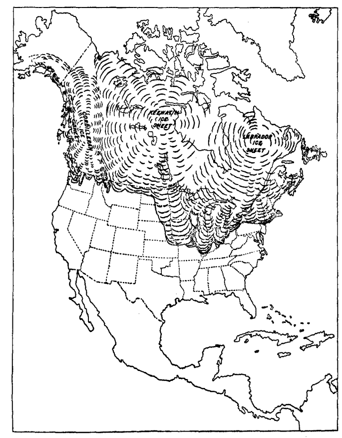


FIGURE 11.—Map of North America showing the area covered by the Pleistocene ice sheet at its maximum extension and the three main centers of ice accumulation.

possibly five, though the ice did not reach the same limit during every advance and probably did not retreat to the same position during the interglacial stages. Northern New Jersey was covered by ice at least twice, at widely separated times. The earlier of the two sheets, known as the Jerseyan, was probably contemporaneous with one of the earlier sheets in the West, but with which one is not positively known. It was followed, after an interglacial epoch, by the Wisconsin ice sheet.

JERSEYAN GLACIATION.

At the time of its greatest extent the margin of the Jerseyan ice was near a line connecting Pittstown, Hamden, Allerton, Drea Hook, Readington, Raritan, and First Watchung Mountain north of Somerville. Cushetunk Mountain seems to have been a barrier, causing a reentrant angle in the ice front, on either side of which ice lobes advanced several miles farther south. Apparently First and Second Watchung mountains were also barriers against which the ice rested.

The ice over the Highlands was probably thin and deposited its drift in a more or less discontinuous sheet, but it covered practically all the area north of its margin, its extent being indicated by the occurrence of numerous erratic bowlders and many patches of drift thick and broad enough to conceal the underlying rock. It was naturally much thicker and deposited thicker and more continuous drift in the interhighland valleys and on the Triassic lowland. In places it overrode and buried beds of the Pensauken formation, but for the most part it did not reach the parts of the Somerville peneplain covered by those beds. That the southern limit of the Jerseyan drift is ill defined, marked chiefly by scattered bowlders, is due not only to the great erosion that has taken place since its deposition but also to the fact that the glacier formed no massive terminal moraine, a fact indicating that the edge of the ice began to melt back soon after the advance had ceased.

INTERGLACIAL EPOCH.

The Jerseyan glaciation was succeeded by an interglacial epoch, during or perhaps before which the region was slightly uplifted and tilted southeastward, the uplift somewhat increasing the gradient of the streams, so that their fall was greater than it was during the closing stages of the cycle in which the Somerville plain was formed. However, as the region is only 20 to 30 miles from the sea and lies at a low altitude, even these increased gradients must have been comparatively low, and erosion could not have been rapid, despite the fact that the rock is shale and is easily cut. Nevertheless, the larger streams now flow across the Triassic lowland in broad valleys with gentle side slopes, at a level more than 200 feet below the lowest summits on which portions of the Pensauken formation and of Jerseyan drift remain. Furthermore, the area of surface now below the level of the Somerville plain is several times as great as that of the surface remaining at that level. Not all of the Somerville plain was completely dissected in interglacial time, but most of it was, and the conclusion seems inevitable that the time which elapsed between the deposition of the

Jerseyan drift and the deposition of the Wisconsin drift was much longer than that which has elapsed since the withdrawal of the Wisconsin ice sheet.

In the region northwest of the Triassic lowland the events of the interglacial epoch are not so clearly marked. In the Musconetcong and German valleys, however, the streams notably lowered their channels in rock after the deposition of the Jerseyan drift and before that of the Wisconsin drift.

After or perhaps during the latest stages of the erosion that dissected the sheet of Jerseyan drift, the main streams crossing the Triassic lowland, notably the North and South branches of the Raritan, aggraded their valleys somewhat, the average thickness of the filling being probably less than 20 feet, though in places it was nearly 40 feet. The material deposited was derived partly from the Jerseyan drift.

WISCONSIN GLACIATION.

Invasion by the ice.—The Wisconsin ice sheet advanced to a position now marked by a terminal moraine, which runs east and west across the quadrangle from Pequest to Rockaway. In a few places and for short times the ice passed a mile or so beyond the moraine, but that its southern margin was nearly stationary at this line for a long time is proved by the existence and character of the moraine. In its advance the ice seems to have buried or carried away all the older drift, for nowhere north of the terminal moraine has Jerseyan drift been recognized beneath Wisconsin drift. During the invasion the ice removed the mantle of disintegrated rock from wide areas and somewhat eroded the firm rock beneath. That the average amount of erosion, however, was not great, probably not more than 25 feet, appears from comparison of the general topography of the areas north and south of the moraine. Along certain lines, particularly in the valleys, however, the erosion was probably considerably greater.

In the part of the quadrangle east of Green Pond Mountain the Wisconsin ice moved S. 30°–48° W., or nearly parallel to the rock structure. West of Green Pond Mountain it moved more nearly south or even a little east of south. As the Kittatinny Valley trends S. 40° W., the ice moved obliquely from its southeast side onto the Highlands. The direction of movement, somewhat generalized, is shown in figure 12.

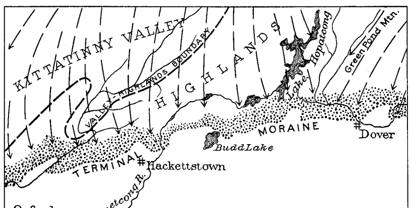


FIGURE 12.—Sketch map of the northern part of the Raritan quadrangle showing the position of the terminal moraine and the direction of the ice movement.

Glacial lakes.—A small glacial lake temporarily occupied the upper Black River valley in front of the ice but seems to have been entirely filled by the outwash that now forms Succasunna Plains. A much larger lake covered for a longer time the Great Meadows north of Danville, having been formed behind the moraine after the ice had withdrawn from it a short distance, but this lake was finally drained by the cutting down of its outlet across the moraine above Townsbury. At its highest stage it stood about 550 feet above the present sea level.

The largest glacial lake in New Jersey and the one whose history has been most carefully worked out was Lake Passaic, which occupied the upper Passaic Valley between the Highlands on the northwest and Second Watchung Mountain on the south and east. The greater part of the lake lay in the Passaic quadrangle, and as its history is given fully in the Passaic folio[a] it will be given only in outline here.

The drainage of the Lake Passaic basin now escapes in a roundabout way through the gaps at Little Falls and Paterson, but in preglacial and perhaps also in interglacial time the gaps in First and Second Watchung mountains at Milburn and Short Hills, now filled with drift, were deep enough to drain the southern half of the basin and were occupied by the master stream of that area. If all the filling is of Wisconsin age, as seems probable, Lake Passaic did not come into existence until the ice advanced to the line of the moraine between Short Hills and Morristown and closed the Short Hills gap. The water of the lake then rose until it overflowed the lowest point of the rim, at Moggy Hollow, 2 miles east of Bedminster, crossing Second Watchung Mountain through a pass the bottom of which is 331 feet above sea level. At its highest stage the lake level was not more than 25 feet above the outlet through which the water escaped to the North Branch of the Raritan. Meanwhile the former outlet of the basin at Short Hills had been closed by drift, and even when it was uncovered by the melting ice the Moggy Hollow pass took all the outflow, and the lake, maintaining essentially the same level, increased in area by occupying that part of the basin from which the ice withdrew. During this stage the obscure shore features already described were formed. (See p. 18.)

When the ice had retreated far enough to lay bare the outlet at Little Falls the basin north of the moraine was drained to the level of the new outlet—about 185 feet above sea level—and Lake Passaic ceased to exist. Before the lake was finally drained it seems to have stood at a stage when its level was 65 to 75 feet below the maximum and then to have risen again approximately to its former height. These changes of level were probably connected with oscillations in the position of the edge of the ice, which alternately opened and closed an outlet somewhere, possibly in Great Notch or possibly beneath the ice along the course of the present Passaic.

Shallow lakes in the southern part of the basin survived for a time the opening of the Little Falls outlet. A long, narrow lake, which found its outlet across the moraine west of Summit, lay between Long Hill and Second Watchung Mountain, at an altitude of 239 feet. Another lake persisted for a time in the area of Great Swamp north of Long Hill, as is indicated by the probable fact that some part if not all of the narrow gorge of the Passaic at Millington is postglacial.

Withdrawal of the ice sheet.—Some of the events connected with the withdrawal of the ice sheet have just been mentioned in connection with Lake Passaic. Others are more general. A comparatively thin sheet of till was left over the country north of the terminal moraine. Glacial drainage was concentrated in the valleys, some of which were much obstructed by stagnant and semidetached masses of ice, around which and between which and the valley sides kames and kame terraces were formed. Where the drainage was unimpeded valley trains were built up. Shallow lakes and swamps were formed in the undrained hollows in the drift and along the moraine-dammed valleys. Herds of mastodons wandered about the region presumably at this time, for their remains are found in late Pleistocene and post-Pleistocene beds, as at Mastodon Pond, in the terminal moraine northwest of Hackettstown.

RECENT EPOCH.

Since the withdrawal of the Wisconsin ice sheet no extensive changes have occurred in the region. Pequest River has cut a gorge 40 to 45 feet deep across the terminal moraine at Townsbury and the Musconetcong has trenched it to a less extent north of Hackettstown. The Raritan above the confluence of the Millstone has developed a flood plain, one-half to three-fourths mile wide, at a level about 25 feet below that of the glacial gravel. Many ravines and small valleys have been developed in the drift, and a few small lakes, including the successors of Lake Passaic, have disappeared in consequence of the lowering of their outlets or the filling in of their bottoms. The dissection of the Somerville peneplain has been continued and the valleys have been slightly deepened. The Wisconsin drift has been leached to a depth of 2 or 3 feet and in places to 5 or 6 feet. Exposed surfaces of the more resistant rocks that were smoothed and polished by the ice have been so roughened by weathering that although many of them retain their "sheep's-back" outlines, most of them have lost all traces of striæ. Exposed limestone ledges have almost uniformly lost not only their striæ but also their glaciated outlines and are generally as angular, rough, and honeycombed by weathering as are the ledges south of the terminal moraine. The occurrence of recent deformation and change of altitude is definitely proved by the northward rise of the old shore lines of Lake Passaic, which, although necessarily level when formed, now rise 67 feet in 30 miles, thus showing uplift of the land greater than can be ascribed to any deformation of the surface of the lake by the attraction of the ice.

Alluvial deposits, mostly narrow, have been formed along the larger streams. In marshy places—such as the Great Meadows, the upper Black River valley, and the basin of Lake Passaic—and in former small ponds vegetable matter has accumulated and deposits of peat have been formed.

ECONOMIC GEOLOGY.

MINERAL RESOURCES EXPLOITED.

The principal mineral resources of the Raritan quadrangle are iron ore, building stone, crushed rock, and limerock. Resources of less value are clay, sand, gravel, peat, and roofing slate. Copper and graphite have been mined, and small deposits of talc, asbestos, and mica have been explored. Most of the iron ore mined is magnetite but a little of it is limonite. Magnetite has always been and still is by far the most valuable mineral product of the quadrangle.

The soils of the quadrangle are a source of considerable wealth, though they are not naturally so fertile as soils that are underlain by some other sorts of rock. The water resources of the quadrangle are valuable for both water supplies and for the development of power.

IRON.

MAGNETITE.

DISTRIBUTION.

Magnetite has been observed at a great number of places in the Raritan quadrangle and has been mined at many of them, as shown on the economic-geology map. Ore has been shipped at different times from more than a hundred mines and groups of mines in that part of the Highlands. During recent years, however, only nine mines have been operated—the Oxford group, near Oxford furnace; the Hude mine, 1½ miles northwest of Stanhope; the Dickerson mine, 4½ miles southwest of Dover; the High Ledge mine, at Ledgewood; the Huff mine, three-fourths of a mile north of Wharton; the Hurd and Orchard mines, at Wharton; the Richard mine, 1¼ miles northeast of Wharton; and the Mount Hope mine, at Mount Hope. The following mines were once important producers, but none of them except the Baker mine, from which a little ore was raised in 1906, has been active during the last decade: The Kishpaugh mine, 2½ miles northwest of Danville; the Hurdtown mine, at Hurd; the Weldon mines, at Weldon; the High Bridge mine, at High Bridge; the Hacklebarney mine, at Hacklebarney; the Swedes mine, 1 mile east-northeast of Dover; the Byram mine, 3 miles southwest of Dover; the Stirling mine, south of Wharton; the Mount Pleasant and Baker mines, 1 mile north of Wharton; and the Alden and Teabo mines, 3 miles northeast of Wharton. Several openings near Mine Hill, west of Dover, and others at Chester yielded a fairly large output. Among those near Dover were the Millen, the Baker, the Bryant, and the Brotherton. The most important mines near Chester were the Hedges, the Cooper, and the Squier. All the mines near Mine Hill and Chester have been closed for a number of years, although several of them still contain reserves of ore.

A great number of smaller mines, scattered throughout the quadrangle, were operated for short periods at different times, the most promising being those near Mount Olive, where many openings have been made along a line of strong magnetic attraction. Some were operated vigorously for a short time and yielded a fairly large quantity of lean ore. The positions of all the openings are shown on the economic-geology map.

Some of the mines in the quadrangle were operated before the Revolutionary War, and most of them, as well as many small unnamed openings, were worked to supply local forges before the introduction of furnaces using anthracite and coke made it necessary to procure a large and steady supply of ore of practically uniform quality. All the mines now operated are worked in connection with furnaces and their operators are consequently assured of a steady demand for all the ore they can raise.

At the time of maximum production of New Jersey iron ore (1880–1882) several of the most active mining centers in the State were in the Raritan quadrangle. In the narrow strip of country between Hacklebarney and Mount Hope, a distance of 14 miles, there was a series of almost contiguous mine openings. The deposits were found in several rather narrow belts or ranges, separated by belts, generally wider, of practically barren rock, the whole series of belts constituting a mineralized zone ranging in width from 1000 feet to several miles.

CHARACTER AND COMPOSITION.

The ore of all the mines except the few in the Franklin limestone is of practically the same character, though differing in purity from place to place. It consists of an intimate mixture of magnetite, hornblende, pyroxene, quartz, feldspar, biotite, apatite, titanite, and pyrite and pyrrhotite, in various proportions. Hornblende, pyroxene, and apatite are, aside from magnetite, the most persistent components, and quartz is common. Apatite occurs in small green, gray, or brown granules, at some places abundantly, at others only in traces. Pyrite and pyrrhotite occur almost universally in the ore, but in much of it only sparingly. They are the principal ore constituents in several mines, however—in the Silver mine, near Cranberry Reservoir, for instance, where they constitute about 73 per cent of the ore. Some of the sulphide occurs in veinlets that were formed after the magnetite. Calcite also is in places of late introduction, forming thin layers along fractures. Manganese has been found in nearly all the samples in which it has been sought but occurs only in very small quantity in the ores mined in the gneisses.

A few of the ores are rich in titanium, which occurs in titanite and probably also replaces some of the iron in the magnetite, particularly at the Van Syckle and the Naughright mines, the ore of the former containing from 9.82 to 15.05 per cent and that of the latter from 6.4 to 7.5 per cent of titanium oxide. Indeed, the mines on the range in which these two are situated are notable for the large proportion of titanium in their ores.

The ore of the mines in the Franklin limestone differs in several particulars from that in the gneiss. It is commonly high in manganese and low in phosphorus and contains little or no titanium. Very naturally it contains abundant calcite,

[a] U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), and New Jersey Geol. Survey folio No. 1, p. 19, 1908.

much of which is highly manganiferous. It includes also garnet and pyroxene and in some places the sulphides of copper, lead, and zinc. The sulphides and the garnet are particularly abundant where the limestone has been intruded by masses of black dioritic rock, as at the Glendon mine, northwest of Cranberry Reservoir, where the ore is a mixture of magnetite, garnet, and calcite. Great masses of dioritic rock are so intimately mixed with the ore and limestone that it is hard to distinguish the boundaries between the different rocks. In the adjacent quadrangle on the west the ores in the limestone are mixtures of magnetite and limonite containing nodules of pyrolusite, but in the Raritan quadrangle no such ores are known. The ores in the limestone, like those in the gneisses, consist of crystalline aggregates of magnetite and small amounts of other minerals.

The chemical character of the ores is shown in the following analyses of material actually shipped and smelted:

Commercial analyses of iron ore from mines in the Raritan quadrangle.

	Mine.	Iron.	Phosphorus.	Sulphur.	Manganese.	Titanium.
1	Howell farm	53.05	.37	1.24	1.39	
2	Do	50.72	.19	.18	2.02	
3	Stinson	49.79	.02	.00	2.74	
4	Do	60.66	.006	Trace.	.40	
5	Hurdtown (at Hurd)	66.02	.196	.169	Trace.	.08
6	Hurd (at Wharton)	61.39	.952	.046	.03	.42
7	Kishpaugh	54.25	.128	.05	.39	Present.
8	Fox Hills	57.50	.04	.59	.00	Trace.
9	Hann	56.97	.37	.09	.00	.64
10	Elizabeth	60.96	.426	.008	.03	.63
11	Leonard	60.00	.92	.03	.03	.63
12	Richard, north vein	65.80	.196	.011	.04	.78
13	Richard, south vein	60.18	.672	.008	.015	.60
14	Van Syckle	50.39	Trace.	1.21	.00	7.08
15	Canfield's phosphate	39.10	6.51	.03		

1, 2. In limestone; New Jersey Geol. Survey Ann. Rept. for 1878, p. 101.
3. In limestone; New Jersey Geol. Survey Ann. Rept. for 1879, p. 85.
4. In limestone; ore contains garnet. Idem.
5. In gneiss; shipment, 1880. Tenth Census Rept., vol. 15, p. 157, 1886.
6. In gneiss; average sample, 1908. Analyst, R. B. Gage.
7. In gneiss; average shipments. New Jersey Geol. Survey Ann. Rept. for 1873, p. 88.
8. In gneiss; New Jersey Geol. Survey Ann. Rept. for 1879, p. 46.
9. Idem, p. 76.
10, 11, 12, 13. In gneiss; average sample, 1908. Analyst, R. B. Gage.
14. In gneiss; New Jersey Geol. Survey Ann Rept. for 1873, p. 55.
15. In gneiss; New Jersey Geol. Survey Ann. Rept. for 1871, p. 35.

Complete analyses of the ores of several of the mines in the quadrangle, all in gneiss, are given below. The Hurdtown mine is no longer active.

Chemical composition of ore shipped from mines in the Raritan quadrangle.

	1	2	3	4	5	6	7
SiO_2	4.06	26.83	3.77	8.48	8.46	7.62	6.87
Al_2O_3	1.78	2.71	.79	.86	.77	.49	1.59
Fe_2O_3	61.18	34.26	61.16	55.99	56.18	55.24	57.46
FeO	29.78	18.98	29.56	26.98	27.81	26.12	27.23
MgO	.43	5.82	.64	1.89	1.88	1.89	1.01
CaO	1.29	5.87	1.23	2.42	1.68	4.34	2.98
Na_2O	.09	1.21		.33	.22	.27	.12
K_2O	.03	.69		.19	.36	.20	.18
H_2O-	.05	.66	.16	.15	.28	.21	.21
H_2O+	.24	1.02					
TiO_2	.14	1.24	1.30	1.01	1.06	1.05	.70
CO_2	.26	.95					
P_2O_5	.89	.07	.45	1.54	.98	2.44	2.18
S			.01	.01	.008	.02	.05
FeS_2 (pyrite)	.14						
Cr_2O_3			.00	.00	.00	.00	.00
MnO	Trace.	.14	.06	.02	.04	.04	.03
NiO			.00	.00	.00	.00	.00
CaO			.00	.00	.00	.00	.00
BaO			.00	.00	.00	.00	.00
SrO			.00	.00	.00	.00	.00
V_2O_3			.095	.08	.11	.08	.08
C (in carbonaceous matter)	.03						
	99.79	100.45	99.225	99.95	99.838	100.01	100.14

1. Sample from shipment from Hurdtown mine (at Hurd). Tenth Census Rept., vol. 15, p. 157, 1886.
2. Single sample, lean ore, Richard mine. Analyst, W. T. Schaller.
3. Average sample, Mount Pleasant vein, Richard mine, 1908. Analyst, R. B. Gage.
4. Average sample, south vein, Richard mine, 1908. Analyst, R. B. Gage.
5. Average sample, Elizabeth mine, Mount Hope group, 1908. Analyst, R. B. Gage.
6. Average sample, Leonard mine, Mount Hope group, 1908. Analyst, R. B. Gage.
7. Average sample, shipping ore, 1908, Hurd mine (at Wharton). Analyst, R. B. Gage.

These analyses correspond to mixtures of minerals in approximately the following proportions:

Approximate mineral composition of ore as shipped from mines in the Raritan quadrangle.

[The numbers at the heads of the columns indicate the samples denoted by the same numbers in the table above.]

	1	2	4	5	6	7
Quartz	.16	2.19	2.16	1.26	1.38	2.46
Feldspars	2.87	14.05	3.73	4.32	3.21	2.16
Amphibole and pyroxene	5.75	26.98	6.47	7.88	7.18	4.74
Magnetite	88.65	49.43	81.43	81.44	80.08	83.52
Ilmenite	.80	2.27	1.98	2.13	2.18	1.37
Apatite	1.00	1.67	3.70	2.35	5.71	5.04
Calcite	.63	2.19				
Pyrite	.14		.02	.01	.04	.09
Water	.29	1.67	.15	.28	.21	.21
V_2O_3			.08	.11	.08	.08
	99.79	100.45	99.72	99.78	100.02	99.67

As it comes from the mine the ore generally contains more feldspar, quartz, and pyroxene or hornblende than is shown by any of the analyses except No. 2. Before it is shipped it is either hand-cobbed or concentrated by magnetic separators.

RELATIONS.

The magnetite bodies are not confined to any particular sort of rocks but occur indifferently in the several varieties of gneiss and in the Franklin limestone. The relations of the ore bodies in the gneisses to the inclosing rocks are similar to those of the various sorts of gneiss to one another. Thus the ore-bearing gneisses and the segregations within them strike and dip conformably with the country rocks, the ore shoots pitch with the gneissic structure, and the layers wedge out or dovetail like other members of the gneissic complex. The prevailing strike is northeasterly, and the dip is commonly to the southeast. In the Raritan quadrangle the only departures from this rule are in the vicinity of Oxford furnace, where the Washington and McKinley veins strike northwest and dip southwest, and at the Kishpaugh mine.

The ore rocks in many places may be regarded simply as phases of the gneiss that are particularly rich in magnetite, and these ferriferous phases are interleaved in different proportions with other gneisses of different types. In certain localities really enormous bodies of rock carry 15 to 25 per cent of iron in the form of magnetite, more or less regularly distributed; in other places the magnetite is segregated in a few parallel layers, either closely or widely spaced; in still others it occurs in single veins, and these contain the largest individual masses of ore. Wherever the magnetite is densely segregated the ore is commonly accompanied by "vein rock," distinct in appearance and in places different in composition from the country rock of the locality. The vein rock is generally rich in hornblende and resembles common phases of the Pochuck gneiss, but much of it is pegmatite that is mineralogically very like the Byram gneiss. In lean portions of the vein, whether the material is hornblendic gneiss or pegmatite, the magnetite may be rather uniformly disseminated or it may occur in thin layers that conform with the attitude of the vein as a whole, this attitude being in turn conformable with the foliation of the country gneisses. The ore bodies are in places divided by intercalated tabular masses of hornblendic rock, pegmatite, or country gneiss, and some such "horses" hold their positions for long distances.

The relations of the ores to the matrix are much the same in limestone as in gneiss. In places where the ores are adjacent to intrusions of hornblendic rock silicate minerals of metamorphic derivation are intermingled with the magnetite, but as a rule calcite is the most abundant mineral. At many localities the calcite contains a noteworthy amount of manganese, the combination forming manganocalcite, which takes on a brown coating when exposed to the weather.

ORE SHOOTS.

Shape and position.—In general the minable bodies of magnetite ore are not coextensive with the veins but occur as characteristically pod-shaped shoots. Some veins carry several shoots, disposed edgewise one above another and separated by comparatively barren rock. Figure 13 illustrates diagrammatically rather than accurately the manner in which the ore shoots commonly occur. The rock between any two shoots in the same layer or vein is called a pinch, and the rock that thus cuts out the ore is called cap rock if it occurs along the crest, or bottom rock if it occurs along the keel of a shoot. The pinches, though poor in ore, are not entirely barren. In some veins the walls close in, reducing the width of the ore bodies to a few feet or even a few inches. More commonly, however, the space between the shoots is occupied by rock, which in some places is a pegmatite full of magnetite, in others is country rock (gneiss) traversed by a few or many very narrow stringers of magnetite, connecting the shoots with one another, and in still others is a mass of coarse hornblende crystals cut by tiny veinlets of ore running parallel with the general direction of the gneiss. As a rule ore bodies are abruptly terminated only by faulting. In several of the more important mines extensions of ore shoots that were supposed to have been exhausted have been eventually found by following magnetite stringers through the pinches.

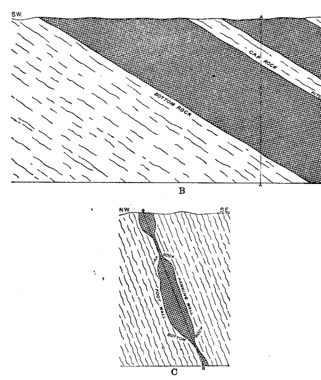


FIGURE 13.—Diagrammatic plan and sections of ore shoots characteristic of the magnetite deposits of the Highlands.

A, Plan showing the pod-shaped lenses parallel to the strike of the inclosing gneiss.
B, Longitudinal section in the plane of the dip of the ore shoot along the line B-B in the plan.
C, Vertical cross section along line A-A in the plan.

The planes of successive ore shoots in any vein are generally almost parallel, and they invariably conform to the attitude of the neighboring gneisses, which ordinarily pitch 15°–50° to the northeast or east (fig. 13) and only rarely to the southwest. Exceptionally, as at the Kishpaugh mine, on the east slope of Jenny Jump Mountain, the ore shoots pitch southwestward. The features described are typically exhibited in several mines near Wharton and Mount Hope.

Most ore layers are essentially tabular, their principal irregularities being the swells and pinches described. Some, however, as shown by gently curved outcrops and variations in the angle of dip, are slightly warped and some seem to turn back upon themselves as if sharply folded. In other places the rock slab may project into the ore body from beneath or from above, separating it into two parts which may have the appearance of the limbs of a fold.

Not uncommonly two or more parallel veins lie so close together that they may be worked from a single shaft, as in several of the mines near Wharton, at Mount Hope, and at Weldon (fig. 17, p. 26). Intercalated layers of rock are common and in places they persist for considerable distances, thus dividing the ore bodies into several parallel portions. Ordinarily horses of rock wedge out and give place to ore in all directions, but some of them cause the vein to fork upward, downward, or sidewise.

Dimensions.—The magnetite veins or layers range in thickness from a fraction of an inch to 80 feet, but most of those that have been mined measure from 4 to 15 feet. Only a few veins, such as those at the Hurdtown mine, appear to be definitely limited on the dip. Along the strike individual ore layers show great differences in persistence, but the thicker veins generally hold their own for longer distances than the thinner. The Hibernia vein, in the adjoining Passaic quadrangle, has been developed for a mile along its course, and if, as seems entirely possible, it is represented by the ore opened in mines farther southwest, in the Raritan quadrangle, its entire length is $2\frac{1}{2}$ miles. In the Wharton-Mount Hope range some of the veins can be fairly well identified for 2 miles or more in spite of several cross faults which break their actual continuity. On the other hand some valuable ore bodies occur in veins that can be definitely traced only 300 to 400 feet along the strike.

Most shoots of massive ore narrow rather abruptly toward the bottom and the top. As a rule their total length along the pitch is not accurately determinable from their workings, which end where the thickness of the ore falls below 4 feet. Most of them, however, persist downward for considerable distances. Several individual shoots extend downward for 1000 to 2000 feet, and that at the southwest end of the Hurdtown mine was mined for about 6000 feet from the outcrop to a point where extraction became no longer profitable—that is, to a vertical depth of 2600 feet.

The breadth of the shoots, measured in the plane of the layer at right angles to the longest dimension, the axis of the pitch, is variable, but in many of them the distance from pinch to pinch is not far from 100 feet. The interval between shoots is commonly not greater than their breadth. Their minable length may be from 30 to 60 times their width, though the limit expressed by these ratios is by no means invariable.

FAULTING.

Where the magnetite ore bodies terminate abruptly the presence of a fault can be inferred, for normally the edges of the veins or shoots pass gradually into the country rock. Several faults that affect the ore bodies have been recognized, one of the strongest being a cross fault along the brook between Hickory Hill and the mines of the Mount Hope group, where the veins are displaced 160 feet horizontally and about 450 feet vertically. A fault along Black River at the Hacklebarney mine has a horizontal displacement of about 200 feet, and another, between the Sterling and Corwin mines, one of approximately 80 feet. Many cross faults have a horizontal displacement of 20 feet or less. The cross faults normally trend northwestward, generally almost at right angles to the strike of the veins. The dip of the cross faults ranges from northeast to southwest, at angles between 70° and 90°. The horizontal displacement of most of the veins is toward the southeast, or to the right as one faces northeast; that is, the portion of the vein northeast of the break is thrown out southeastward into the hanging wall. Displacements to the right as defined above occur where the downthrow is on the southwest side of the fault, and displacements to the left where the downthrow is on the northeast side of the fault. Displacements to the right have been noted in the Mount Hope, Mount Pleasant, Randall Hill and Hacklebarney mines, and displacements to the left in the Byram and Mount Pleasant mines.

A few faults strike nearly parallel with the ore beds and dip northwestward at various angles. Such faults follow the rule that the footwall is the downthrown block. Examples occur in the Mount Pleasant mine.

ORIGIN OF THE MAGNETITE ORES.

The character of the magnetite deposits, which are associated with rocks of so many different kinds, indicates that all of them originated in much the same manner. All the ore is regarded as of magmatic origin. The iron is thought to have been contributed by a magma or molten mass contained in the deep-seated reservoir which furnished the material that formed also the granitoid gneisses and the pegmatites that constitute so large a part of the pre-Cambrian rocks of the Highlands. After these rocks had partly cooled they were invaded by masses of magma rich in iron, some of which were afterward enriched by iron-bearing solutions or vapors rising from the same subterranean source. Some of the ore layers may be merely injected bodies of the magma that had been segregated or "differentiated" from the parent magma at a great depth.

The magnetite that is disseminated through the gneisses has plainly been separated from the magma that yielded the rock and was one of its earliest components to crystallize. The magnetite that occurs as bunches in the gneiss appears to have been segregated from the magma. Between such masses and stringers or sheets of ore there are many gradations. The distribution of the iron mineral in layers in the magnetite-bearing gneisses resembles the distribution of hornblende in the less ferriferous phases of the gneiss. In both sorts of rock there may have been intrusions, at different times, of portions of the fundamental magma which had by some process become distinct in chemical composition, or some of the magnetite may have been deposited by hot solutions which penetrated the rocks before they were completely crystallized.

Magnetite occurs in coarse pegmatite as well-formed crystals embedded in the feldspar and hornblende and as large ill-formed grains and angular masses between the silicate minerals. Thus it occurs in two generations. Part of it crystallized before any of the other constituents, and the remainder and larger part after the other minerals had been formed. The pegmatites are regarded as of aqueo-igneous origin and as having been derived from the same magma that had previously furnished the granitoid gneisses of the region. The later magnetite was probably introduced by solutions that penetrated the pegmatite masses before they had completely consolidated.

The ore bodies in the gneisses probably originated in a manner analogous to those in the pegmatites. The hornblende and magnetite in such layers are in some places intercrystallized as if of contemporary formation; in other places magnetite fills spaces between the crystals of hornblende. This later magnetite corresponds to the second generation of the same mineral in the pegmatite masses.

The ores in the crystalline limestone were probably similarly introduced, both as true injections and in solutions that emanated from the deep magma. At the Roseville and Glendon mines, where the ore masses are accompanied by basic igneous intrusions, many metamorphic silicate minerals have been developed in both the ore and the limestone, but in the Pequest group of deposits, including the Queen and Ahles ore bodies, silicates are essentially lacking, though the ore contains scattered crystals of quartz and of feldspar.

FUTURE DEVELOPMENT.

The occurrence of bodies of magnetite appears to be independent of the variety of the rock and no structural features or conditions peculiar to the ore ranges have been discovered. The most careful geologic work has furnished no means of determining favorable or unfavorable conditions for the occurrence of ore in any undeveloped tract of land or for the occurrence of large ore bodies in any established ore range. But despite this lack of basis for specific prediction the statement is warranted that systematic exploration by deep drilling in any of the ore ranges will disclose the fact that their general features persist to any attainable depth. Individual veins may die out but others will appear lower down and it may even be contended that if the country were planed down 1000, 1500, or 2000 feet the aggregate amount of ore outcropping at each level would be the same as that found at the present surface.

PROMINENT MINES.[a]

Mines on Jenny Jump Mountain.—The only important mine on Jenny Jump Mountain is the Kishpaugh, but a large number of pits have been dug in search of ore, especially along the belt of Franklin limestone on the east slope of the ridge and along a series of small lenticular patches of limestone entirely surrounded by gneiss on the east side of the crest of the ridge. Several of these explorations have yielded small quantities of ore. All the ore contained a noteworthy amount of manganese and most of it was low in phosphorus.

The Howell Farm mine comprised a number of separate openings in the limestone at the northeast end of the mountain, where the limestone is in comparatively thin layers interbanded with gneiss. Openings were made in both gneiss and limestone, but only those in limestone were thought to be promising. In the northernmost, which was on a line of strong magnetic attraction, the ore body was 10 feet thick, this measurement including some layers of limestone, and dipped 70° SE. About 300 yards to the southwest several openings were made in a vein 8 feet thick, which dipped 60° SE. and carried ore containing calcite and graphite.

The Kishpaugh and Cook Farm mines were on the east slope of Jenny Jump Mountain, 2 miles northeast of Danville and about one-fourth mile east of the belt of mines in the Franklin limestone. The Kishpaugh mine was opened in 1871 and was worked almost without interruption until its destruction by fire in 1900. During its comparatively short life it was one of the most productive mines in the State, yielding in all 125,000 tons of ore. Near the surface the vein was 50 feet thick, but it narrowed downward to 8 feet. The ore occurred in shoots dipping 35° SE. and pitching southwest. Toward the northeast the ore body decreased in thickness to a single foot, but beyond the pinch lay another shoot, 90 feet high and 18 feet thick, with a 12-inch layer of exceptionally rich ore next the footwall. This shoot dipped 28° SE. and pitched 15° SW., but with increasing depth the dip became steeper. Explorations made farther southwest showed that the vein extended in that direction also, its total developed length being 2000 feet. At the southwest end of the vein the Cook Farm shaft, sunk through coarse gabbro-like rock, cut the ore body at a depth of 350 feet, where it was 25 feet thick, dipped 38° SE. and pitched southwest. Test borings showed that it had about the same dimensions as in the old mine to the northeast but that it was of poorer quality.

The ore first mined was mixed with considerable mica and hornblende, but it contained 52 per cent of iron and so little phosphorus that it came within the Bessemer limit. A notable feature of the deposit was the depth to which the ore was disintegrated, for even at a depth of 100 feet it was so soft that it needed only an occasional blast to break it up.

Oxford group of mines.—The Oxford group is situated along several veins just south of Oxford furnace. The openings have been known by different names at different times. They may be divided into a western subgroup, including the Washington mine and its predecessors (the old Harrison and Clark mines), and the Oxford group proper, of which the McKinley, Carwheel, old Staley, Lanning, New, and Welch mines were the most productive.

Mining was begun about 170 years ago, the first mines having been opened to supply ore for the Oxford furnace, which began running in 1743, and except for short periods the group has been continuously productive ever since. In 1840 Rogers called attention to the immense quantity of ore contained in at least two veins, which he supposed to be divided in places into several nearly parallel branches. In 1868 Cook reported seven veins, trending north of west and diverging slightly. His map shows three veins crossing the road from Oxford to Washington and another close to the highway on the west, all being curved. The mines of the Oxford group proper and a number of less important workings were opened on these veins. Not all the shafts were operated simultaneously, but the closing of old mines and the opening of new ones was merely a migration of shafts along the same veins. The ore of these veins was of good quality and was comparatively low in sulphur.

The McKinley, Carwheel, and New mines (Oxford group proper) were close together on a hill half a mile south of the Oxford furnace. The west end of the Carwheel mine was worked during the later part of the eighteenth century by open pits. In the early part of the nineteenth century the Carwheel shaft was sunk and later the New mine shaft. These mines were the principal sources of ore for the Oxford furnace during the middle of the last century. In 1881 they were abandoned and the ore was raised through the Welch shaft and through slope No. 3. In 1902 slope No. 3 was replaced by the McKinley mine, a slope which was opened about 125 feet farther south and operated till 1905 but which has remained idle since.

The shafts are situated along two parallel curved ore shoots, that of the Carwheel mine, on the southwest, and that of the New mine, a few feet away. The ore bodies, once supposed to be connected, dip northeast and pitch steeply southeast. In their most thoroughly developed portion they strike northwest, but at their northwest ends they are said to veer to the north and finally to assume the northeasterly trend characteristic of magnetite veins in the Highlands. At their south ends, in the bottom of the McKinley mine, they are reported to dip 56° E. and to strike north, but the walls are irregular and the ore is much mixed with rock. The ore from the vein in the Carwheel mine was purplish and that from the vein in the New mine was gray-black. In mining no distinction was made between the ore taken from the two veins, and ore was mined from both in all the shafts.

It is impossible to estimate closely the amount of ore taken from these veins, but some idea of its volume may be gained from the facts that when abandoned the New mine shaft was 250 feet deep and its workings were about 750 feet long and that the McKinley shaft, on the Carwheel vein, was about 500 feet deep and its workings were about as long as those of the New mine.

In the Welch mine shaft the two ore bodies were called the Welch and the Slope veins. The deposits were separated from those worked by the Carwheel and New mine shafts by a mass of pegmatite and perhaps by a fault, but the appearance of the ore indicates that the Slope vein is the extension of the Carwheel vein and the Welch vein that of the New mine vein.

About half a mile west of the Oxford group proper is the Harrison, a double vein, high in sulphur, now worked through the Washington mine. A sixth vein lies a third of a mile northwest of the Washington mine, and a seventh (the Franklin) crosses the road running from Oxford furnace to Oxford Church about 1500 feet northwest of the furnace. The sixth and the Franklin veins have never been explored sufficiently to test their value. The outcrop of the Franklin vein is curved and concave toward the northwest, whereas the other vein, which is also curved, is concave toward the southeast. The two may be parts of the same vein folded into an S-shaped curve.

The Washington mine is on the westernmost productive vein at Oxford furnace. The vein consists of two parallel seams of ore separated by 12 feet of rock. As developed with the aid of a magnetic survey, it is over 4000 feet long and incloses an ore body which strikes N. 25° W. and dips 45° SW. and whose thickness is uniformly about 11 feet, no distinct pinches having been found in it.

The ore is high in sulphur and must therefore be roasted before it can be smelted. Part of the roasted ore is smelted in the Oxford furnace and part is shipped elsewhere. The mine has recently been operated continuously and has yielded about 100,000 tons annually.

Hude or Stanhope mine.—The Hude mine is on the south side of a ridge or hill a mile north of Stanhope. It is one of the oldest mines in the quadrangle, having been worked for more than 100 years. At first the ore was raised from small open pits, but afterward it was taken out through drifts near the base of the hill. One of these drifts entering from the southeast, named the Pardee mine in figure 14, is the present mine opening.

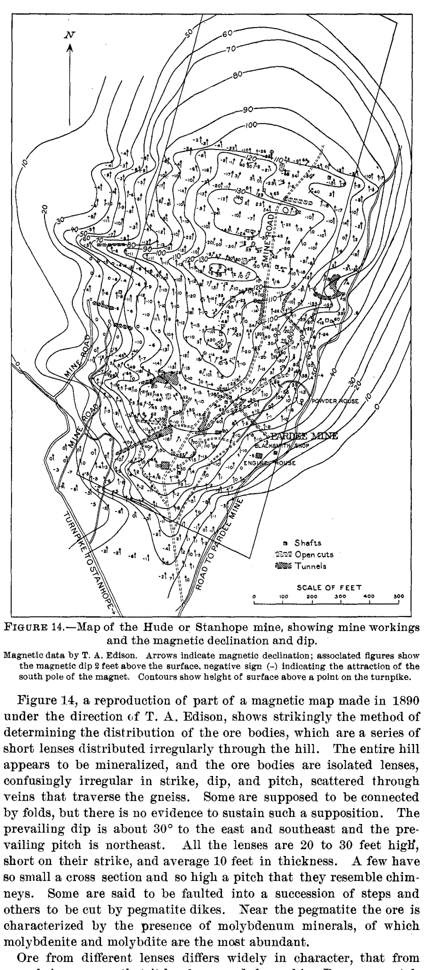


FIGURE 14.—Map of the Hude or Stanhope mine, showing mine workings and the magnetic declination and dip.

Magnetic data by T. A. Edison. Arrows indicate magnetic declination; associated figures show the magnetic dip 2 feet above the surface, negative sign (-) indicating the attraction of the south pole of the magnet. Contours show height of surface above a point on the turnpike.

Figure 14, a reproduction of part of a magnetic map made in 1890 under the direction of T. A. Edison, shows strikingly the method of determining the distribution of the ore bodies, which are a series of short lenses distributed irregularly through the hill. The entire hill appears to be mineralized, and the ore bodies are isolated lenses, confusingly irregular in strike, dip, and pitch, scattered through veins that traverse the gneiss. Some are supposed to be connected by folds, but there is no evidence to sustain such a supposition. The prevailing dip is about 30° to the east and southeast and the prevailing pitch is northeast. All the lenses are 20 to 30 feet high, short on their strike, and average 10 feet in thickness. A few have so small a cross section and so high a pitch that they resemble chimneys. Some are said to be faulted into a succession of steps and others to be cut by pegmatite dikes. Near the pegmatite the ore is characterized by the presence of molybdenum minerals, of which molybdenite and molybdite are the most abundant.

Ore from different lenses differs widely in character, that from some being so pure that it has been used for making Bessemer metal, that from others being high in phosphorus, and that from still others being high in sulphur. The average annual yield of the mine is about 10,000 tons, all of which is used at the Stanhope furnace.

Mount Olive mines.—The Mount Olive mines are near the southwest end of a rather wide belt of magnetic attraction, which begins just north of South Branch of Raritan River and extends nearly to Shippenport, a distance of 6 miles, with an average width of 800 feet. Numerous shafts, drifts, and pits, sunk rather close together, show that the entire belt is underlain by ore. The Mount Olive, Drake, Salmon, Osborne, Church, and Hilt mines were once large producers, though on the whole they carried lean ore. The formerly important Hurdtown and Weldon mines, northeast of Lake Hopatcong, are situated on another belt of attraction that is nearly on the strike of the Mount Olive belt and that may be its continuation. The two belts, however, may be entirely distinct, as there is no surface connection between them.

A mile southeast of and parallel to the Mount Olive belt is the East Mount Olive belt, which extends northeastward from the Hoppler mine for about 5 miles, to a point just south of the Church mine. Its average width is a little less than that of the western belt and it also shows less magnetic attraction. It has not been so thoroughly explored as the other belt and it contains no important mines, as its ore is so lean as to be unmerchantable.

These two belts of magnetic attraction, 5½ miles long and 1500 feet in combined width, are believed to contain an enormous quantity of magnetite. So far as known, however, the magnetite is rather uniformly distributed and forms a lean ore, which must be concentrated before it can be used. The area probably contains no large rich ore bodies.

[a] Information concerning the mines whose position is shown on the economic-geology map but which are not mentioned in this description may be found in a report by W. S. Bayley, entitled Iron mines and mining in New Jersey (New Jersey Geol. Survey Final Rept., vol. 7, 1910).

Explorations near Mount Olive uncovered a practically continuous ore-bearing belt nearly 3 miles long. In some of the earlier work in the southern part of the belt two thin seams of ore were found close together, the western one being but 4 inches thick and the eastern one 12 inches. The dip ranged from 35° to 70° SE. and the pitch was northeast. Farther north three veins were found, the middle one being 10 feet thick.

In 1880 the most promising openings, together with the Stevens mine, were taken under one management and worked as the Mount Olive mine for about a year. The total production up to that time was about 25,400 tons. The vein, whose thickness averaged 5 feet and reached 27 feet in a few places, had been worked for 400 feet and in places to a depth of 175 feet. In 1883 operations were again begun. A new shoot was discovered and was opened by a new slope 175 feet long. The deposit dipped 35°–40° SE. and was crossed by a fault that threw the vein to the right. All the mines were closed in 1886.

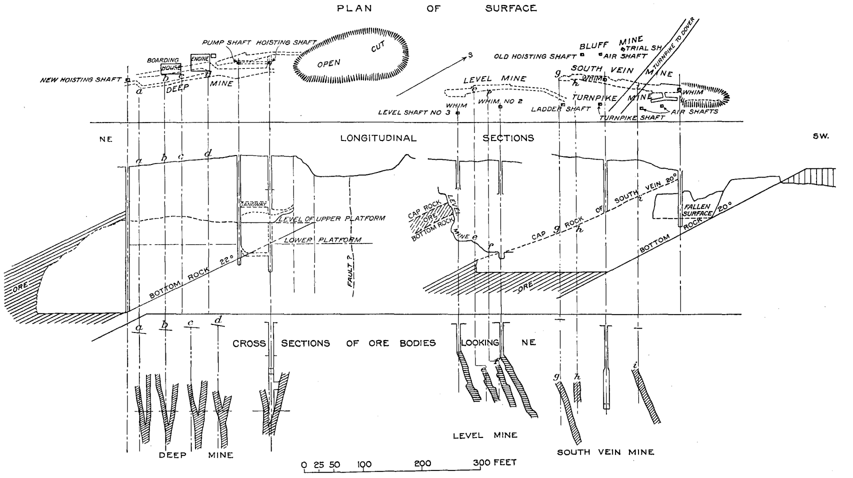


FIGURE 15.—Map and sections of the Hurd mine.

Plan shows also the horizontal projection of outcrop of ore body beneath the drift. Slightly modified from map and sections by P. Brady, in Geology of New Jersey, p. 607, 1868.

The explorations showed clearly that the ore is in a number of small deposits arranged in lines. Pegmatite appears to have been abundant in all the mines and it is probable that much of the ore was a magnetite-bearing variety of that rock. All the Mount Olive ores contained considerable limonite and a great deal of pyrite.

Hurd or Hurdtown mine.—The mine at Hurd was formerly one of the best known and most prolific in the State. In 1868 it was producing 20,000 tons annually, and its total production to June, 1880, was estimated at more than 500,000 tons. In 1895 the ore began to fail, the bottom workings were abandoned, and mining was confined to the pillars and other supports remaining in the old workings. Search for new deposits was made by diamond drill, but only small seams were found beneath the old shoot, at a depth of 600 feet from the surface, and the mine was practically abandoned after reaching a vertical depth of 2600 feet, or 1600 feet below sea level, and a depth, measured on the slope, of 6000 feet. In 1901, as the result of renewed explorations, a new shoot 9 feet thick was discovered south of a small fault and west of the three shoots that so long had furnished ore. A little ore was raised in 1902, but in 1903 all work ceased.

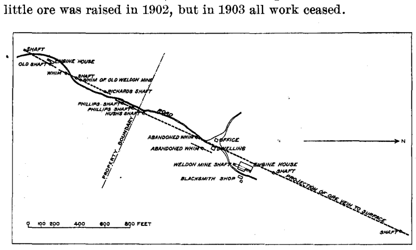


FIGURE 16.—Sketch map of the surface features at the Weldon mines.

The horizontal projection of the ore bodies is represented by dashed lines.

Originally there were two principal workings, the northeastern being named the Deep mine and different parts of the southwestern being called the Level, Turnpike, South Vein, and Bluff mines. (See fig. 15.) As both ore bodies were curved and were of practically the same dimensions it was supposed that they were separated by a cross fault having the upthrow on the northeast side.

At the southwest end of the southwestern ore body the vein is said to have appeared in the northeast wall of an old open pit (shown in fig. 15 as fallen surface) as a fold with a southeast limb that was nearly vertical and a northwest limb that dipped 45°–60° SE. The bottom of the fold pitched 26°–31° NE. and was explored by a slope which finally reached a length of 6000 feet. The South Vein and Bluff mines were on the southeast limb and the Level mine on the northwest limb.

The Deep mine, northeast of the supposed fault, was presumably on both limbs, as the ore body was Y-shaped and differed from that in the southern workings in continuing below the junction of the limbs, as though it were a branched vein with a horse of rock between the branches. The pitch of the trough was a little flatter than in the southwestern mines and the axial plane of the ore body was more nearly vertical, so that the northwest limb dipped 75° SE. and the southeast limb was nearly vertical. The ore in the western limb appears not to have been worked.

Throughout the extent of the mine workings the shoot maintained its general character, except that in the upper workings the ore and wall rock graded into one another, whereas in the lower workings the two were sharply separated and the ore was exceptionally clean. Cap, bottom, and wall rocks completely inclosed the ore body, which appeared as an oblique chimney of ore, having a thickness of 35 feet and a height of 60 to 90 feet. Thin layers of rock projected from the cap into the ore shoot, but the bottom rock seemed to be uninterrupted. Near the bottom of the mine a small fault caused a displacement of 14 to 16 feet to the right. Longitudinal and vertical sections of the mine as it was in 1882 are shown in figure 15.

The ore from the different parts of the vein was very different in quality. In some places it contained considerable apatite and in others much pyrite in films coating joint cracks. Chalcedony was abundant in places as yellow mammillary incrustations on the walls of fissures in the ore and as irregular masses inclosed in magnetite. It was also found lining geodes. Translucent quartz cut by seams and threads of magnetite was seen; also masses of ore cut by thin seams of white quartz.

Weldon and Lower Weldon mines.—The Weldon and Lower Weldon mines are near Weldon, about a mile and a half northeast of the Hurdtown mine. The openings extend for half a mile alongside the road as a series of pits and shafts, most of which are now caved. (See fig. 16.)

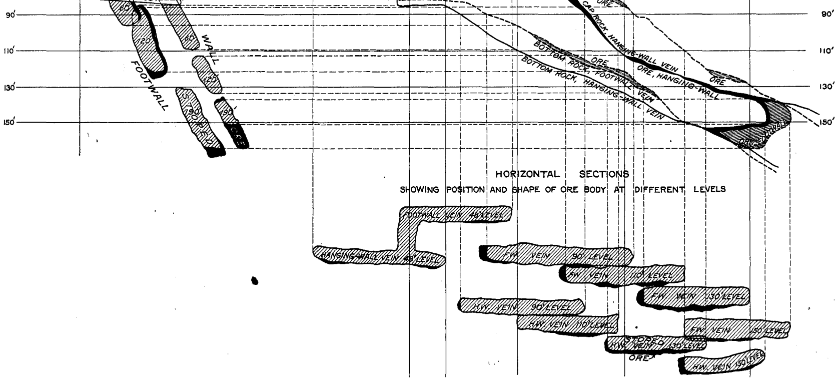


FIGURE 17.—Sections through the ore bodies of the Weldon mine.

The longitudinal vertical projection shows the hanging-wall vein in solid lines and the projection of the footwall vein in dashed lines.

The Weldon mine was opened in the early part of the last century. Later it was abandoned and in 1868 the openings were full of water. Still later it was reopened and was operated intermittently until 1890, when a concentrator was erected to remove the phosphorus from the rich ore and to concentrate the lean ore so that the whole might be sold as of Bessemer grade. By the end of 1891 a new shaft had been sunk 300 feet and as the concentrator had successfully separated 2000 tons of ore a second one was built. By 1896, however, the plant was abandoned because of the expense of preparing the ore for market. In 1901 the mine was again operated for a few months in a small way. A small offset, which threw the vein its own thickness, was encountered, and when this was crossed, the water in the old workings was tapped, the new workings were flooded, and all work was stopped. In 1902 the mine was unwatered and 4000 tons of ore were raised. It was then shut down and has not been operated since.

The ore body exploited in 1868 was from 4 to 7 feet thick and had been worked for half a mile by narrow open pits. Its dip was 50°–75° SE. The main workings were at the northeast end of the vein, where two shoots of ore, side by side, dipped 75° SE. and pitched 30° NE. The thickness of the west shoot was 3 to 4 feet and that of the east shoot 4 to 5 feet; their height was 30 feet. The shoots converged downward and were only 7 feet apart at the bottom of the mine in 1872. (See fig. 17.) When the shaft sunk in 1891 had reached a depth of 300 feet it had penetrated three new shoots, 20 to 60 feet high and 2 to 9 feet thick, which were separated by 8 to 30 feet of rock and pitched 30° NE. and dipped 50° SE. The ore was non-Bessemer and averaged 58 to 60 per cent of iron.

The Lower Weldon mine was on the same vein as the Weldon. It was operated in 1873 but was closed a few years later and was idle in 1879. It was again worked in 1890, when it was 360 feet deep, but was abandoned before 1896. In 1901 a little exploratory work was done, but so far as known no ore was raised.

The shoots, of which there were two, one above the other, were very regular. They dipped 50° SE. and pitched 30° NE. and were 6 to 8 feet thick, including about 3 feet of clean ore that yielded 58 per cent of iron. Rock and ore were interbanded, the rock being highly micaceous. The upper shoot was exhausted in 1891; the lower, which was 4 feet thick and 25 feet high, was worked until the mine was abandoned in 1896. Both shoots were beneath those of the Weldon mine.

The ore of both mines was lean. It is described as containing quartz, feldspar, and apatite.

High Bridge or Taylor mines.—The Taylor mines, together with a few pits on the hill to the west, formed a line of openings one-fourth mile long just north of High Bridge. Some of the openings are reported to have been made as early as 1720 and to have yielded an abundance of good ore. The mines were worked intermittently until 1886, when they were abandoned.

The vein ranged in thickness from 2½ to 8 feet and dipped 68° SE. Near its northeast end it was crossed by a fault that caused a displacement of 20 feet. A thick layer of pyritiferous ore on the hanging-wall side was thrown on the dump but was examined years afterward and was found to have become sufficiently free from sulphur to be used in the forge.

The ore was found in a series of shoots that lay slightly oblique to the course of the vein, which was about northeast. All the ore bodies pitched northeast, those at the north at a greater angle than those farther south. In the southwest part of the vein there were four parallel shoots, separated from one another by only a few feet of rock. One was 55 feet thick, and the others reached in places a thickness of 100 feet. With increasing depth the thickness decreased and at the bottom of the shafts when work ceased it was only 1 or 2 feet. It is noteworthy that none of them pinched out completely.

Chester group of mines.—From 1870 to 1883 Chester was the center of much mining activity, no less than 26 mines being operated in its immediate vicinity along seven distinct lines or ranges which probably represent as many mineralized zones, each comprising, perhaps, several veins. Most of the lines are short, but one that passes through Chester is 18 miles long, extending from the Hacklebarney mines at the southwest to the Swedes mine at the northeast. Along or close to the direct line between those points are 28 groups of openings from which ore has been taken. They are not all on the same vein, but the several veins are so close together and so distant from other veins that they may be described as constituting a mineral zone. The larger mines were situated along the middle lines and most of the mines on the other lines were small, many of them being merely explorations. The ore in all the veins was lean, so that nearly all the operations were abandoned after the removal of the surface ore.

The Hacklebarney mines comprised many shafts and pits along both sides of Black River at Hacklebarney, in the nonglaciated region south of the terminal moraine, where rock disintegration has extended to great depths. The mines were first worked about 150 years ago and when active produced a large annual output, the ore being used in forges in the vicinity. Up to 1868 all the ore was mined near the surface, where it occurred in veinlike masses with earth walls, the ore having been altered to a soft red mixture of limonite, hematite, and magnetite, free from sulphur. At greater depths it was black and hard and contained so much sulphur that it had to be roasted before it was used. During several periods between 1868 and 1896

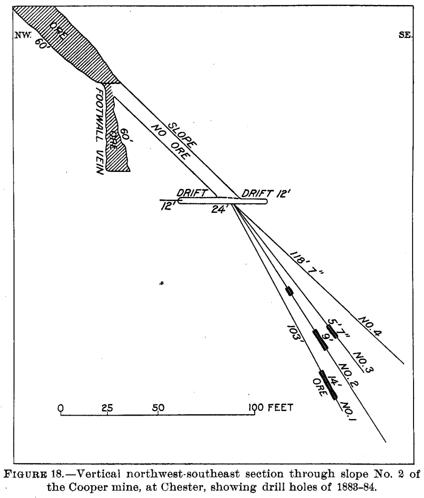


FIGURE 18.—Vertical northwest-southeast section through slope No. 2 of the Cooper mine, at Chester, showing drill holes of 1883–84.

mining was carried on here, ore being taken from at least five different veins, on both sides of the river. Gradually all operations ceased and the plant was abandoned about 1896. When actively worked it produced annually about 20,000 tons.

Ore was taken from 12 or 15 small shoots 1 to 12 feet thick and 15 to 200 feet high. The dip of those on the southwest side of the river was 70° SE. and their strike was north-northeast, a little more nearly north than those on the northeast side. At the river a great fault throws the veins on the north side of the river about 200 feet to the east. On the hill northeast of the river the explorations disclosed a great series of alternating belts of rock and ore dipping 65° SE. and pitching 20°–30° NE. The most persistent vein, the Tunnel vein, had a uniform thickness of 5 to 6 feet and a regular dip of 55° SE. The whole hill appears to have been crossed by a great mineralized zone consisting of many parallel veins. Small faults are numerous, but the only great displacement is at the north end of the westernmost pit, where a vertical fault perpendicular to the ore bodies displaced the vein 30 feet to the east. On the southwest side of the river at least five faults were developed in the workings, all with offsets in the same direction. None of the workings on either side of the river was deep, so that the persistence of the ore downward was not determined.

The ore of most of the veins at Chester was rather lean. It contained pyrite and biotite in definite bands interlaminated with other bands of comparatively pure magnetite. The biotite was a dark-green variety and occurred generally in layers one-fourth to one-half inch thick between layers of magnetite one-half inch or more thick.

The Sampson or Skellenger mine, which is located at Chester and is the southernmost of the long series of mines on the east Chester vein, was opened in 1867 and worked continuously on surface material until 1873. In 1880 it was reopened and worked until 1885. By 1883 it had reached a depth of 285 feet on the steep slope of the footwall and a length of 350 feet. Up to 1880 it had yielded 39,200 tons of ore, mainly from a single large shoot 350 feet long, 3 to 8 feet thick, and 300 feet high, with well-developed cap and bottom rocks. Below this was a second shoot, on which operations were begun before the mine closed in 1885. The dip of the ore bodies was mostly southeast but not at a uniform angle, and in places it was high to the northwest. Their pitch was 22° NE. The ore mined at a depth of 180 feet was a hard blue magnetite containing pyrite.

The Cooper mine, a mile northeast of Chester, consisted of a number of large open pits and shafts on the northeast extension of the Swayze vein. It was opened at the end of 1879 and was worked almost continuously until 1885. Ore was found in an unbroken line 1465 feet long, terminated on the northeast by a fault with a throw of 40 feet to the east. The dip of the fault plane is south and its strike is oblique to that of the vein, which was from 15 to 30 feet thick and dipped 45° SE. The ore to a depth of 74 feet was soft and red and was mined by open pits. At a greater depth it was hard and the mining was underground. The ore occurred in shoots pitching 25° NE. and dipping 45°–65° SE. At one time rock that was supposed to be "bottom rock" was found, but on drilling through it a deposit of ore, supposed to belong in a lower shoot, was struck.[a] (See fig. 18.) In 1885 a slope was driven for 120 feet along drill holes 2 and 3 (fig. 18), but only thin strings of ore were discovered and the mine was closed. The ore was distinctly banded with thin laminæ of mica. At slope No. 3, nearly in the middle of the vein on the property, the vein contained two ore deposits, 9 feet and 2 feet in thickness, separated by 2 feet of rock. From 1881 to 1885, inclusive, the mine shipped 90,000 tons of ore.

The Langdon and the Pitney mines are at the southwest and northeast ends, respectively, of a line of magnetic attraction that is continuous for 2000 feet, on the west side of the road from Hacklebarney to Pottersville, a mile south of Hacklebarney. Several pits put down in 1879 found ore, and by June, 1880, openings at the northeast end had produced 6700 tons, all surface ore. Below this ore, in a vein 12 to 15 feet thick, a shoot pitching southwest was discovered, but its ore proved to be lean and the mine was abandoned in 1882.

Work was carried on more persistently at the southwest end of the line. The Langdon mine was opened in 1880. The first ore was taken from open pits, but after the surface material had been removed the pits were timbered and work was continued underground until 1886, when all work ceased. At the southwest end of the mine two shoots of ore were found, pitching 20° SW. and dipping southeast. The southwesternmost shoot in its thicker part was 10 to 15 feet thick; the other shoot, which was displaced about 7 feet to the left by a fault, was 11 to 15 feet thick. Later explorations made farther northeast uncovered a third shoot, 7 to 14 feet thick, dipping 45° SE. and pitching 15° SW.

The five shoots of the two mines were apparently in the same vein, which everywhere dipped southeast. The remarkable feature about them was their southwest pitch, which is uncommon in the quadrangle. The ore in both mines was red and free from sulphur to a depth of 30 feet, below which it was hard and was contaminated with mica. Among the materials in the ore were veins of calcite, crystals of some zeolitic mineral, zircon, and a violet mineral in amorphous incrustations, probably fluorite. Recorded analyses show that the ore was very lean.

Wharton belt.—The Wharton belt is apparently a branch of the Chester belt, which it leaves near Ironia. It extends northward for a short distance and then turns northeastward and runs parallel to the northeast end of the Chester belt at a distance of 2 or 3 miles to the west. Wharton is about midway of its most productive part. This belt, with its great number of veins and numerous deposits, is noteworthy, for nowhere else in the State are so many ore bodies so closely crowded together and nowhere else have so many large mines been developed in so small an area. (See fig. 19.)

In all about forty mines, distributed along three parallel lines separated by narrow zones of barren territory, were operated in this belt. Some of the mines were large, but most of them were small and produced separately but little ore. In the aggregate, however, these mines contributed largely to the output of iron ore of the State and their product on the whole was of good quality. Some of them were probably abandoned because of the exhaustion of the ore bodies, but others were closed with large reserves of ore in sight.

The ground south of Rockaway River is honeycombed with openings, which form almost continuous lines, very little unworked ground remaining between them. Openings are less numerous north of the river, but the land there has been explored as far as the Hickory Hill mines, and some of the mines on that side of the stream have been among the most important producers in the State. The part of the belt south of the river ranges in width from a quarter of a mile to a mile and comprises a series of veins that contain a large number of ore bodies. The Hurd mine is the only one now operated south of the river, but the Dickerson, Byram, Baker, Stirling, and North River have each produced great quantities of ore. Historically considered, the Dickerson mine is perhaps the most interesting in this portion of the State.

The Dickerson mine, 8 miles southwest of Dover, one of the oldest in the State, having been opened in the eighteenth century, is on a vein a short distance west of that worked by most of the mines in the vicinity. Originally the ore was used in neighboring forges, being carted as far south as High Bridge and as far north as Hamburg. After the Morris Canal was opened the ore was sent to the Lehigh region for smelting. It is estimated that during its life the mine produced a million tons of ore, its largest output for any one year being 48,000 tons.

Ore was obtained from three principal deposits. The largest was an irregular lens whose long axis dipped 60° SE. and pitched 35°–48° NE., parallel to the foliation of the surrounding gneiss. At its borders the ore was penetrated by wedge-shaped tongues of rock. Where purest it was crossed by joint planes perpendicular to its walls. At a depth of 1200 feet the large vein and one of the others merged, forming an ore body 78 feet long and 40 feet thick. Below, the shoot rapidly decreased in size and the quantity of rock intermingled with the ore constantly increased. In 1892, after all the ore in the known shoots had been taken out and after explorations had failed to reveal new deposits, the mine was closed. In 1905 a small shoot was found on the hanging-wall side of one of the veins and during the next three years about 25,000 tons of ore, all of the granular variety known as shot ore, was taken out. Some of it contained as much as 2 per cent of phosphorus.

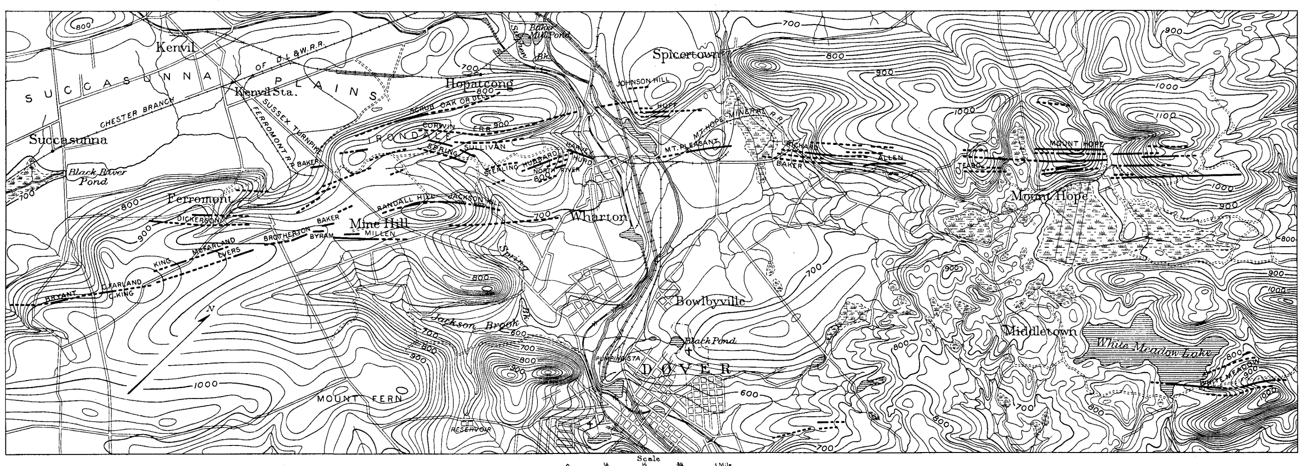


FIGURE 19.—Map of the Wharton iron-ore belt, showing the mines and ore bodies.

Mines and ore bodies by George M. Hopkins, Geology of New Jersey (atlas), 1868. Solid lines represent extent of ore bodies mined in 1868; dashed lines represent ore traced by magnetic needle but not worked in 1868.

Swedes mine.—Fifty years ago the Swedes mine, a mile east of Dover, on the north side of the Morris Canal, was one of the important mines in the quadrangle. As early as 1855 ore had been removed along a distance of 850 feet, at one place to a depth of 175 feet. The mine was worked almost continuously until 1875, when it was closed, and in 1882 it was permanently abandoned. At that time it was 220 feet deep and 1300 feet long.

The vein, which dipped 57° NW., was thin in its southwestern part, ranging in thickness from 1 to 3 feet, but farther northeast it widened to 13 feet, and in the extreme northeast corner of the mine it was 9 feet thick. The ore body, which was irregular in shape, consisted of a mixture of magnetite and hornblende with an indistinct schistosity dipping and striking with the structure of the surrounding gneiss. The vein was made up of a series of subordinate beds or seams, mostly composed of mixtures of magnetite and black hornblende in crystals of considerable size. Some seams, however, were composed of magnetite, more or less pure, and some of feldspar or quartz.

The footwall material resembled the ore in being composed of magnetite and hornblende but was more schistose. In some places the walls were apparently pegmatite, and a horse in the ore probably consisted of the same rock. Among the materials in the

The Byram mine, 2½ miles west of Dover and three-fourths mile northeast of the Dickerson, was formerly one of the most important in the quadrangle. It was opened in the early part of the last century and was abandoned in 1883. The ore was in two lenses, both dipping 50° SE.; the larger was 3 to 8 feet thick. The vein was remarkable for the close crowding of faults, at least six horizontal displacements to the left, ranging from 18 inches to 14 feet, being noted. The ore was crumbly and in some stopes was high in phosphorus, some specimens being apparently about half apatite.

The mines just south of Wharton are separated into two groups by a fault, southwest of which are the Stirling, Hubbard, North River, and New Stirling mines and northeast of which are the Harvey and the Hurd mines. (See fig. 19.) Together they were formerly called the Irondale group. The mines southwest of the fault were in lenses on the same vein.

The Stirling mine was operated long before 1855 and by 1868 had produced 150,000 tons of ore. It was worked continuously until 1883, when it was abandoned. Its principal shoot was 1600 feet long, 90 to

[a] New Jersey Geol. Survey Ann. Rept. for 1883, p. 153; idem for 1884, p. 79.

150 feet high, and 7 feet thick on the average. Its footwall dipped 45° SE. and its bottom rock pitched 15°–18° NE. The Stirling vein is broken and is terminated on the southwest by a fault with an offset of 80 feet to the west. The ore of the Stirling shoot was crumbly and contained much apatite, especially in the middle stopes.

The Hubbard and the North River mines were on the same vein but worked a shoot northeast of and above the Stirling lens. The Hubbard, which was on the south end of the shoot, a few hundred yards northeast of the Stirling mine, occupied about 600 feet of the vein. The North River mine was about 300 feet farther north. Both mines were opened before 1855 and by 1868 the ore had been removed from the Hubbard mine to a depth of 200 feet at the rate of 6000 tons a year and the North River mine had yielded a total of 20,000 tons. The ore body was 1 to 14 feet thick and dipped 30°–45° SE.

The New Stirling mine was opened in 1890 to obtain the ore in the northeast part of the Stirling shoot beneath the North River shoot. The ore body ranged in thickness from 3 to 18 feet, dipped 48° SE., and pitched northeast. It yielded a 60 per cent non-Bessemer ore at the rate of 90 tons a day. The mine was worked independently until 1900, since which time it has been operated in conjunction with the Hurd mine. In 1897 a drift carried through a fault discovered an ore body 6 to 12 feet thick, 60 feet high, and several hundred feet long on the northeast side of the offset beneath the Harvey ore shoot, originally worked by the Hurd mine. The ore was taken out partly through the New Stirling slope but mainly through the Hurd shaft.

The Harvey and the Hurd were originally two separate mines on what was probably the continuation of the North River shoot. The Harvey mine, which was southwest of the Hurd, was opened, worked, and abandoned before 1855. It was evidently reopened soon afterward, for it is described as being 400 feet long, 300 feet deep, and from 2½ to 10 feet wide in 1868. Soon afterward the workings were merged with those of the Hurd mine.

The Hurd mine, which should not be confused with the Hurdtown mine at Hurd, has been one of the most prolific producers in the State. By 1868 it had been worked for a length of 190 feet and a depth of 70 feet. It was closed soon after 1868 but was reopened in 1873 and operated for a year. In 1879 mining was again resumed and was continued on a small scale with short interruptions until 1897, when the discovery of ore under the old Hurd workings by the drift from the New Stirling mine increased its activity. In 1905 a new deposit was discovered and since then the mine has been worked vigorously to supply ore for the Wharton furnace. The shoot mined in the early years was 100 to 130 feet high and not more than 9 feet thick. It dipped 52° SE. and pitched northeast. The shoot now being mined is in places 15 feet thick, but its other dimensions have not been disclosed. The deposit, however, is large. The ore from this shoot contains a large percentage of iron but is also high in phosphorus.

The Orchard mine is in Wharton, on the south side of Rockaway River, a few hundred yards north of the Hurd mine. It was opened about 1850 and up to 1868 had produced 50,000 tons of ore. Work was stopped in 1874 but was resumed in 1878 and continued until 1884, the product averaging 12,000 tons a year. In 1886 the mine was reopened, and in 1890 a drift 800 feet long was driven southeastward from the 700-foot level. The mine was closed in 1893 but was reopened in 1907, when work in the Hurd mine showed the presence of unexpected deposits beneath those formerly worked. The vein is the northeastern extension of that in the Hurd mine. The old shoots averaged 5 feet in thickness, dipped 48°–57° SE., and pitched 30° NE. The shoot now being worked lies under the old one and is the northeast end of the new Hurd shoot. Under Rockaway River the upper deposits were cut off by a fault and their extension in the line of strike has been vainly sought on the north side of the river. They are supposed to be continued by a vein about 150 feet to the right, which was formerly worked by the Washington Forge mine and whose continuation south of the river was sought without success. The ore is used at the Wharton furnace.

The Huff mine, on the east slope of a hill north of Rockaway River, half a mile north of Wharton, was opened a little before 1855 and was operated intermittently until 1886. Mining was resumed in 1905 and has continued since without interruption. The present annual yield is 12,000 tons and the total production is 120,000 tons. The ore is in a succession of shoots dipping 60° SE. and pitching 35° NE., in two veins separated by 10 to 14 feet of rock. The west vein averages 9 feet and the east vein 6 feet in thickness. The ore is rather lean and contains considerable mica. That mined in 1886 averaged 45 per cent of iron as it came from the mine.

The Mount Pleasant mine, a quarter of a mile northeast of the Orchard mine, on the north side of Rockaway River, was opened in 1786 and was operated almost continuously until 1896, when it was abandoned. Up to June, 1880, it yielded about 336,000 tons of ore, most of which came from its northeast end. In 1896, when the mine was closed, its workings were 3500 feet long and 1400 feet deep, measured on the slope. Four veins are reported to cross the property. Most of the mining was done on the Main vein, which averaged 6 feet in thickness, and on which five shoots of ore were developed. These shoots dipped 57° SE. and pitched northeast. Their average height was about 60 feet. The mine was noted for its many faults, five being cross faults, dipping approximately 75° NE., and a sixth a fault dipping 35° NE. and intersecting several of the first five, displacing their upper ends 12 to 15 feet to the southwest. The ore was also cut by a number of faults that have been described as "cross-slides" and that are presumably strike faults, dipping 40°–75° NW., in an opposite direction to the dip of the vein. They crossed the vein at the pinches between the ore bodies and thus emphasized its shootlike character. The downthrows, all of which, so far as observed, were on the footwall sides of the faults, ranged from 5 to 35 feet.

The ore of the Mount Pleasant mine was a mixture of magnetite, calcite, quartz, chalcopyrite, apatite, siderite, pyrite, and zircon. The calcite occurred in veinlets and as incrustations in fissures in the wall rocks. The siderite was in seams and bunches in quartz and also formed a matrix cementing masses of granular magnetite and quartz. The apatite occurred as rough, apparently crystalline masses 6 inches in diameter in an aggregate of quartz, apatite, and magnetite. The quartz, besides being found in the wall rocks, occurred as lenses in the magnetite, where it contained "bunches" of chalcopyrite.

The Richard mine, three-fourths mile northeast of the Mount Pleasant mine, adjoins the Baker mine on the northeast and is immediately southwest of the Allen mine. It is now the second largest producer in the quadrangle. Five veins cross the property. The three at the southeast are continuations of the Baker veins; the next to the northwest is the continuation of the Mount Pleasant vein; and the northwesternmost is regarded as the Teabo vein. The southeasternmost, which is the largest, was opened for 2700 feet and yielded nearly all the ore mined in earlier years. In some of the shoots the ore was 20 feet thick; in others it pinched to 12 inches. Both pinches and shoots pitched 15° NE. and dipped 53° SE. The output of the mine from 1856 to 1904 was 2,212,833 tons, an average of 48,000 tons a year. Since 1904 approximately 1,250,000 tons have been raised, making the total yield to the present time a little more than 3,500,000 tons. The rock associated with the ore is largely a phase of the Pochuck gneiss but includes a few small veins of calcite and seams of coarse pink feldspathic rock. The wall rock, which is gray and consists of alternate bands of Losee and Pochuck gneiss, is separated from the ore by thin selvages of dark micaceous gneiss. Thin sheets of magnetite fill some of the smaller fault cracks and connect the displaced ends of the ore deposit. The ore is of high grade, the average analysis for 12 years, representing shipments of more than a million tons, showing 60.2 per cent of iron.

The Allen mine occupies the part of the belt between the Richard and the Teabo mines. It was opened before 1855 and was worked continuously until 1882, when active operations ceased. Only one vein has been worked, but it included several shoots that increased in size toward the northeast. The southwest shoots were the leaner, the ore being more intermixed with rock. The dip of the ore bodies was 65° SE. and their pitch was low to the northeast. Their thickness in some places was as great as 23 feet. The rock on the dumps, which has no counterpart in any other mine in the State, is said to have been taken from the hanging wall of the northeast workings. It is distinctly conglomeratic, being composed of nodules of greenish white feldspar embedded in a schistose matrix of magnetite, hornblende, and biotite, the nodules being so enwrapped by the matrix as to suggest that they were solid while the matrix was still plastic. Some of the nodules, moreover, are schistose with a foliation that is not conformable with the foliation of the matrix. The matrix is traversed by small veins of pyrite. It contains fissures and cavities lined with quartz crystals mixed with limonite, or with incrustations of transparent mammillary opal, and, in places, with rhombohedral crystals of pure white opaque siderite. In some places also the footwall contains cavities lined with similar siderite crystals and well-terminated quartz crystals.

The same structure, or one closely similar, is observed also in the ore, which in some parts of the mine consists of large masses of a breccia-like aggregate of angular pieces of magnetite cemented by white siderite. Cavities in the ore are lined with small rhombohedrons of siderite, pyrite crystals, and hexagonal plates of olive-green mica, and are partly filled with limonite powder. Veinlets of white siderite lined with pyrite cross the ore body in various directions; where they swell bunches of quartz crystals are embedded in the siderite.

In many of the fragments on the dumps the nodules are apparently distorted porphyritic crystals of oligoclase. Under the microscope they are seen to be aggregates of oligoclase and epidote embedded in a matrix of green hornblende, a little green pyroxene, and some magnetite. In some fragments the conglomeratic rock is interlaminated with a light-colored rock containing a few large feldspar crystals. Both rocks are apparently igneous. A slight crushing of some of the components suggests that the nodular character of the feldspar masses may be due to the rounding of porphyritic crystals by friction.

The Teabo mine, which is a little southwest of Mount Hope and which adjoins the Allen mine on the northeast, was extensively worked in the early part of the nineteenth century by a shaft more than 200 feet deep. It was closed before 1855, reopened a year or two before 1868, and abandoned in 1891. In 1902 a new shaft, sunk a considerable distance north of the old shafts, found a 6-foot vein of 50 per cent ore at a depth of 240 feet. During that year about 1000 tons of ore were raised. Work was again suspended in 1903, but explorations were resumed in 1905 and continued for two years. The principal mining was on a vein known as the Teabo vein, that was supposed to correspond very nearly to the main vein at the Allen mine. There were at least three shoots, each about 45 feet high and all dipping 70° SE. and pitching 21° NE. The top shoot averaged 5 feet in thickness and was mined for a length of 1057 feet. The middle shoot averaged 16 feet in thickness and the lower one 18 feet. The ore was of two varieties, some being finely granular with a jointed structure and a purplish tinge, and some being coarsely granular and containing considerable quartz and mica.

Mount Hope and Hickory Hill mines.—The Mount Hope group of mines, at the northeast end of the Wharton belt as shown in figure 19, has furnished ore for more than 125 years and constitutes one of the most valuable mining properties in the State. The mines originally comprised workings in nine ore bodies, four on Mount Hope, three on Hickory Hill, and two on Mount Teabo. (See fig. 20.) The ore was reached in the early openings northeast of Mount Hope by two inclined planes that descended to a depth of 100 feet and penetrated an ore body with an average thickness of 10 feet and a dip of 68° SE. Later a drift, known as the Big tunnel, was driven into the hill from the southeast. It intersected five veins, of which the four larger ones are shown on the map (fig. 20).

All the ore bodies were cut by many veinlets of pyrite, some of them 2 to 3 inches thick, and the wall rocks were traversed by veins of epidote. The country rock near the ore bodies contains masses of large crystals of apatite, quartz, black mica, hornblende, and calcite and scattered crystals of cupriferous pyrite. In the ore were found also seams of chalcedony and pyrite and nodules of red hematite in an irregular mixture of quartz and feldspar. On some of the dumps are found masses of cellular quartz containing limonite, chalcedony, and fluorite, in veins cutting hornblende schist, and specimens of black crystalline hornblende containing disseminated apatite, some crystals of which are several inches long.

The group known as the Hickory Hill mines is separated from the mines on Mount Hope by a fault that intersects the surface near the brook between Mount Hope and Hickory Hill.

Mining on all the veins has continued with slight interruption to the present time. In 1874 the Hickory Hill and the Mount Hope mines were shut down, but the latter were reopened in 1880. The aggregate production of the entire group of mines to the end of 1880 was estimated at a million tons.

All the veins in the Mount Hope territory exhibited the pinch and shoot structure very perfectly. In the Jugular or Taylor vein at Mount Hope some of the shoots were 30 feet thick. They pitched 30°–40° NE. and dipped 70°–75° SE. (See fig. 21.) The shoot that was worked in 1886 was separated from another above it by a pinch 18 inches thick and was terminated below by another pinch of approximately the same thickness. At no place in the development of the vein did the ore entirely disappear, the shoots being connected through the pinches by thin seams of ore. At the Elizabeth mine the shoot that was worked from 1893 to 1899 had a maximum height of 140 feet, a thickness of 3 to 25 feet, a dip of 65°–70° SE., and a pitch of 25°–30° NE.

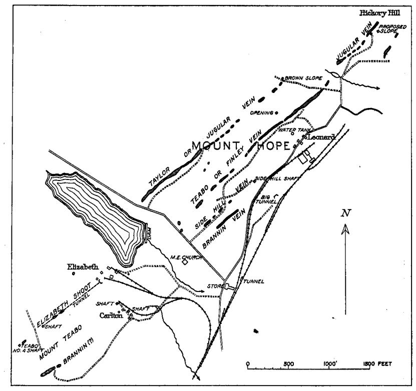


FIGURE 20.—Sketch map of the surface features, including ore pits, at the Mount Hope mines.

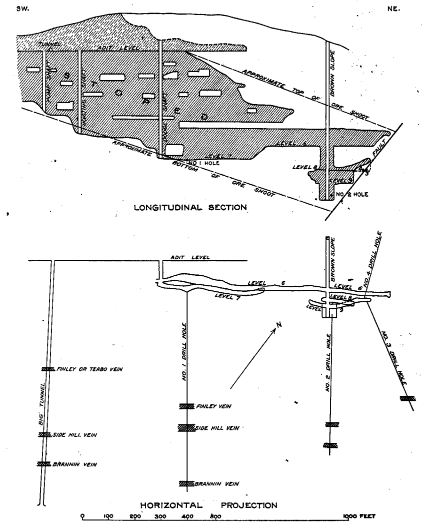


FIGURE 21.—Horizontal projection and longitudinal section of the Taylor mine, Mount Hope.

All the ore of both the Mount Hope and the Mount Teabo mines contains considerable hornblende and biotite and the ore of the Carlton mine, on the northeast side of Mount Teabo, is particularly lean. All this ore and that from the Leonard mine, at Mount Hope, is passed through a magnetic concentrator before shipment.

Other mines.—The Van Syckle mine, in Bethlehem Township, Hunterdon County, a mile west of Van Syckles, is of interest because of the fact that its ore contained more titanium than that of any other mine in the State. It was opened in the later years of the eighteenth century but was soon abandoned and lay idle for nearly a hundred years. It was reopened in 1864 and was operated at times until 1875, when it was again abandoned. Probably its entire output did not exceed 10,000 tons. The main deposit was 11 feet thick and the ore was interlaminated with streaks of chloritic rock. A second deposit, farther northwest, was 7 feet thick, but the ore was very lean. Ten samples of material taken from different parts of the vein showed on analysis an average of 12 per cent of titanium oxide, and it is reported that three samples of ore showed an average of 0.21 per cent of vanadium oxide.

The ore of the Naughright mine, about a mile north of Naughright, on the east slope of Schooley Mountain, is also noted for its large content of titanium.

The Silver mine, along the railroad a mile south of Cranberry Reservoir, was more properly a mine of pyrite than of magnetite. Its ore consisted of masses, seams, and bunches of pyrite in an aggregate of pyrite and pyrrhotite, magnetite, and a dark-green fibrous mineral which was possibly chlorite. An analysis made for the New Jersey Survey in 1886 showed 73 per cent of iron sulphides. The deposit was never worked.

Canfield's phosphate mine was a magnetite mine whose ore contained so much apatite that it was at one time seriously considered as a source of phosphoric acid. The mine was one-eighth mile northeast of the Dickerson mine, apparently on a vein east of the Dickerson veins. The ore is a granular aggregate of magnetite and apatite containing small quantities of quartz, orthoclase, and biotite. By volume the magnetite and apatite are approximately equal and by weight the apatite constitutes 35 per cent of the rock.

The Hurdtown Apatite mine, which is a mile southwest of the Hurdtown mine, on the north side of the road from Hurd to Nolan's Point, was opened and abandoned before 1855. The ore is a pyritiferous magnetite containing a large amount of apatite, as well as pyrrhotite, calcite, and the ordinary silicates, which occur in some specimens in large quantity. The apatite, which is green, amber, or brown, partly transparent and partly opaque, occurs in irregular seams intermixed with the pyrrhotite and in crystals embedded in that mineral. Some of it is in distinct crystals with hexagonal outlines and rounded edges and some in large almost pure masses, but most of it is in an aggregate of the minerals mentioned. The pyrrhotite is abundant, occurring in masses several inches in diameter. Some of it is pure, but most of it includes grains of apatite. Much of the magnetite is embedded in the pyrrhotite as nodules. It possesses a perfect cleavage into thin plates, many surfaces of which are striated. Magnetite also occurs embedded in apatite and in aggregates with the silicates. The pyrite is abundant but not so abundant as the pyrrhotite. Although the ore contains much apatite it is not so rich in it that it can be profitably used as a source of phosphate.

The Glendon mine, in Green Township, Sussex County, on the northwest slope of Allamuchy Mountain, is the only magnetite mine in the quadrangle, elsewhere than on Jenny Jump Mountain, that is wholly in the Franklin limestone. The ore, which appears to be an irregular impregnation in white limestone near intrusions of dark scapolitic diorite, consists of magnetite, pyrite, hornblende, and garnet crystals and is reported to be manganiferous. In the neighborhood of the openings there is a great deal of pegmatite and in the mine pits there is much scapolitic diorite.

The Hoit mine, near the top of Mount Mohepinoke and a mile north of the Pequest mine, is especially noteworthy because the walls of its ore body are of rock different from that associated with the ore in any other mine in the State. It is a much-sheared garnetiferous quartzose schist containing garnet and sillimanite in fairly large amounts. Its origin is not known, but it may be an altered sedimentary rock. The ore is compact and banded like many other ores of the State, but unlike them it contains numerous irregular masses of garnet in addition to the augite, hornblende, and quartz that are found in the other ores.

LIMONITE.

OCCURRENCE.

Limonite or brown iron ore has been extensively mined at only three localities in the Raritan quadrangle—the Beatyestown mines, $3\frac{1}{2}$ miles west of Hackettstown; the Neighbor and Dafford mines, near Califon; and the Bird mine, near Clinton. In several other localities minor deposits have been noted.

Most of the deposits occur in the Kittatinny limestone, generally near the top or near the base of that formation. A few deposits, including that at the Bird mine, occur in the Martinsburg shale. The geologic setting of the brown ores is thus like that of many similar deposits that occur in the great Appalachian Valley from Vermont southward to Alabama.

In New Jersey the bodies of ore are commonly irregular, more or less lenticular layers that conform in position with the contacts between the limestone and the overlying and underlying rocks—that is, with the Jacksonburg limestone above or with the Hardyston quartzite or the pre-Cambrian gneisses below. Some of the ore masses are highly inclined and resemble veins; others are horizontal and blanket-like. The boundaries of the deposits are generally irregular, and offshoots from the more massive layers penetrate the associated rocks along joint breaks or along the planes between the strata. The lenticular ore masses are separated from one another by barren limestone or by highly ferruginous clay which may contain distributed nodules of ore.

The ore is commonly made up of large and small nodular masses intermixed with ocherous earth, clay, or sand and rock fragments. Some of it, known as rock ore, can be prepared for commercial use by hand sorting, but the greater part of it must be washed to free it from clay and sand.

ORIGIN.

The material of the ore, including the iron oxide, is in a way residual, having been derived from the disintegration of great masses of rock by the long-continued action of atmospheric waters. It is not, however, residual in the sense that it comprises only substances that remained entirely insoluble during the process of ore formation, for portions of the iron have evidently been contributed by solutions, and the same material may have been many times dissolved and as many times precipitated before an ore mass was finally segregated.

If the ores were merely insoluble residues they might occur in widespread surficial blankets, but if they were formed in part of iron that was transported in solution their observed localization at the top and the bottom of the Kittatinny limestone may be very readily explained, for the sharp change in the character of the rock at those horizons undoubtedly would have favored the deflection of circulating waters into rather well-defined channels.

In New Jersey the source of the iron of the limonite ores must be sought essentially in the very minor amounts of iron compounds originally disseminated through the masses of limestone and shale that formerly filled the broad valleys now lying between mountain ranges of more resistant rock. At the Beatyestown mine portions of the limestone with which the ore is associated contain over 80 per cent of siderite (ferrous carbonate). However, as siderite was not generally an abundant component of the rocks in this region, it is more probable that the limestone has been locally enriched with iron by gradual chemical replacement. Such replacement has been regarded as actual and necessary for the segregation of certain brown ores in Alabama, New York, and Connecticut.

MINES.

The limonite deposit about one-half mile north of Beatyestown is the most important in the quadrangle. Three openings have been made on it—the Shields, the Thomas, and the Brown mines.

The Shields mine was opened in 1868 and was worked steadily till 1881, mainly from an open pit, producing about 20 tons of ore daily. From 1872 to 1880 it produced 41,121 tons. Work was resumed in 1899, when ore containing 40 per cent of iron was discovered in paying quantity at a depth of 20 feet. In 1906 a shaft was sunk in the bottom of the old pit and from it a drift was run to the ore. Since then mining has been continued on a small scale. The Thomas mine, north of the Shields mine, worked the same deposit. It was never as prolific as the Shields, though it has yielded considerable ore. In the census year 1879–80 its production was 2050 tons. The Brown mine, adjoining the Shields mine on the south, was opened in 1873, worked a few years, and closed. It was again worked in 1880 but has not since been operated as an independent mine.

The ore in all these mines is near the top of the Kittatinny limestone. In the Shields pit the walls are limestone, but at the Brown mine the west wall is reported to be "slate." The ore is believed to be in part a replacement of the limestone along its bedding planes. At the bottom of the Shields pit the rock was found to be more ferriferous than elsewhere. A specimen analyzed in 1871 contained 82.23 per cent of ferrous carbonate.

The ore of all the mines was found immediately under the soil. It consisted of limonite mixed with yellow clay and sand and contained streaks of blue-black earth and large nodules of limestone. The mixture was washed before shipment. The ore that was being raised in 1908 consisted more largely of limonite, being a mixture of lumps of pure, dense limonite and an ocherous clay. A sample of washed ore obtained in 1880 and a lump of the pure limonite obtained in 1908 were analyzed, with the results indicated below:

Composition of limonite ores from the Beatyestown mines, New Jersey.

	1	2
SiO_2	19.24	3.36
Al_2O_3	4.72	.76
Fe_2O_3	60.99	82.01
MgO	.70	.01
CaO	.34	None.
Na_2O	.10	.09
K_2O	1.46	.02
H_2O-	.52	1.08
H_2O+	8.88	11.86
CO_2	.06	--------
FeS_2	.077	--------
SO_3	--------	.024
P_2O_5	.588	.246
NiO	.06	--------
CoO	.04	--------
MnO	1.81	.38
C (in carbonaceous material)	.11	--------
	99.695	99.84

	Fe.	P.	S.	Mn.	H_2O.
1	42.73	0.257	0.041	1.40	8.88
2	57.41	.107	.010	.29	11.86

1. Washed ore from the Shields mine. Sample obtained from pile of 25 tons at Stanhope furnace. Tenth Census Rept., vol. 15, p. 176, 1886.

2. Nodule of dense, black limonite from Beatyestown mine. Analyst, R. B. Gage, New Jersey Geological Survey. Both MnO and MnO_2 may have been present in the ore. No attempt was made to separate them.

The analysis of the washed ore shows that it contains, in addition to visible ingredients, small quantities of organic matter, pyrite, apatite, and carbonates. Both analyses show much greater amounts of P_2O_5 than is necessary to combine with the CaO in the mineral apatite, so that some of it is probably combined with iron to form an iron phosphate.

The surface of the German Valley in the vicinity of Califon appears to be generally underlain by limonite, though so far as known the ore does not occur in deposits that are sufficiently thick for profitable working.

Ore was first discovered here in 1871, on the east side of the valley, near the road running north along the foot of the Fox Hill Range. During the following year the region was thoroughly explored by 100 test pits. Nearly all of these struck ore in small masses or concretions mixed with yellow earth and white sandy clay. One mass was 25 feet thick. The explorations seemed to show that the ore occurs in a narrow deposit extending for some distance along and near the contact of the limestone and the gneiss. Explorations made in 1879 and 1880 indicate that the ore occurs also in the limestone entirely across the valley, from the base of the Fox Hill Range on the east to the base of Schooley Mountain on the west.

Ore has been shipped only from the Neighbor and Dafford mines, situated about 2 miles north of Califon, near the center of the valley. In 1879 and 1880 the Dafford mine produced 500 tons of ore and the Neighbor mine 896 tons. Both mines were, however, abandoned immediately thereafter because of the presence in the ore of 3.74 per cent of lead and about 10 per cent of zinc. In later years the country around the mine was explored for zinc, but as only small scattered pockets of sphalerite were found no development was undertaken. A specimen taken from one of these pockets was reported to contain 8.429 per cent zinc and 3.10 per cent sulphur; another specimen gave 34.76 per cent zinc and 31.90 per cent sulphur.

Limonite has been found in commercial quantity south of the Highlands only at the Bird mine, a quarter of a mile west of Clinton. In most of the area the conditions are not favorable for the occurrence of the ore, as the Kittatinny limestone is generally absent.

The Bird mine was discovered in 1873 and 2000 tons of ore, lying at the bottom of the Martinsburg shale, were mined from an open pit. About one-fourth of this required washing, the rest being shipped as mined. Immediately thereafter the mine was abandoned, although test pits sunk near it indicated the presence of large quantities of ore.

COPPER.[a]

Visible grains of chalcopyrite are not infrequently found in the intrusive diabase associated with the Newark group and also with the calcite and zeolites resulting from the alteration of the more vesicular portions of the extrusive basalts. Flakes and thin sheets of metallic copper are also found in veins and joint cracks and more rarely rounded, shotlike and irregular granules of copper occur in the more massive portions of the first Watchung basalt sheet as much as 40 or 50 feet above its base. Copper is also a constituent of the pyroxenes of both the basalt and the diabase, but occurs in extremely minute quantities. Secondary copper minerals are also found along oxidized and stained joint cracks of the various trap masses, but none of the copper deposits in the trap is of commercial value.

In the sandstones and shales of the Newark group, however, copper ores of possible commercial value are found in disseminated grains and irregular masses and here and there in veinlike aggregates and impregnated fault breccias. The principal copper-bearing minerals are chalcocite and native copper, associated with minor amounts of chalcopyrite, chrysocolla, cuprite, malachite, and azurite.

Copper ores have been mined in the Raritan quadrangle at Chimney Rock near Bound Brook, north of Somerville, and near Flemington. Only the mines near Somerville have been worked in recent years.

Lewis summarizes the origin of the ores in substance as follows:

All the Newark (Triassic) copper ores of New Jersey were deposited from hot copper-bearing solutions, doubtless magmatic waters, which derived both their heat and their copper salts from the great underlying Palisades-Rocky Hill trap sill and its offshoots. The deposition of chalcocite in the heated rocks near the intrusives and of native copper with a little chalcocite in the more remote and therefore colder regions may have been chiefly the result of cooling, supplemented perhaps in part by reactions with the widespread calcite of the sedimentary rocks. Conditions favorable to the extensive accumulation of these deposits have been supplied by some relatively impervious member, a dense shale or a trap sheet, which has impeded the movements of the uprising solutions sufficiently to permit them to cool and therefore to form extensive deposits, and also to allow time for possible reactions with the calcite of the sediments and for leaching out the ferric coloring, in part, by the acid waters.

APATITE.

The mineral apatite (chemically tricalcium phosphate) occurs in variable but generally small amounts as a constituent of the magnetite ores of the Raritan quadrangle. In portions of certain ore bodies distributed grains of the mineral are distinctly visible, and in these localities it forms so great a proportion of the rock that the possibility of mining it profitably has been considered. Thus far, however, it has not been produced commercially and does not seem likely to be in the near future.

The most striking occurrence of apatite-bearing ore is at the Canfield phosphate mine, southwest of Dover, near the Dickerson iron mine. Here a layer of magnetite-apatite rock, 8 feet thick, has been exposed by shallow workings. The vein, which dips 65° SE., may be traced by means of the magnetic needle for about 1000 feet along the strike, from southwest to northeast. The ore is a granular aggregate of magnetite and apatite. Samples contain over 50 per cent of apatite by weight, together with small amounts of quartz, feldspar, and mica, and the average rock is reported to contain about 32 per cent of apatite.

The Hurdtown apatite mine is on the east side of Lake Hopatcong, about a mile southwest of the Hurdtown iron mine. The material exposed consists essentially of apatite, magnetite, pyrrhotite, and pyrite, with calcite and silicates as gangue minerals.

The brown or green apatite occurs alone or intergrown with pyrrhotite in irregular ramifications throughout the ore layer

[a] The copper ores have been exhaustively described by J. V. Lewis (New Jersey Geol. Survey Ann. Rept. for 1906, p. 131, 1907). The matter here given is mainly summarized from his report.

of magnetite and pyrite. Much of the apatite is massive, but some of it is in well-formed crystals. The deposit is small and is of no commercial value.

GRAPHITE.

Graphite has long been recognized as a constituent of the crystalline rocks of the New Jersey Highlands and has usually been described as occurring either in the Franklin limestone or in the gneisses.

In the Raritan quadrangle graphite occurs—(1) as a component of the Franklin limestone; (2) in bands of garnetiferous mica schist; (3) in pegmatite dikes; (4) in fine-grained quartz-mica schist, especially in that which is associated with pegmatite.

The first and second methods of occurrence are common, but the graphite is present in quantities so small that it is of no commercial importance. The third method of occurrence is also rather common, especially in pegmatites that contain mica, the graphite lying in large plates between the quartz and feldspar grains of the coarse-grained rock, from which it can be separated only with great difficulty. At Bloomingdale, in the Passaic quadrangle, graphite has been mined from a pegmatite dike and from schists lying in contact with it and has been put on the market. The project, however, was not successful, although the ore in the dump is said to have yielded on analysis 11.2 per cent carbon.

The fourth method of occurrence is the most important in the Raritan quadrangle. Graphitic schists occur at a number of rather widely scattered places and at three localities the proportion of graphite they contain is so large that mills were erected to separate it. One mill, about a mile south of High Bridge, separated in 1880 a product in the form of thin round scales that analyzed 95.79 per cent carbon and 3.6 per cent insoluble earthy substance. More recently a second mill was erected at High Bridge but was not operated except in an experimental way. A third was at the Dickinson graphite mine, on the road running north from Washington Corners, about midway between that place and Brookside, the main source of supply being a coarse black quartz-graphite schist, which may be a sheared pegmatite.

Explorations for graphite have also been made (1) by three pits within a mile and a quarter west of High Bridge, on the road to Glen Gardner, and in the fields on the south, an average sample of material raised yielding, as reported, 10.09 per cent graphite and a single sample 27.82 per cent; (2) by two pits three-quarters of a mile south of High Bridge, on the side of the road to Clinton; and (3) by two pits and a shaft about a quarter of a mile west of Fairmount, on the road to Farmersville, where the graphite was disseminated through gneiss in a distinct belt striking northeast, the rock raised through the shaft containing 6.87 per cent carbon. Attempts were also made to mine zones of graphite schist at the Engelmann mine, on Peapack Brook about a mile and a quarter northwest of Gladstone, where samples of the schist contained 13.04 per cent and 14.95 per cent carbon, and at a point about half a mile farther north on the same stream where it is crossed by the road to Mount Paul.

Explorations for graphite are also reported to have been made at Bett's exploration, west of Morristown, where several shafts disclosed an ore containing 6 per cent carbon; at a point a mile east of Mendham, on the road to Morristown, where graphite constitutes 7.89 per cent of a rock exposed in the side of the road; and at the Fisher mine, on the south side of the road between Pottersville and Fairmount Church, where machinery was set up in 1880 to separate the mineral from a "coarse crystalline rock."

Graphite is also known to occur in quantity in Washington Township, Morris County, about a mile southeast of Fairmount Church; on the road between Chester and Mendham, about 2 miles east of Chester; and about 1¼ miles southwest of Mendham on the road between that place and Gladstone. It is found also in noticeable quantity in an epidote rock where the road from Peapack to Pleasant Valley crosses North Branch of Raritan River.

TALC, ASBESTOS, AND MICA.

Talc, asbestos, and mica have been obtained at a few points in the Raritan quadrangle but only in very small quantities. The talc and asbestos have been quarried from the Franklin limestone at the northeast end of Jenny Jump Mountain, where they were developed along slickensides and shear zones in the limestone; not, however, in sufficient quantity to make the deposit of economic value. The mica, which has been dug about a mile west of Readingsburg, on the road to Cokesbury, is a golden-brown variety in small flakes or scales, contained in a disintegrated rock that was probably a pegmatite. So far as known no muscovite occurs in the quadrangle, the pegmatite, which in most regions contains it, being in the Raritan area almost exclusively a hornblendic variety from which muscovite is nearly or quite absent.

There is no present prospect that any of these three substances will be found in paying quantities in the quadrangle.

BUILDING STONE.[a]

Granite, gneiss, sandstone, and limestone are quarried in the quadrangle for building stone. Marble and slate have been worked but are not utilized at present.

GNEISS AND PEGMATITE.

The gneisses of the Highlands afford good rough building stone at almost any point where outcrops are favorably situated for working. North of the terminal moraine abundant supplies may be obtained from almost any ridge. South of the glaciated area most of the rock has been so deeply weathered that the outcrops are soft and crumbly and only exceptionally yield solid material.

Quarries that produce commercial stone are not numerous. Most of them intermittently produce crushed rock for railroad and highway ballast and make Belgian blocks.

A quarry at Dover yields a light-gray gneiss consisting of medium-grained feldspar, quartz, and greenish-black hornblende in somewhat variable proportions. The rock is jointed into layers 3 to 10 feet thick, broken by other joints at right angles at intervals of 3 to 40 feet. A quarry west of Mount Arlington works a medium-grained, light gray and pink gneiss, which is crossed at intervals by bands that are strongly hornblendic and by veins of pegmatite. The layers are generally 10 feet thick and the quarry has been extensively worked for Belgian blocks and curbing and also for monumental stone, the pink gneiss taking a fine polish. This quarry is the largest in the quadrangle and the only one that is producing monumental stone. Northeast of Waterloo a medium-grained pale pinkish gray to deep brownish pink gneiss of uniform texture, cut by joints spaced from a few inches to several feet, has been quarried intermittently. Another quarry, 2 miles north of this place, works a light-gray fine-grained gneiss consisting of white and pale-pinkish feldspar and quartz and a very little dark augite, though some layers of darker rock contain more augite. There is also some coarse pegmatite. The gneissic lamination is distinct. Another quarry, a mile south of Cranberry Lake station, is in a fine-grained white to very light-gray gneiss, speckled with minute pink garnet crystals. Owing to the general absence of dark-colored minerals the banded structure in this gneiss, though present, is inconspicuous. One-half mile north of the north end of Cranberry Reservoir another quarry is opened in a coarse-grained gray gneiss through which streaks and lines of black hornblende are equally disseminated. The rock is massive and solid and shows no distinct lamination. All these quarries are in the glaciated area.

Two quarries are worked in the German Valley, south of the terminal moraine. One, three-quarters of a mile north of the village of German Valley, is in a gneiss of medium texture and uniform gray color, in bedlike layers 3 to 15 feet thick cut by cross joints 1 to 10 feet apart, so that large blocks are readily obtainable. The other, west of the station, is in a light-gray, fine-grained gneiss composed essentially of white feldspar and quartz, specked with dark grains of hornblende.

A coarse-grained gray to grayish-pink pegmatite granite was quarried for railroad abutments years ago near Port Murray and a medium coarse grained light-gray hornblendic gneiss, much like that at the north end of Cranberry Reservoir, has been quarried a little near Townsbury.

At a number of other points quarries have been opened to furnish building stone for local use, but they are worked intermittently, mainly to supply material for foundations, bridge piers, and other rough work. Stone suitable for dressing is abundant and at many points it might be worked profitably were it not for the lack of transportation facilities. The dimension and monumental stone quarried in the quadrangle is identical with that quarried in other parts of the Highlands area, and with improvement in the means of transportation there is no reason why these deposits should not prove equally valuable.

Pegmatite is quarried at only one point, a mile northwest of Mendham, where a much-decomposed and crumbly rock, impregnated with a bright blue vivianite which coats its component grains, is blasted out and the blue gravel-like material is used for ballasting private roadways.

Chemical analyses of five varieties of granite are given in Lewis's report.[b]

MARBLE.

The only point in the quadrangle at which the Franklin limestone has been systematically quarried for use as building stone is at the Rose Crystal Marble quarry, on the east side of Jenny Jump Mountain, about 2 miles north of Danville, at the junction of the road skirting the east side of the mountain and that crossing it to Shiloh and Hope. Here the rock is a beautiful coarse-grained pink and white marble mottled with light-green spots of pyroxene and spangled with small glistening black dots of phlogopite. It is said to take a fine polish. Many years ago a small quantity was shipped to Philadelphia and used in the interior decorations of public buildings, but the cost of the long haul to the nearest railroad station, then at Hackettstown, was a serious handicap.

The only other point in the quadrangle where the Franklin limestone has been quarried for building stone is 2 miles east of Mendham, where the rock is an ophicalcite, composed mainly of white calcite and light-green serpentine with the structure of a breccia. Some years ago the stone was used in Morristown, but the quarry has not been operated recently.

From time to time rough rock is obtained for foundation and pier work from quarries at Andover and Stag Pond, but no attempt at regular quarrying has been made at any of them.

LIMESTONE.

The Kittatinny limestone has been used throughout the region in which it occurs for foundations, rough walls, bridge piers, residences, schools, churches, and other buildings. Although the stone has given satisfaction, its use has been only local, and demands have been met from temporary quarries on many convenient ledges, from which good stone could be procured at small expense. The stone has been used at Blairstown in several large, handsome buildings.

SANDSTONE, QUARTZITE, AND CONGLOMERATE.

The limestone conglomerate of the Newark group, which occurs northeast of Lebanon, is similar to the well-known "Potomac marble" from Point of Rocks, Md., but it is not used for building or decorative purposes.

A fine-grained finely laminated gray sandstone belonging to the Newark group is quarried at Martinsville, north of Bound Brook. The stone is sprinkled with scattered scales of white mica and with less numerous small brown specks due to the oxidation of pyrite crystals. Banded gray and brown sandstones have also been quarried east of Pluckemin.

The Hardyston quartzite has been quarried at Oxford Furnace, a mile northeast of Danville, 3 miles southwest of Allamuchy, and in the Pohatcong Valley. It occurs in regular beds, some soft enough to dress readily and others very hard. The narrowness of its outcrop, as a rule not near railroad lines, has prevented its use to more than a small extent.

The finer-grained beds of Green Pond conglomerate have been used for building stone to a slight extent near Kenvil and Succasunna, and in some localities more or less use has been made of glacial bowlders derived from it and from the somewhat similar Devonian conglomerate of Bearfort Mountain. The white or light-colored pebbles embedded in the dark-red to chocolate-brown matrix produce attractive and very artistic effects whether the stone is used by itself or in combination with other material. It is, however, very expensive to work because of its great hardness and the difficulty of splitting it.

SLATE.

Slate has been quarried at a number of places between Stephensburg and Port Murray and northeast of Hope, but not in recent years. Roofs of the slate from Port Murray show a uniform dark color after 25 years exposure. With adequate capital and improved quarrying methods to reduce waste the quality of material at some of these localities may be such as to warrant reopening them.

LIME, FLUX, AND CEMENT ROCK.

FRANKLIN LIMESTONE.

The Franklin limestone has been used in the manufacture of lime and land plaster and as a flux, but at present no quarries in it are being worked systematically. Occasionally a little rock is removed from old quarries and burned for lime or land plaster, but the quantity so utilized is very small. Formerly, when the farmers in the Highlands burned their own lime, they used bowlders of the Franklin and Kittatinny limestones gathered from the glacial drift or material quarried from any convenient exposure. Almost any occurrence will supply material for land plaster, but, so far as known, only the quarry at Andover, the quarries southeast of Stag Pond, and the exposures along the east side of Jenny Jump Mountain can supply rock pure enough to make good building lime. Elsewhere the presence of hornblendic igneous rocks and the interlamination of sandy layers seriously impair the quality of the rock.

At a few places in the quadrangle the rock contains so little magnesium carbonate that it might readily be used as a flux or in cement mixtures. This is true of the rock of the Andover quarry, which in some places contains only one-half of one per cent of magnesium carbonate. Unfortunately rock of this quality is so scarce or is so interbedded with layers rich in magnesium carbonate that large supplies at a reasonable cost for quarrying are not certainly available. A mile northwest of Oxford Furnace, however, just outside the quadrangle, a large quarry in the Franklin limestone is producing great quantities of rock that is used as a flux and in cement manufacture.

[a]The paragraphs on building stone have been compiled in large part from a report by J. V. Lewis, New Jersey Geol. Survey Ann. Rept. for 1908, pp. 53-124, 1909.

[b]Op. cit., pp. 65-80.

Analyses of averages of samples of the Franklin limestone obtained at the several quarries in the quadrangle are given by H. B. Kümmel.[a]

The most significant analyses available are those furnished by the Bethlehem Steel Co., for they represent shipments of 55,000 to 80,000 tons from two quarries near McAfee, in the adjoining Franklin Furnace quadrangle, where rock is quarried that is identical with much of that occurring in the Raritan quadrangle. The analyses show clearly that the rock when considered in the mass is a fairly pure limestone.

Analyses of limestone shipped during 1905 from the Bethlehem Steel Co.'s quarry at McAfee.

Date.	SiO_2.	Fe_2O_3, Al_2O_3.	$CaCO_3$.	$MgCO_3$.	S.	P.
January	1.54	1.24	94.23	4.09	.025	.005
February	2 43	1.35	93.09	4.16	.031	.006
March	1.80	.80	94.37	3.44	.019	.006
April	2.19	1.70	91.17	3.93	.018	.006
May	2.30	.72	92.42	4.35	.033	.006
June	1.67	.77	93.10	3.19	.030	.006
July	1.92	1.10	93.10	3.51	.024	.006
November	1.85	.92	91.92	4.49	.030	.007
December	1.55	.96	93.01	4.14	.020	.009

Formerly fluxing material was furnished by a quarry north of Andover and by quarries southeast of Stag Pond, but these have been idle for years.

PALEOZOIC AND LATER LIMESTONES.

The Kittatinny limestone has been quarried in many places and burned for lime. Some of the quarries are large and must have yielded great quantities of stone. In some localities they have not been worked for years and in others they are worked only intermittently to supply local demands; the number that are idle indicates that the use of this stone for lime is much less than in former years. The quarries at Middle Valley, Clinton, Annandale, Prescott Brook, and Peapack are now active or have recently been operated; those at Penwell, Changewater, and Gladstone have been idle for long periods. The limestone contains 15 to 20 per cent of magnesium carbonate. Most of the lime made in the quadrangle is used in agriculture.

The upper beds of the Jacksonburg limestone are suitable for the manufacture of Portland cement but are not so used in the Raritan quadrangle, as the outcrop of the formation is narrow and does not closely adjoin railroad lines.

The shores and bottom of White Pond, north of Marksboro, are covered with a deposit of white marl which exceeds 14 feet in thickness at many places. Numerous attempts have been made to utilize it, but none have been commercially successful. Its composition is shown by the following analysis:

Analysis of white marl, White Pond, Marksboro.[b]

Calcium carbonate	92.25
Magnesium carbonate	2.98
Sand and clay	1.56
Water, vegetable matter	3.21
	100.00

CRUSHED STONE.

The basalt sheets afford unlimited quantities of rock for road metal and concrete. Large quarries are in active operation at Chimney Rock, Bernardsville, and Millington, and one near Middle Valley is at work on a large trap dike in the gneisses. Besides these, small temporary plants are frequently established to crush stone for some local improvement, field stones being commonly used for this purpose. The tailings from the cobbing and separator plants at the Mount Hope mine and at the Hibernia mine, in the Passaic quadrangle, afford several sizes of crushed stone for concrete or road metal.

SAND AND GRAVEL.

North of the terminal moraine and in the valleys for some distance south of it deposits of glacial sand and gravel are numerous. Pits have been opened in many places to obtain a local supply for mortar, road material, and concrete. More extensive openings are found near Ironia, Kenvil, Succasunna, and Carey. At the latter place the deeply disintegrated ledges of the Green Pond formation, there a friable pebbly sandstone, have been extensively mined, chiefly for fire sand and core molds.

CLAY.

No high-grade clay is found in the Raritan quadrangle, but clay suitable for the manufacture of common brick is utilized at Somerville and Flemington and occurs at other points, notably along Dead River south of Millington and in the swamps along Passaic River north of Long Hill. At Flemington the lower portion of the clay bed is disintegrated red shale, and the upper portion is wash from the steep slopes of a disintegrating trap (basalt) hill near by. The mixture burns to a product of good red color and hard body. At Somerville the clay contains many bits of waterworn red shale and some yellow quartz pebbles, which are more common in the upper portion. The body of the clay, which is composed of the finest material derived from the disintegration of the red shale, was accumulated in slack water during the closing stages of the Pleistocene, probably while Raritan River was temporarily dammed by glacially derived sand and gravel discharged into it from the north near Bound Brook. The clay has a very high tensile strength and burns red. At Port Murray partly weathered and disintegrated Martinsburg shale is used in the manufacture of fireproofing. It is rather lean and its tensile strength low. Common brick have been made intermittently near Karrsville and west of Washington, and clays which might be used for making bricks occur at the limonite mines near Beatyestown.

[a] New Jersey Geol. Survey Ann. Rept. for 1905, pp. 175-191, 1906.
[b] Idem for 1877, p. 24.

PEAT.

Peat occurs in many of the swamps and wet meadows of the quadrangle, notably in Great Meadows along Pequest River north of Danville, where it has a thickness of over 7 feet and is 2000 to 3000 acres in extent. Several plants have been established on these meadows. The upper layer of the peat is dug, dried, and pulverized, and is shipped to fertilizer plants, where it is used in the manufacture of commercial fertilizers, or it is applied as a top dressing to sandy or worn-out soils. So far no serious efforts have been made to utilize it as fuel or as a source of nitrogen, though both of these forms of utilization may be possible. Tests made by the Geological Survey of New Jersey show calorific values ranging from 7697 to 10,162 British thermal units and a nitrogen content ranging from 0.88 to 2.62 per cent.

SOILS.

The soils of the northern part of the quadrangle are derived chiefly from the mantle of drift of the Wisconsin glacial stage and those of the southern part from the disintegration of the underlying rock. In the middle part, where there are disconnected patches of an older drift sheet, the soils are due in part to it and in part to the disintegration of the rock beneath. All the glacial drift soils are somewhat closely related in character to the underlying rock, particularly in those areas where the drift is thin or only moderately thick.

North of the terminal moraine the areas of gneiss and granite should in large part be classed as nonagricultural land. Ledges of rock are abundant and the soils are exceedingly stony and bowldery and large areas have been left in forest. South of the moraine rock ledges are much less common, and a much larger part of the country is under cultivation. On level surfaces and gentle slopes the soil is deep, loamy, easily cultivated, and not very stony. On steep slopes the fine material has been washed away, leaving the coarse behind, and in many places rendering the soil excessively stony and causing most of it to be left uncleared.

In the interhighland valleys, such as the Musconetcong and Pohatcong valleys, the soils consist in part of decomposed underlying limestone or shale, in part of loam washed down the steep slopes of the bordering mountains of gneiss, in part of early glacial drift, and in slight part of outwash sand and gravel of the Wisconsin glacial stage. The limestone soils are clayey and very fertile; the drift soils are somewhat more stony.

In the Kittatinny Valley the limestone and shale areas have been glaciated and the soil types are glacial rather than residuary. The till gives rise to a stony, clayey loam, much of it calcareous a short distance below the surface. The flat-topped areas of stratified drift are commonly covered with a loamy to clayey soil, but the slopes are very loose and gravelly. In places the soil on the areas of the Martinsburg shale is very thin, consisting of little more than small fragments of the rock itself. Likewise, in places the soil over the limestone is thin, warty ledges are abundant, and the land is fit only for pasture or timber. Along the upper Pequest and to a less extent on some other streams considerable areas of black peaty soils mark the bottoms of former shallow glacial lakes.

In the Triassic area southeast of the Highlands the Brunswick shale, which is the most widespread formation, has disintegrated into a red silty clay containing minute bits of rock and but few large fragments. Here and there a harder layer yields a few weathered slabs. Where the rock is more of a sandstone, the soil is a sandy loam. Owing to the rapid removal of the soil, it is thin, readily exhausted, and vegetation on it suffers in time of drought. The areas of quartzite conglomerate are covered with a thick and very stony soil, the stones of which form a protective covering which in places attains a thickness of 8 or 10 inches and prevents the removal of the finer material beneath. The sandstone of the Stockton formation produces a sandy soil strewn with weathered slabs. The Lockatong formation forms a rather heavy clay soil strewn with slabs of argillite and flagstone. On the plateau west of Flemington the soils are in many places wet and heavy. The soils on the trap ridges are in general thin and stony but locally are under cultivation, yet the greater part of them has been left in forest.

WATER RESOURCES.[a]

Surface supplies.—The surface waters of the Raritan quadrangle are ample for domestic and industrial needs and are low in mineral content.

In an average year, when the rainfall amounts to 44.09 inches, the flow of the streams of the Highlands is equivalent to 24.41 inches on the drainage area. In an exceedingly dry year, when the rainfall is as low as 31.63 inches, this run-off drops to 16.82 inches. On the red shale area the rainfall is a little greater and the average run-off is 21.72 inches, which, in extreme drought, falls to 16.25 inches for the Raritan and to 14.83 inches for small streams. During extreme drought the minimum daily flow for streams of the Highlands for each square mile of drainage area, when not held back in ponds, may fall as low as 81,000 gallons for streams with ordinary basins, 110,000 gallons for streams with low, flat, drift-covered basins which furnish large ground flow, and 5000 gallons for small red-shale streams. With adequate storage reservoirs the larger streams will yield from 570,938 to 669,000 gallons daily for each square mile of tributary area, the larger amount being yielded by streams of the Highlands.

Rockaway, Somerville, Raritan, High Bridge, Glen Gardner, and Washington have public supplies drawn from surface streams; Junction, Flemington, Clinton, Dover, Hackettstown, and Bound Brook are supplied in part by streams and in part by wells.

Water power.—Some of the streams furnish water power of considerable potential value. By utilizing the normal flow of the streams—that is the flow without storage—it is possible to develop 0.069 continuous horsepower for each square mile of drainage area for each foot of fall, except for small streams on the red-shale areas which have little ground flow. This amount of power will be available for an average of nine months each year, but during the driest month of an extreme drought it will fall as low as 0.014 horsepower on the ordinary streams and 0.025 horsepower on those with large ground flow. If storage in mill ponds be provided so that the entire daily flow of the stream can be concentrated into 12 hours, the horsepower may be doubled. With greater storage to carry the excess water of wet periods over the dry months these maximum amounts of power may be made available for longer periods than nine months a year.

Water power has been developed most extensively at High Bridge, Pottersville, Raritan, and Hackettstown and to a much less extent at Flanders, Readingsburg, Waterloo, and Allamuchy. In addition 50 net horsepower are now or have recently been in use at each of twenty or more other places and still smaller powers have been developed at many points.

Quality.—The following table gives the average chemical composition of water from Raritan River at Bound Brook, together with the maximum and minimum determinations made on a series of samples collected daily for a year. The figures represent approximately the general chemical composition of the drainage and show it to be a calcium carbonate water of low mineral content, suitable for all industrial purposes. The streams of the Highlands are somewhat lower in mineral content:

Maximum, minimum, and average analyses of water from Raritan River at Bound Brook, N. J.[a]

[Parts per million.]

Constituents.	Maximum.	Minimum.	Average.
Turbidity	272	5	37
Suspended matter	202	.8	36
Coefficient of fineness	1.88	.16	1.16
Silica (SiO_2)	19	12	16
Iron (Fe)	.7	.09	.15
Calcium (Ca)	16	8.2	12
Magnesium (Mg)	1.6	4.0	3.9
Sodium and potassium (Na+K)	14	6.3	9.1
Carbonate radicle (CO_3)	.0	.0	.0
Bicarbonate radicle (HCO_3)	56	38	51
Sulphate radicle (SO_4)	18	10	12
Nitrate radicle (NO_3)	1.0	2.8	1.9
Chlorine (Cl)	5.4	3.8	4.7
Dissolved solids	104	64	85

[a] The maximum and minimum figures for dissolved constituents are for the analyses corresponding to maximum and minimum dissolved solids. Analyses by R. B. Dole, Chase Palmer, M. G. Roberts, and W. D. Collins of samples collected daily from September 10, 1906, to September 12, 1907.

Underground water.—The amount of ground water available differs considerably with the geologic structure. In the Triassic sandstone and shale areas moderate amounts can usually be obtained at depths ranging from 50 to 150 feet. In 38 wells in these rocks the average depth recorded by the Geological Survey of New Jersey is 107 feet and the average yield is 19 gallons a minute. The maximum yield, 107 gallons, was obtained from the deepest well, 405 feet, but it must not be inferred that the deeper wells always yield the more abundant supply.

[a] For further information see Vermeule, C. C., Water supply of New Jersey: New Jersey Geol. Survey Final Rept., vol. 3, 1894; La Forge, Laurence, Water resources of the central and southwestern highlands of New Jersey: U. S. Geol. Survey Water-Supply Paper 110, pp. 141-155, 1905.

The gneisses of the Highlands are much less pervious than the Triassic sandstones and shales, and the areas underlain by them show greater range in the depths of the wells and the amounts of water found. In the vicinity of Bernardsville the average depth of 12 wells drilled in gneiss is reported to be 320 feet and the average yield 15 gallons a minute. One well only 86 feet deep is reported to yield 100 gallons a minute; two wells 621 feet deep produce 3½ and 8 gallons; and two others about 700 feet deep are practically dry. The deep mines at Mount Hope, Wharton, Oxford, and other points farther north afford some data as to the amount of water in these rocks. Several of these mines are 1000 feet or more in depth, but in none of them is the amount of water so large as to be very troublesome, although pumping is necessary in all. In one mine with 125,000 square feet or more of underground workings the pumps throw 300 gallons or less a minute. Considering the great extent of the underground workings at some mines, comparatively little water is found in them, and it is evident that the gneiss is relatively dry except locally along open seams or crushed zones. All the data from this and adjoining regions of similar geologic structure indicate that only small amounts of water can be obtained from wells in gneiss and that a relatively large number of dry wells may be expected, though some wells in gneiss have yielded large quantities. The basalt and diabase rocks also contain very small amounts of water and wells in them will usually not prove satisfactory.

Very little information is at hand regarding deep wells in the Paleozoic formations. A well at Paulina supplies Blair Academy and a portion of the town of Blairstown. Two wells in limestone at Clinton yielded only 2 and 3 gallons a minute. Nearly all the wells in the belts of Paleozoic rock are in glacial drift.

In most places in the northern part of the quadrangle the glacial drift, which along the line of the terminal moraine and in the valleys reaches great thicknesses, furnishes water at moderate depths and in some places supplies flowing wells. Several of the latter at Dover are 60 to 224 feet deep. At Mount Arlington station a well penetrates 267 feet of glacial drift, until recently the greatest thickness of drift known in the State. Other wells in drift from 34 to 95 feet in depth, reported from Andover, Allamuchy, Lake Hopatcong, Tranquility, and Huntsville, yield 6 to 30 gallons a minute.

Springs.—Though springs are numerous, especially in the Highlands, the water of only a few has been bottled for shipment as table water. Hoctawanna Spring, near Budd Lake, and Indian Spring, near Rockaway, reported shipments in 1908. In earlier years the water of Beacon Mountain Spring, near Denville, was shipped. Schooley Mountain Spring, about 2 miles south of Hackettstown, on the road to the Schooley Mountain House, was formerly a popular resort. Its water was analyzed by C. McIntyre, jr., in 1870, and was found to be a calcium carbonate water of low mineral content, doubtless more or less typical of the ground waters of the mountainous area. Ground waters in the low lands near the coast are probably somewhat more highly mineralized.

Analysis of water from Schooley Mountain Spring.

[Parts per million.]

Silica (SiO_2)	13
Iron (Fe)	4.8
Aluminum (Al)	1.3
Calcium (Ca)	18
Magnesium (Mg)	7.8
Sodium and potassium (Na+K)	7.2
Bicarbonate radicle (HCO_3)	88
Sulphate radicle (SO_4)	20
Chlorine (Cl)	4.5
Total solids	123

Annandale, Blairstown, Netcong, Stanhope, and Wharton use ground waters for public supplies.

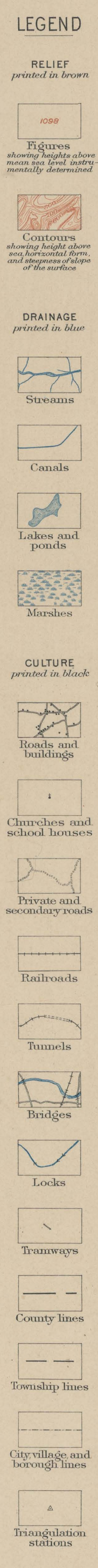
June, 1913.

TOPOGRAPHY

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF NEW JERSEY
HENRY B. KÜMMEL STATE GEOLOGIST

NEW JERSEY
RARITAN QUADRANGLE



Henry Gannett, Chief Topographer.
George H. Cook, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey and C.C. Vermeule.
Topography by Geological Survey of New Jersey.
Surveyed in 1881-86.
Revised in 1903 under the direction of H.M. Wilson, Geographer, and Hersey Munroe, Topographer in charge; by Robert Coe, J.M. Whitman, Jr., J.I. Gayetty, A.T. Fowler, B.B. Alexander, Ira M. Flocker, and J.P. Gardner.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 20 feet.

Datum is mean sea level.

Edition of Aug. 1905, reprinted May 1911.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

STATE OF NEW JERSEY
HENRY B. KÜMMEL STATE GEOLOGIST

NEW JERSEY
RARITAN QUADRANGLE

LEGEND (continued)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

(Areas of metamorphic rocks of unknown origin are shown by hachures)

PRE-CAMBRIAN

pgn — Pochuck gneiss *(dark gneisses composed of pyroxene, hornblende, oligoclase, and magnetite, partly igneous in origin)*

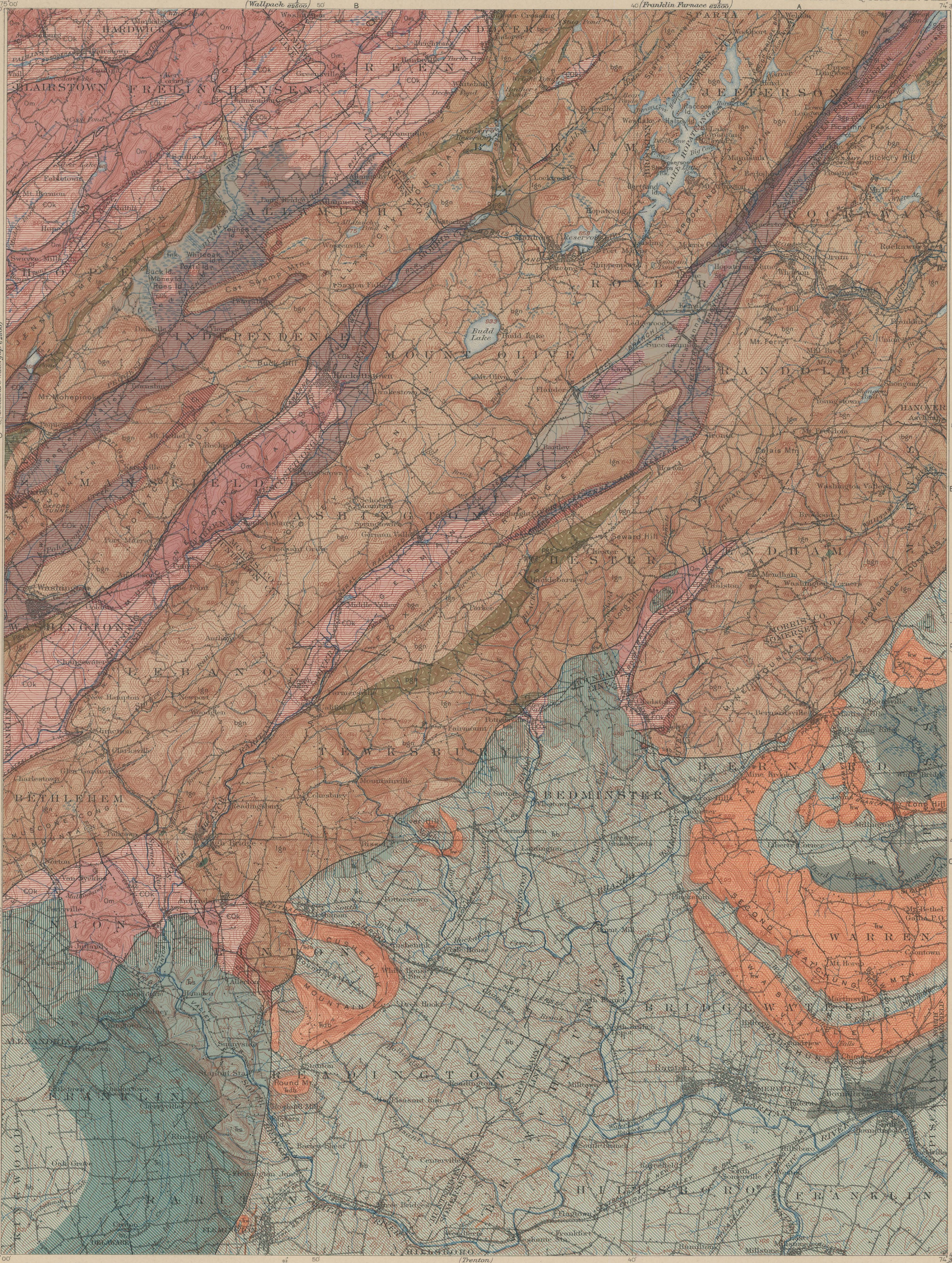
gs — Graphite schist *(including garnetiferous graphite schist and mica-graphite schist)*

fnk — Formation not known *(deeply covered by drift)*

Note: *In areas deeply covered by drift the patterns are subdued by an overprinted color and the boundaries are dotted. The Quaternary deposits are represented on the surficial geology map.*

Faults

Concealed faults *(covered by younger deposits)*



LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines; metamorphism is indicated by hachures combined with the line patterns)

TRIASSIC — Newark group

Ŧb — Brunswick shale *(soft red shale with few beds of sandstone)*

Ŧl — Lockatong formation *(dark argillite and fine-grained slabby sandstone)*

Ŧs — Stockton formation *(gray sandstone, arkose, and red shale)*

Ŧc — Conglomerates in the Brunswick, Lockatong, and Stockton formations

UNCONFORMITY

DEVONIAN

Dc — Cornwall ("Pequanac") shale *(black fissile shale and slate)*

Dk — Kanouse sandstone *(light-colored sandstone, or quartzite)*

SILURIAN

Sd — Decker limestone *(dark-gray impure limestone)*

Sl — Longwood shale *(red shale)*

Sgp — Green Pond conglomerate *(conglomerate and quartzite)*

UNCONFORMITY

ORDOVICIAN

Om — Martinsburg shale *(shale, slate, and sandstone)*

Oj — Jacksonburg limestone *(dark-blue or black massive and shaly limestone, with conglomerate at base)*

UNCONFORMITY

CAMBRIAN

€Ok — Kittatinny limestone *(blue limestone, often magnesian, with occasional cherty layers)*

€h — Hardyston quartzite *(vitreous, ferruginous, calcareous quartzite, in part feldspathic)*

UNCONFORMITY

PRE-CAMBRIAN — Metamorphic

fl — Franklin limestone *(white and mottled marble, containing pyroxene, chondrodite, and serpentine; in places includes slaty rocks resembling sheared volcanics)*

IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs)

TRIASSIC

Ŧdb — Diabase *(sheets and basaltic dikes intrusive in the Newark group)*

Ŧw — Watchung basalt *(three successive lava flows interbedded in the Brunswick shale)*

Included in Newark group

PRE-CAMBRIAN

bgn — Byram gneiss *(gray granitoid gneiss composed of microcline, microperthite, quartz, and hornblende, with a little pyroxene and biotite)*

lgn — Losee gneiss *(white granitoid gneiss, composed of quartz, oligoclase, pyroxene, and some hornblende and biotite)*

Legend is continued on the left margin.

Henry Gannett, Chief Topographer.
George H. Cook, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey and C.C. Vermeule.
Topography by Geological Survey of New Jersey.
Surveyed in 1881-86.
Revised in 1903 under the direction of H.M. Wilson, Geographer, and Hersey Munroe, Topographer in charge; by Robert Coe, J.M. Whitman, Jr., J.I. Gayetty, A.T. Fowler, B.B. Alexander, Ira M. Flocker, and J.P. Gardner.

TRUE NORTH — MAGNETIC NORTH — 8½°
APPROXIMATE MEAN DECLINATION 1902.

Scale 1/125000
1 ½ 0 1 2 3 4 5 Miles
1 ½ 0 1 2 3 4 5 Kilometers
Contour interval 20 feet.
Datum is mean sea level.
Edition of Nov. 1911.

Pre-Cambrian geology by W. S. Bayley.
Paleozoic geology by H. B. Kümmel and Stuart Weller.
Triassic geology by H. B. Kümmel.
Surveyed in 1895 to 1909.

SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY.

SURFICIAL GEOLOGY

STATE OF NEW JERSEY

HENRY B. KÜMMEL, STATE GEOLOGIST

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

NEW JERSEY
RARITAN QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

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

QUATERNARY

Recent

Qal — Recent alluvium *(in stream bottoms)*

Qs — Swamp muck *(alluvium and humus)*

Pleistocene — Wisconsin stage — (Passaic)

Qlpc — Loam and clay deposits of Lake Passaic

Qlps — Shore deposits of Lake Passaic *(stratified sand and gravel of beaches)*

Shore line of Lake Passaic

Qe — Eskers *(ridges of stratified drift)*

Qk — Kames, kame terraces, and stratified drift of kame habit *(irregular deposits of stratified drift)*

Qsd — Stratified drift *(chiefly valley trains or over-wash plains; in places thin)*

Qt — Till *(in places very thin and rock exposures numerous)*

Qtm — Terminal moraine *(belt of thick drift with very irregular topography)*

Qem — Extra-morainic drift *(in part of late glacial age but mixed with early glacial drift)*

Qoa — Older alluvium *(locally includes some eolian sand; mostly interglacial; possibly Pensauken in part)*

Jerseyan stage

Qed — Early glacial drift *(chiefly till much older than the moraine; thin in many places)*

Scattered bowlders of early glacial drift

Qp — Pensauken formation *(nonglacial gravel and sand; perhaps contemporaneous with early glacial drift)*

PRE-QUATERNARY

bd — Bed rock *(outside the glacial moraine; small bedrock outcrops inside the moraine included with till)*

Note: *Sand, gravel, and clay pits in surficial deposits are shown on Economic Geology map.*

Henry Gannett, Chief Topographer.
George H. Cook, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey and C.C. Vermeule.
Topography by Geological Survey of New Jersey.
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TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.

Datum is mean sea level.

Edition of Aug. 1911.

Geology by Rollin D. Salisbury, assisted by Henry B. Kümmel, C.E. Peet, and A.C. Whitson.
Surveyed in 1892-1895.

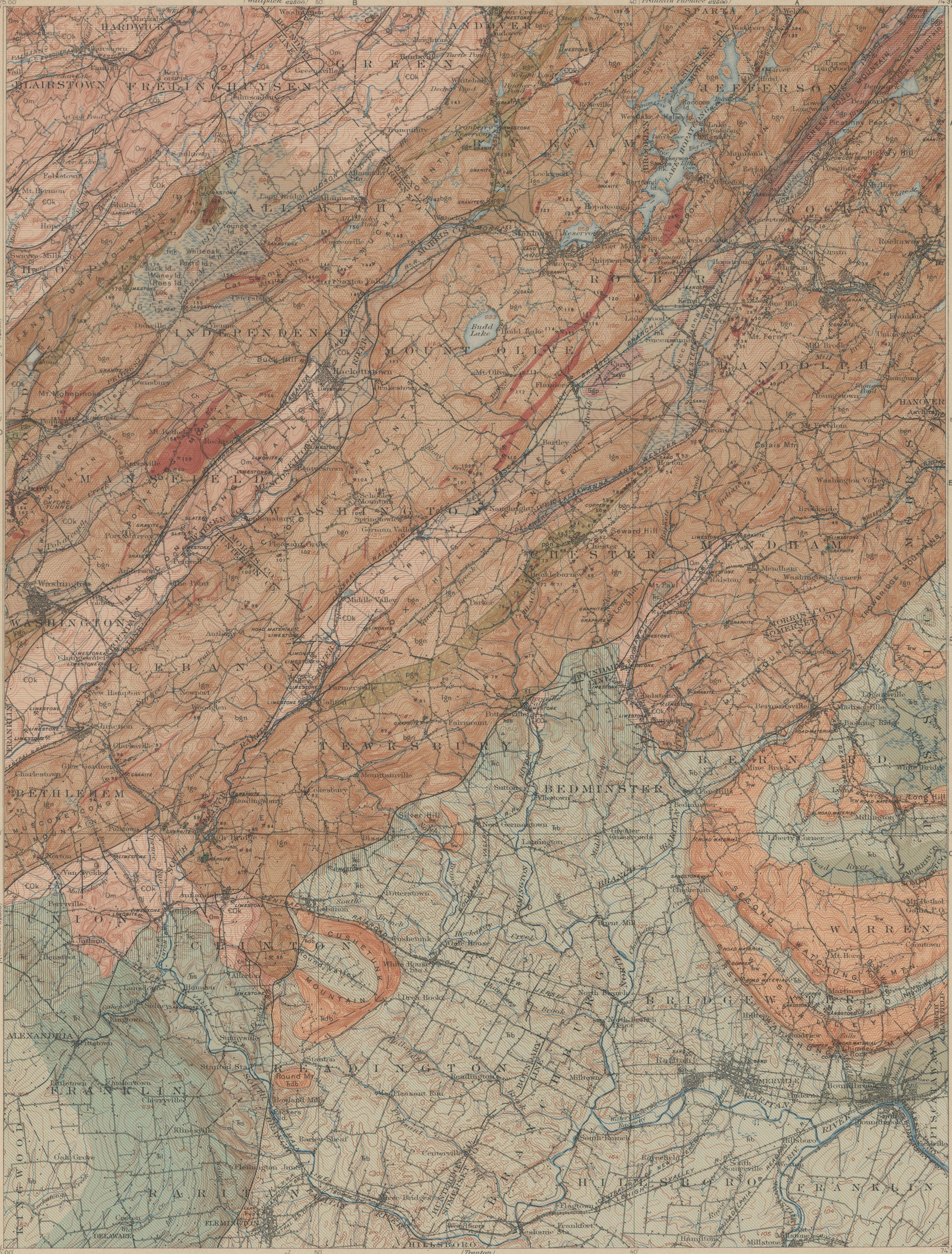
SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY.

ECONOMIC GEOLOGY

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF NEW JERSEY
HENRY B. KÜMMEL, STATE GEOLOGIST

NEW JERSEY
RARITAN QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines; metamorphism is indicated by hachures combined with the line patterns)

TRIASSIC — Newark group

- ₸b — Brunswick shale *(soft red shale with few beds of sandstone)*
- ₸l — Lockatong formation *(dark argillite and fine-grained slabby sandstone)*
- ₸s — Stockton formation *(gray sandstone, arkose, and red shale)*
- ₸c — Conglomerates in the Brunswick, Lockatong, and Stockton formations

UNCONFORMITY

DEVONIAN

- Dc — Cornwall ("Pequanac") shale *(black fissile shale and slate)*
- Dk — Kanouse sandstone *(light-colored sandstone, or quartzite)*

SILURIAN

- Sd — Decker limestone *(dark-gray impure limestone)*
- Sl — Longwood shale *(red shale)*
- Sgp — Green Pond conglomerate *(conglomerate and quartzite)*

UNCONFORMITY

ORDOVICIAN

- Om — Martinsburg shale *(shale, slate, and sandstone)*
- Oj — Jacksonburg limestone *(dark-blue or black massive and shaly limestone, with conglomerate at base)*

UNCONFORMITY

CAMBRIAN

- €Ok — Kittatinny limestone *(blue limestone, often magnesian, with occasional cherty layers)*
- €h — Hardyston quartzite *(vitreous, ferruginous, calcareous quartzite, in part feldspathic)*

UNCONFORMITY

PRE-CAMBRIAN — Metamorphic

- fl — Franklin limestone *(white and mottled marble, containing pyroxene, chondrodite, and serpentine; in places includes slaty rocks resembling sheared volcanics)*

IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs)

TRIASSIC — Included in Newark group

- ₸db — Diabase *(sheets and basaltic dikes intrusive in the Newark group)*
- ₸w — Watchung basalt *(three successive lava flows interbedded in the Brunswick shale)*

PRE-CAMBRIAN

- bgn — Byram gneiss *(gray granitoid gneiss composed of microcline, microperthite, quartz, and hornblende, with a little pyroxene and biotite)*
- lgn — Losee gneiss *(white granitoid gneiss, composed of quartz, oligoclase, pyroxene, and some hornblende and biotite)*

Legend is continued on the left margin.

LEGEND
(continued)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

(Areas of metamorphic rocks of unknown origin are shown by hachures)

PRE-CAMBRIAN

- pgn — Pochuck gneiss *(dark gneisses composed of pyroxene, hornblende, oligoclase, and magnetite, partly igneous in origin)*
- gs — Graphite schist *(including garnetiferous graphite schist and mica-graphite schist)*

- fnk — Formation not known *(deeply covered by drift)*

Note: *In areas deeply covered by drift the patterns are subdued by an overprinted color and the boundaries are dotted. The Quaternary deposits are represented on the surficial geology map.*

Faults

Concealed faults *(covered by younger deposits)*

Known mineral deposits

Magnetite deposits *(indicated by belts of abnormally high magnetic attraction)*

⚒ *Mines and quarries (magnetite unless otherwise indicated)*

Peat, clay, sand, and gravel pits

Mine names, represented on the map by numbers, are printed on the back of this sheet.

Note: Limestone suitable for flux, lime, and cement manufacture is obtainable from Franklin and Jacksonburg limestones; Kittatinny limestone, also, is burned for lime; graphite in commercial quantities may be obtainable from the graphite schist; probably workable ores of copper occur in the Newark group; desirable building stone is obtained from the Losee and Byram gneisses.

Henry Gannett, Chief Topographer.
George H. Cook, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey and C.C. Vermeule.
Topography by Geological Survey of New Jersey.
Surveyed in 1881-86.
Revised in 1903 under the direction of H.M. Wilson, Geographer, and Hersey Munroe, Topographer in charge; by Robert Coe, J.M. Whitman, Jr., J.I. Gayetty, A.T. Fowler, B.B. Alexander, Ira M. Flocker, and J.P. Gardner.

TRUE NORTH — MAGNETIC NORTH — 8½°
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.
Edition of Nov. 1911.

Pre-Cambrian geology by W.S. Bayley.
Paleozoic geology by H.B. Kümmel and Stuart Weller.
Triassic geology by H.B. Kümmel.
Surveyed in 1895 to 1909.
Magnetic data by Thomas A. Edison

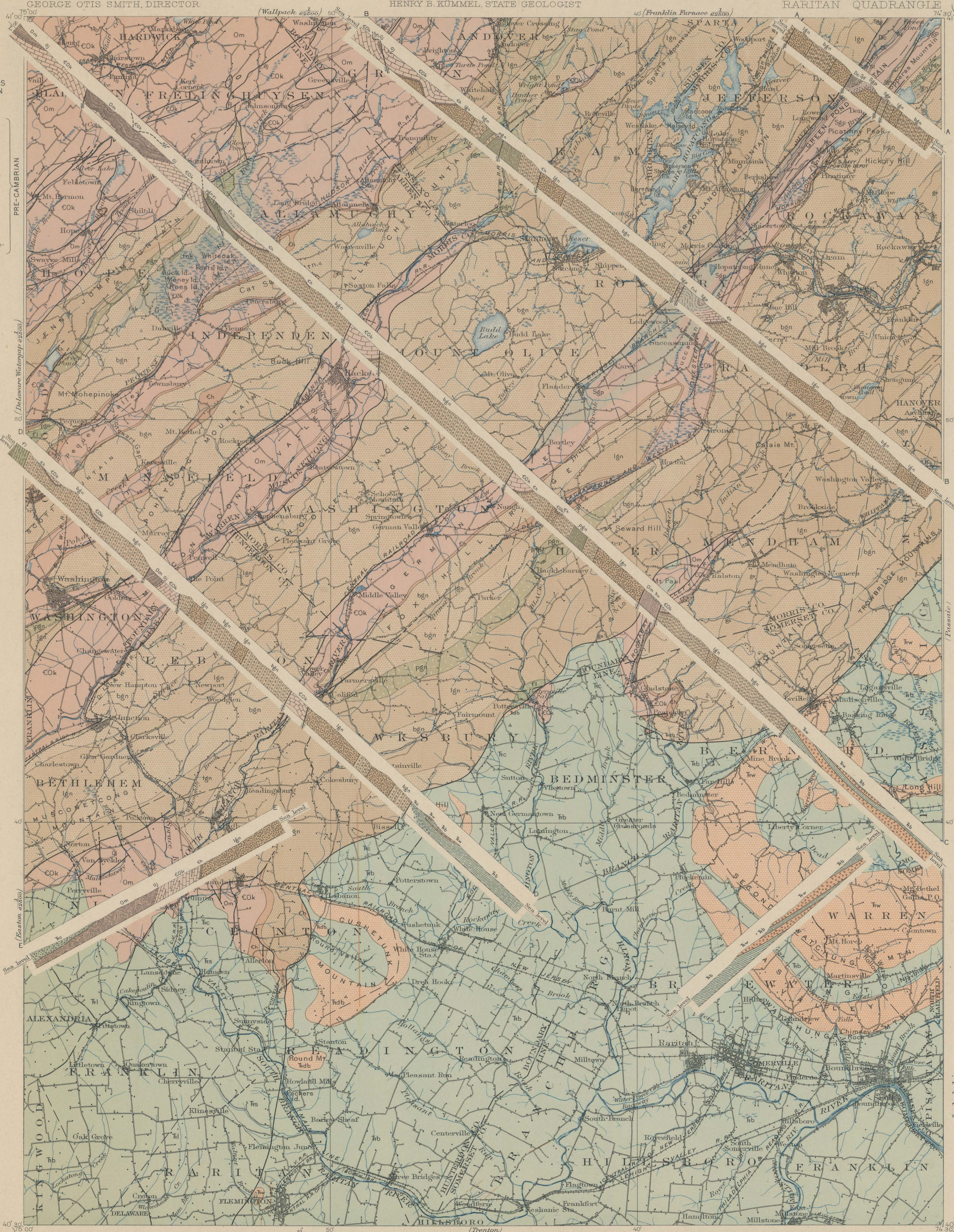
SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY

STRUCTURE SECTIONS

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF NEW JERSEY
HENRY B. KÜMMEL, STATE GEOLOGIST

NEW JERSEY
RARITAN QUADRANGLE



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TRUE NORTH / MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

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Edition of Feb. 1912

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Triassic geology by H. B. Kümmel.
Surveyed in 1895 to 1909.

SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY.

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL	SECTION SYMBOL			
Ꞧb	Ꞧb	Brunswick shale (soft red shale with few beds of sandstone)	Newark group	TRIASSIC
Ꞧl		Lockatong formation (dark argillite and fine-grained slabby sandstone)	Newark group	TRIASSIC
Ꞧs		Stockton formation (gray sandstone, arkose, and red shale)	Newark group	TRIASSIC
Ꞧc	Ꞧc	Conglomerates in the Brunswick, Lockatong, and Stockton formations	Newark group	TRIASSIC

UNCONFORMITY

SHEET SYMBOL	SECTION SYMBOL		
Dc	Dc	Cornwall ("Pequanac") shale (black fissile shale and slate)	DEVONIAN
Dk	Dk	Kanouse sandstone (light-colored sandstone or quartzite)	DEVONIAN
Sd	Sd	Decker limestone (dark-gray impure limestone)	SILURIAN
Sl	Sl	Longwood shale (red shale)	SILURIAN
Sgp	Sgp	Green Pond conglomerate (conglomerate and quartzite)	SILURIAN

UNCONFORMITY

SHEET SYMBOL	SECTION SYMBOL		
Om	Om	Martinsburg shale (shale, slate, and sandstone)	ORDOVICIAN
Oj	Oj	Jacksonburg limestone (dark-blue or black massive and shaly limestone with conglomerate at base)	ORDOVICIAN

UNCONFORMITY

SHEET SYMBOL	SECTION SYMBOL		
€Ok	€Ok	Kittatinny limestone (blue limestone, often magnesian, with occasional cherty layers)	ORDOVICIAN / CAMBRIAN
€h	€h	Hardyston quartzite (vitreous, ferruginous, calcareous quartzite, in part feldspathic)	CAMBRIAN

UNCONFORMITY

SHEET SYMBOL	SECTION SYMBOL			
fl	fl	Franklin limestone (white and mottled marble, containing pyroxene, chondrodite, and serpentine; in places includes slaty rocks resembling sheared volcanics)	Metamorphic	PRE-CAMBRIAN

IGNEOUS ROCKS

SHEET SYMBOL	SECTION SYMBOL			
Ꞧdb		Diabase (sheets and basaltic dikes intrusive in the Newark group)		TRIASSIC
Ꞧw	Ꞧw	Watchung basalt (three successive lava flows interbedded in the Brunswick shale)	Included in Newark group	TRIASSIC
bgn	bgn	Byram gneiss (gray granitoid gneiss composed of microcline, microperthite, quartz, and hornblende, with a little pyroxene and biotite)		PRE-CAMBRIAN
lgn	lgn	Losee gneiss (white granitoid gneiss composed of quartz, oligoclase, pyroxene, and some hornblende and biotite)		PRE-CAMBRIAN

Legend is continued on the left margin.

LEGEND
(continued)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

SHEET SYMBOL	SECTION SYMBOL		
pgn	pgn	Pochuck gneiss (dark gneisses composed of pyroxene, hornblende, oligoclase, and magnetite, partly igneous in origin)	PRE-CAMBRIAN
gs		Graphite schist (including garnetiferous graphite schist and mica-graphite schist)	PRE-CAMBRIAN
fnk	fnk	Formation not known (deeply covered by drift)	

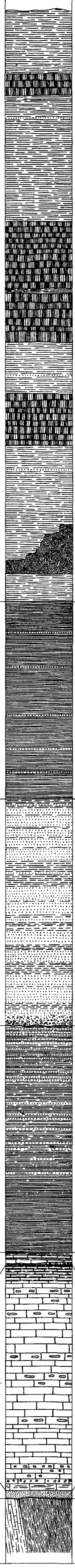
Faults

Concealed faults (covered by younger deposits)

COLUMNAR SECTIONS

GENERALIZED SECTION OF THE ROCKS EXPOSED IN THE RARITAN QUADRANGLE.

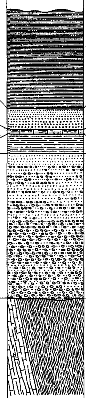
SCALE: 1 INCH = 1000 FEET.



System.	Formation.	Symbol.	Section.	Thickness in feet.	Character of rocks.	Character of topography and soil.
TRIASSIC (NEWARK GROUP)	Brunswick shale. (Interbedded Watchung basalt.)	TRb (TRw)		5000+ (2250)	Soft red shale with local beds of red sandstone. Conglomerates along the western margin of the outcrop. Three basaltic lava flows, having an aggregate thickness of 2250 feet, are interbedded in the shale.	Wide rolling lowland and red sandy clay-loam soil. Basaltic lava flows form low linear hills.
				(0-600±)	Diabase sheet intrusive in the shale.	Low linear hills and round knobs.
	Lockatong formation.	TRl		1800-3600	Dark-colored argillite and fine-grained slabby sandstone. Conglomerates along the western margin of the outcrop.	Ridges and plateaus rising steeply above adjacent plains. Sandy clay-loam soil.
	Stockton formation.	TRs		2800-3100	Gray, yellowish, and reddish-brown sandstone, mostly massive and moderately hard. Basal beds arkosic and locally conglomeratic. Red shale intercalations at various horizons, and conglomerates along the western margin of the outcrop.	Low ridges and valleys. Sandy clay-loam soil.
	UNCONFORMITY					
ORDOVICIAN	Martinsburg shale.	Om		3000±	Fine black shale, slate, and sandstone. Sandstones dark to bluish gray, in part calcareous, and most numerous in upper portion of formation.	High rolling hills, upland floor of Kittatinny Valley. Stony clay and loamy soils, generally thin.
	Jacksonburg limestone.	Oj		135-150	Dark fossiliferous limestone and shale; limestone conglomerate at the base.	Hill slopes. Clayey soil.
CAMBRIAN	Kittatinny limestone.	€Ok		2500-3000±	Massive-bedded bluish-gray magnesian limestone containing layers of black chert and oolite. Shales and interbedded thin limestones at top and base.	Lowland floor of Kittatinny Valley, chiefly rolling hills; locally rough "warty" topography. Clayey soils, in places thin.
	Hardyston quartzite.	€h		5-200	Arkosic quartzite, in places conglomeratic.	Hill slopes.
PRE-CAMBRIAN	Byram, Losee, and Pochuck gneisses and Franklin limestone.	bgn lgn pgn fl			Gneisses of both sedimentary and igneous origin and crystalline limestone, composing the basement upon which the Paleozoic sediments were deposited.	High ridges with plateau-like summits, dissected near their margins, and steep slopes. Thick stony soils in areas not covered by glacial drift.

GENERALIZED SECTION OF THE ROCKS EXPOSED IN THE NORTHEAST CORNER OF THE RARITAN QUADRANGLE.

SCALE: 1 INCH = 1000 FEET.



System.	Formation.	Symbol.	Section.	Thickness in feet.	Character of rocks, topography, and soil.
DEVONIAN	Cornwall ("Pequanac") shale.	Dc		1000±	Dark thick-bedded shale, somewhat sandy toward the top. Low rolling hills. Sandy clay soil.
	Kanouse sandstone.	Dk		215	Fine-grained white quartz conglomerate, with greenish sandstone above. Valley bottoms and low ridges. Sandy soil.
SILURIAN	Decker limestone.	Sd		50	Dark-gray impure siliceous and shaly limestone. Valley bottoms.
	Longwood shale.	Sl		200±	Soft red shale. Valley bottoms. Clay soil, largely covered.
	Green Pond conglomerate.	Sgp		1500±	Coarse quartz conglomerate, interbedded with and grading upward into quartzite and sandstone. High, steep-sided, even-crested ridges. Sandy soil with numerous rock outcrops.
	UNCONFORMITY				
PRE-CAMBRIAN	Byram, Losee, and Pochuck gneisses and Franklin limestone.	bgn lgn pgn fl			Gneisses of both sedimentary and igneous origin and crystalline limestone, composing the basement upon which the Paleozoic sediments were deposited. High ridges with plateau-like tops and steep slopes. Thick stony soil in areas not covered by glacial drift.

LIST OF MINES.

Location indicated on the map by numbers.

1. Cogill.
2. Denmark.
3. White Meadow.
4. Hickory Hill.
5. Mount Hope (active).
6. Mount Hope (active).
7. Teabo.
8. Allen.
9. Richard (active).
10. Baker.
11. Dolan.
12. Mount Pleasant.
13. Huff.
14. Washington Forge.
15. Johnson Hill.
16. Orchard.
17. Hurd (active).
18. J. D. King.
19. Stirling.
20. Scrub Oak.
21. Corwin.
22. Jackson Hill.
23. Randall Hill.
24. Baker.
25. Baker.
26. Baker.
27. Millen.
28. Canfield.
29. Canfield's Phosphate.
30. Byram.
31. Brotherton.
32. Dickerson (active).
33. Evers.
34. McFarland.
35. King.
36. C. King.
37. Bryant.
38. Van Doren.
39. Sigler.
40. Swedes.
41. Munson.
42. Frenchman.
43. Dalrymple.
44. Lawrence.
45. De Hart.
46. David Horton.
47. Combs.
48. Lewis.
49 Connet.
50. Janes.
51. Auble.
52. Thorp.
53. Barnes.
54. Daniel Horton.
55. Skellenger.
56. Beemer.
57. Leake.
58. Squier.
59. Kean.
60. Cooper.
61. Swayze.
62. Budd.
63. Sampson.
64. Creamer.
65. Topping.
66. Dickerson Farm.
67. Hedges.
68. Peach Orchard.
69. Quimby.
70. Harden.
71. Child.
72. Hacklebarney.
73. Gulick.
74. Hacklebarney.
75. Pitney.
76. Langdon.
77. Rarick.
78. Wortman.
79. Bartle.
80. Welch.
81. Fox Hill.
82. Burrill.
83. Cokesbury.
84. Old Furnace.
85. Emery.
86. Sharp.
87. Annandale.
88. Large.
89. High Bridge.
90. Kean or Silverthorn.
91. Van Syckle.
92. Rodenbaugh.
93. Asbury.
94. Miller.
95. Maberry.
96. Eveland.
97. Banghart.
98. Alvah Gray.
99. Apgar.
100. Pidcock.
101. Sharp.
102. Hann.
103. Young.
104. Marsh.
105. Derenberger.
106. Stoutenburg.
107. Lake.
108. Naughright.
109. Wm. Sharp.
110. Hopler.
111. Creamer.
112. Mount Olive.
113 Drake.
114. Osborne.
115. Stephens.
116. Church.
117. Hilt.
118. Wolf.
119. Willetts.
120. Wilkinson.
121. High Ledge.
122. Lowrance.
123. Stanhope (active).
124. Budd.
125. Haggerty.
126. Gove.
127. Burt.
128. Silver Spring.
129. Lurk.
130. Davenport.
131. Hurdtown Apatite.
132. Hurd.
133. Lower Weldon.
134 Upper Weldon.
135. Gaffney.
136. Bedell.
137. Roseville.
138. McKean.
139. Silver.
140. Cascade.
141. Glendon.
142. French.
143. Waterloo.
144. Haggerty.
145. Wintermuth.
146. Young.
147. Frace.
148. Pyle.
149. Hibler.
150. Haggerty.
151. Hibler.
152. Schaeffer.
153. Ayers.
154. Cummins.
155. Green Farm.
156. Searle.
157. Tunison.
158. Egbert Church.
159. Bald Pate.
160. Mitchell.
161. Creager.
162. Lanning.
163. McKinley and Carwheel.
164. New and Welch.
165. Pequest.
166. Henry Tunnel.
167. Hoit.
168. Hoagland.
169. Cook.
170. Kishpaugh.
171. Inshow.
172. Stinson.
173. Albertson.
174. Davis.
175. Shaw.
176. Howell.

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