DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

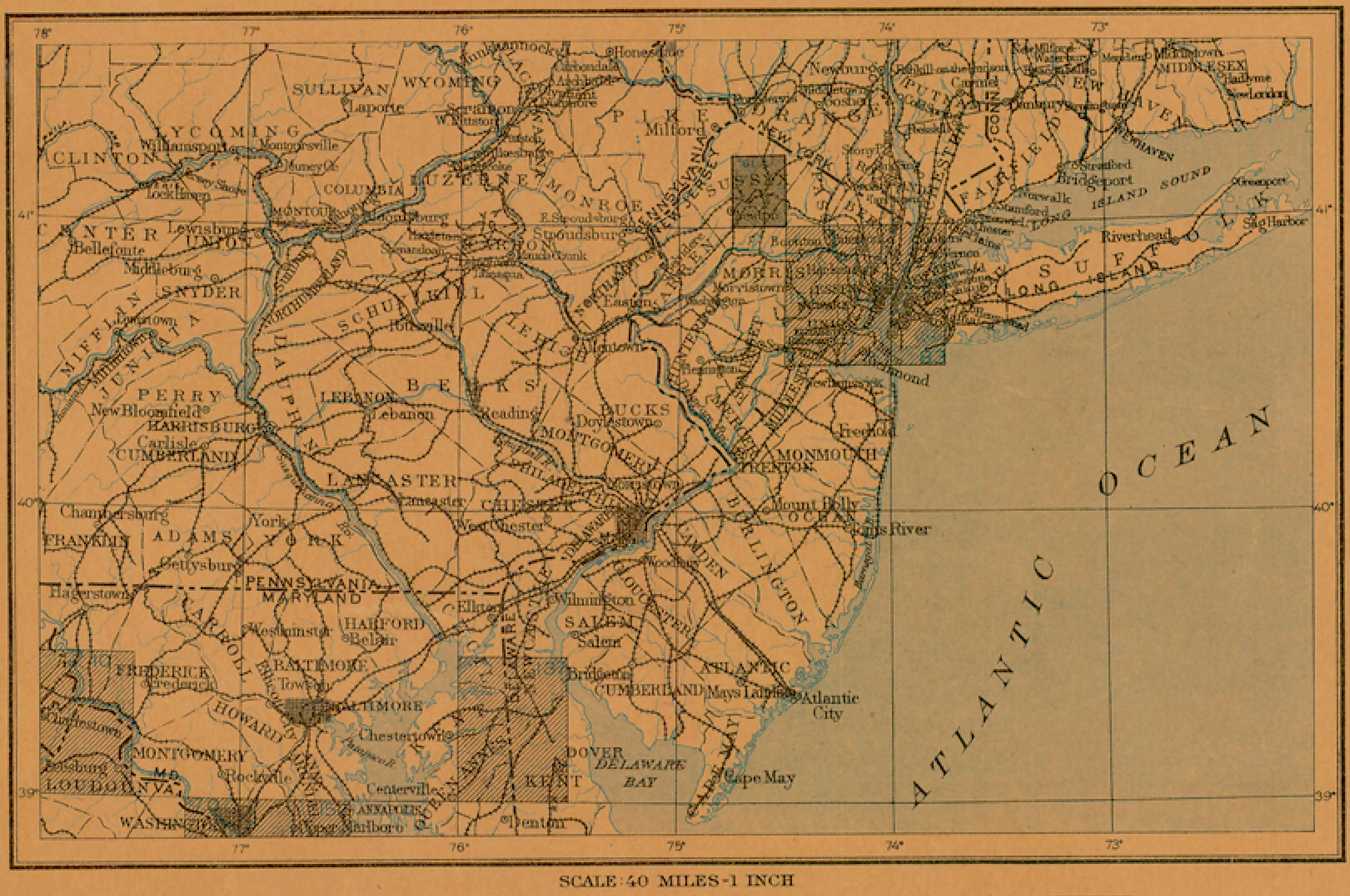
GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS OF THE UNITED STATES

FRANKLIN FURNACE FOLIO

NEW JERSEY

INDEX MAP



FRANKLIN FURNACE FOLIO

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GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES

The Geological Survey is making a geologic map of the United States, which is being issued in parts, called folios. Each folio includes a topographic map and geologic maps of a small area of country, together with explanatory and descriptive texts.

THE TOPOGRAPHIC MAP.

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

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

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map (fig. 1).

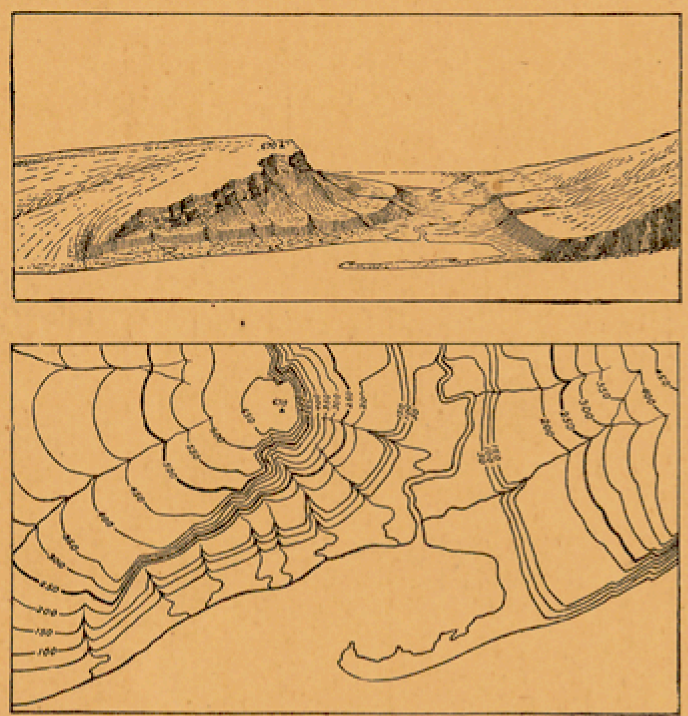

Fig. 1.—Ideal view and corresponding contour map.

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

1. A contour indicates a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours 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 sea; along the contour at 200 feet, all points that are 200 feet above sea; and so on. In the space between any two contours are found elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration all the contours are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contours, and then the accentuating and numbering of certain of them—say every fifth one—suffice, for the heights of others may be ascertained by counting up or down from a numbered contour.

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

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

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

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

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

Scales.—The area of the United States (excluding Alaska and island possessions) is about 3,025,000 square miles. A map representing this area, drawn to the scale of 1 mile to the inch, would cover 3,025,000 square inches of paper, and to accommodate the map the paper would need to measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the *scale* of the map. In this case it is "1 mile to an inch." The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to an inch" is expressed by $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250,000}$, the intermediate $\frac{1}{125,000}$, and the largest $\frac{1}{62,500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale $\frac{1}{125,000}$, about 4 square miles; and on the scale $\frac{1}{250,000}$, 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 in English inches, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map 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 $\frac{1}{250,000}$ contains one square degree—i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ contains one-fourth of a square degree; each sheet on the scale of $\frac{1}{62,500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles.

The atlas sheets, being only parts of one map of the United States, disregard political boundary lines, such as those of States, counties, and townships. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet the names of adjacent sheets, if published, are printed.

Uses of the topographic map.—On the topographic map are delineated the relief, drainage, and culture of the quadrangle represented. It should portray to the observer every characteristic feature of the landscape. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property; save the engineer preliminary surveys in locating roads, railways, and irrigation reservoirs and ditches; provide educational material for schools and homes; and be useful as a map for local reference.

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 the structure sections show their underground relations, as 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.—These are rocks which have cooled and consolidated from a state of fusion. Through rocks of all ages molten material has from time to time been forced upward in fissures or channels of various shapes and sizes, to or nearly to the surface. Rocks formed by the consolidation of the molten mass within these channels—that is, below the surface—are called *intrusive*. When the rock occupies a fissure with approximately parallel walls the mass is called a *dike*; when it fills a large and irregular conduit the mass is termed a *stock*. When the conduits for molten magmas traverse stratified rocks they often send off branches parallel to the bedding planes; the rock masses filling such fissures are called *sills* or *sheets* when comparatively thin, and *laccoliths* when occupying larger chambers produced by the force propelling the magmas upward. Within rock inclosures molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. When the channels reach the surface the molten material poured out thru them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks thus formed upon the surface are called *extrusive*. Lavas cool rapidly in the air, and acquire a glassy or, more often, a partially crystalline condition in their outer parts, but are more fully crystalline in their inner portions. The outer parts of lava flows are usually more or less porous. Explosive action often accompanies volcanic eruptions, causing ejections of dust, ash, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs. Volcanic ejecta may fall in bodies of water or may be carried into lakes or seas and form sedimentary rocks.

Sedimentary rocks.—These rocks are composed of the materials of older rocks which have been broken up and the fragments of which have been carried to a different place and deposited.

The chief agent of 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. In smaller portion the materials are carried in solution, and the deposits are then 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 deposits 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*. Rocks deposited in layers are said to be stratified.

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks, with reference to the sea, over wide expanses; and as it rises or subsides the shore lines of the ocean are changed. As a result of the rising of the surface, marine sedimentary rocks may become part of the land, and extensive land areas are in fact occupied by such rocks.

Rocks exposed at the surface of the land are acted upon by air, water, ice, animals, and plants. They are gradually broken into fragments, and the more soluble parts are leached out, leaving the less soluble as a *residual* layer. Water washes residual material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of standing water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it is called *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 a variety of processes, rocks may become greatly changed in composition and in texture. When the newly acquired characteristics are more pronounced than the old ones such rocks are called *metamorphic*. In the process of metamorphism the substances of which a rock is composed may enter into new combinations, certain substances may be lost, or new substances may be added. There is often a complete gradation from the primary to the metamorphic form within a single rock mass. Such changes transform sandstone into quartzite, limestone into marble, and modify other rocks in various ways.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried and later have been raised to the surface. In this process, through the agencies of pressure, movement, and chemical action, their original structure may be entirely lost and new structures appear. Often there is developed a system of division planes along which the rocks split easily, and these planes may cross the strata at any angle. This structure is called *cleavage*. Sometimes crystals of mica or other foliaceous minerals are developed with their laminæ approximately parallel; in such cases the structure is said to be schistose, or characterized by *schistosity*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are important exceptions.

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, a rapid alternation of shale and limestone. When the passage from one kind of rocks to another is gradual it is sometimes 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 is constituted of one or more bodies either containing the same kind of igneous rock or having the same mode of occurrence. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics.

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

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*.

(Continued on third page of cover.)

TEXAS ENGINEERS LIBRARY
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DESCRIPTION OF FRANKLIN FURNACE QUADRANGLE.

By A. C. Spencer, H. B. Kümmel, J. E. Wolff, R. D. Salisbury, and Charles Palache.

GEOGRAPHY.

By A. C. Spencer.

GENERAL RELATIONS.

The Franklin Furnace quadrangle is bounded by parallels 41° and 41° 15′ north latitude, and meridians 74° 30′ and 74° 45′ west longitude, covering one-sixteenth of a square degree. It is approximately 17 miles in length and 13 miles in width, and has an area of about 225 square miles. The district lies in northwestern New Jersey, mainly in Sussex County, but including a small part of Morris County on the southeast. The principal towns are Newton, the county seat of Sussex County, Sussex (formerly Deckertown), and Branchville. Farming is the principal industry, but zinc ores are mined and dressed at Franklin Furnace, limestone is quarried in several places, and slate quarries have been operated in Lafayette Township. The scenery and pure air of the Highlands and Kittatinny Mountain attract many visitors during the summer, the best-known resorts being Sparta, Stockholm, Branchville, and Sussex. The main line of the New York, Susquehanna and Western Railroad traverses the quadrangle from east to west and is joined at Sparta Junction by the Middletown division from the north. The Lehigh and New England Railroad and the Lehigh and Hudson River Railway extend across the quadrangle from southwest to northeast, and the Sussex branch of the Delaware, Lackawanna and Western Railroad connects Franklin Furnace, Branchville, and Newton with the main line at Netcong, N. J. The abandoned iron mines near Edison are reached by the High Bridge branch of the Central Railroad of New Jersey. The quadrangle is well netted with wagon roads, some of which, particularly in the Martinsburg shale belt, are excellent.

RELIEF.

The Franklin Furnace quadrangle is divisible topographically into three parts—the Kittatinny Mountain region in the northwest corner; the Kittatinny Valley, a depression 7 to 10 miles wide and from 600 to 800 feet deep, lying immediately to the southeast; and the Highlands, occupying somewhat less than one-half of the area, southeast of the valley. These several features have a northeast-southwest trend, which reflects the structure of the underlying formations.

Kittatinny Mountain slopes gently toward the northwest. Within the quadrangle its crest ranges in elevation from about 1400 feet to over 1600 feet, a single peak which reaches 1653 feet being the highest summit. The profile of the mountain crest, as a whole, is notably level, but this is not a marked feature within the quadrangle. The mountain heights represent an old surface of low relief, once extensive, but now preserved only in situations where resistant rocks have withstood erosion. The southeast side of the mountain presents a sharp declivity of 500 or 600 feet, below which the slope merges into the floor of the wide valley.

The Kittatinny Valley is part of a broad longitudinal depression which bisects the Appalachian Province from Alabama to Lake Champlain. It is characterized geologically by rocks relatively less resistant to erosion than those of the bordering uplands. Within the quadrangle broken ridges, formed of many nearly parallel elongated hills, characterize those portions of the valley which are underlain by Martinsburg shale, and similar though less prominent features are present in the areas of the Kittatinny limestone. These ridges are parallel with the axis of the valley, with the general courses of the larger streams, and also with the average strike of the formations. In the central portion of the valley many of the summits rise to elevations between 750 and 800 feet, and a few are from 50 to 100 feet higher. These hilltops are remnants of a former topography which would be restored if the minor valleys of the wide depression were filled. The ancient surface thus defined rises gently from the southeast until it meets the steep slope of Kittatinny Mountain, and is obviously a feature of later origin than the Kittatinny Plateau. Within the several belts of Kittatinny limestone most of the hills rise from 50 to 150 feet above the stream grades, though a few summits are 50 or 60 feet higher. All the larger streams and many of the tributaries are bordered by extensive meadows and swamps, and the floors of the minor valleys taken together constitute a well-marked sublevel or platform below the general floor of the Kittatinny depression.

In New Jersey the Highlands occupy a belt about 25 miles wide lying between the Kittatinny Valley and the Piedmont Plateau. The district is roughly a plateau, as the component ridges and hills rise to a gently undulating surface. In the southern part of this quadrangle the general elevation of the summits is about 1200 feet; toward the northeast the hilltops are about 200 feet higher. Like the top of Kittatinny Mountain this upland surface was formerly a plain, and if the valleys were filled the plateau would be restored. Within the Franklin Furnace quadrangle most of the valleys are shallow and wide, and only the larger transverse streams occupy deep gorges. The Pimple Hills and Pochuck Mountain are outliers separated from the main area of the Highlands by the upper valleys of Wallkill River and Pochuck Creek. In the southeast corner of the quadrangle Green Pond Mountain, formed of resistant sandstones, rises to the general level of the Highlands Plateau, and between this mountain and the gneisses toward the northwest a broad valley has been excavated in soft Paleozoic formations.

DRAINAGE.

The quadrangle is drained by tributaries of three river systems. Wallkill River, flowing northward to the Hudson, receives the waters of more than half the area. Its valley heads just beyond the southern boundary, attains a width of about 5 miles south of Ogdensburg, and between this place and Franklin Furnace flares out to cover the whole of the Kittatinny depression.

West of an irregularly curving divide the northwestern slope of Kittatinny Mountain is drained by short streams to the Delaware, the western side of the area is occupied by the headwaters of Paulins Kill, and the southwest corner drains to Pequest River. Musconetcong River, by way of Lake Hopatcong, receives the drainage of the south-central part of the quadrangle. All these streams flow by southwestward courses to the Delaware.

Two tributaries of Passaic River, the Rockaway and Pequanac, drain the southeast corner and a large part of the eastern side of the quadrangle. The northeast corner drains by way of Pochuck Creek to the Wallkill.

Though the district is one of considerable relief, to an important extent the platform of the stream valleys is imperfectly drained. Swamps and low meadows border most of the streams, both within the Kittatinny depression and within the Highlands. The Wallkill descends but 340 feet in a distance of 20 miles. Near the northern edge of the quadrangle its fall is less than 20 feet in 6 miles, and here it flows through a strip of "drowned lands" which become more extensive farther north, in Orange County, N. Y.

Twenty natural ponds, lying within the area, owe their existence to drainage obstructions of glacial origin. Many small ponds and two of good size at Hamburg and Franklin Furnace are the work of man; and the level of several natural bodies of water has been artificially raised.

DESCRIPTIVE GEOLOGY.

GENERAL RELATIONS.

By A. C. Spencer.

The rocks of the Franklin Furnace quadrangle comprise a series of crystalline gneisses and limestones older than the Cambrian, stratified formations ranging in age from Cambrian to Devonian, and intrusive rocks later than Ordovician.

The district exhibits the northeast-southwest trends of topography and areal geology which characterize the Appalachian Province southward from Hudson River. Red sandstones and shales occur in the northwest corner of the quadrangle, overlying the more massive quartzites and conglomerates of Kittatinny Mountain. These formations, which are of Silurian age, dip to the northwest. Below them are Ordovician shales which cover the greater part of the Kittatinny Valley. Numerous dikes and a few stocks of nephelite-syenite cut the shale in the western part of Wantage Township.

The southeast side of the main Kittatinny Valley is occupied chiefly by a belt of Cambro-Ordovician limestone, separated from the old crystalline rocks by a thin basal sandstone of Cambrian age. Southeast of this belt and well within the general area of the older rocks are several outlying strips of limestone, in the upper Wallkill and Vernon valleys. Each of these strips is limited on the southeast by the basal sandstone and on the west by a fault of considerable displacement.

Between the Paleozoic stratified formations and the rocks of the ancient crystalline complex there is a great unconformity, the older rocks having been deeply eroded previous to the deposition of the Cambrian sandstone.

On both sides of the New York-New Jersey boundary the general area of the Highlands is divided longitudinally by a belt of Silurian and Devonian formations. This belt traverses the southeast corner of the Franklin Furnace quadrangle, where Green Pond and Bowling Green mountains have been preserved by the presence of resistant Silurian sandstones and conglomerates.

Aside from the inlying strips of Cambro-Ordovician limestone and the belt of Silurian-Devonian rocks which have been mentioned, the rocks of the Highlands are gneisses and crystalline white limestones, with minor masses of coarse-grained granite or pegmatite and a few diabasic dikes. The highly metamorphosed limestones occur in a few minor areas west of Wallkill River, and in a zone extending from the vicinity of Ogdensburg northeastward well into Orange County, N. Y. The portion of the white limestone belt which falls within this quadrangle has a maximum width of nearly a mile and is 12 miles long.

That the quadrangle was occupied by the great ice sheet of the glacial epoch is shown by drift deposits of various sorts, by the absence of decayed rock material in place, and by scoured rock surfaces. All the natural ponds of the district are due to drainage obstructions of glacial origin.

PRE-CAMBRIAN ROCKS.

By A. C. Spencer.

INTRODUCTORY STATEMENT.

GENERAL RELATIONS.

The Highlands of southeastern New York and New Jersey form a part of the Appalachian Province. They lie within an irregularly bounded and complexly interrupted area of rocks older than the Cambrian, which extends from Schuylkill River at Reading, Pa., northeastward across Hudson River into Putnam and southern Dutchess counties, N.Y.; eastward across Putnam County into the edge of Fairfield County, Conn.; and from Putnam County southward across Westchester County to Manhattan Island. This roughly hook-shaped area is bounded on the inside by the belt of Mesozoic rocks belonging to the Newark group, which extends from the Hudson Palisades southwestward across New Jersey and Pennsylvania. Around the periphery of the pre-Cambrian area on the northwest, north, and east, the rocks are Paleozoic. The boundary between the area of ancient crystalline rocks and the Newark belt is on the whole a simple one, but the line limiting the older rocks against those of Paleozoic age is sinuous in the extreme. The irregularity of this boundary and the occurrence of many strips of the Paleozoic formations within the general district occupied by the pre-Cambrian rocks result largely from the presence of many northeast-southwest corrugations of the sort characterizing the Appalachian region, to use that term in its broadest application.

The lower Cambrian formations may have been deposited over the whole region, but they now appear only in the areas where they were protected from erosion by having been infolded or downfaulted into the older rocks upon which they lie.

In Pennsylvania, New Jersey, and southeastern New York, from Reading on the Schuylkill to Hudson River, the Paleozoic rocks bordering on and included in the pre-Cambrian area are essentially unmetamorphosed. The Cambro-Ordovician limestone is nowhere changed to marble, and the overlying Ordovician shale, though exhibiting slaty cleavage in many places, has not been converted into schist. Throughout this zone the Paleozoic and pre-Cambrian rocks are invariably exhibited in sharp contrast, because the latter are so completely crystalline. Within the Paleozoic formations intrusive rocks other than diabase dikes of late Triassic age occur in one place only, namely, at Beemerville, N. J.

East of Hudson River the aspect of the lower Paleozoic formations is very different. Immediately north of the pre-Cambrian area in Dutchess County, N. Y., the rocks of "Hudson" time are almost uniformly slaty, and the limestone which occurs between these slates and the pre-Cambrian rocks is crystallized to a considerable extent. In eastern Dutchess County and in northeastern Putnam County the Paleozoic rocks exhibit even greater alteration. The shale and limestone have been completely crystallized, the former being converted into mica schist and the latter into marble. Still farther east, in Connecticut, intrusive rocks appear and are present generally beyond the eastern border of the Westchester County pre-Cambrian area. The Paleozoic rocks that lie within the general pre-Cambrian area in Putnam and Westchester counties, N. Y., are likewise highly metamorphosed, and locally they are also invaded by igneous intrusions. In certain parts of this district the pre-Cambrian rocks, including the Fordham gneiss described in the New York City folio, have suffered the same deformation as the Paleozoic formations associated with them, and it is often a matter of difficulty to distinguish these gneisses in their altered form from phases of the Hudson schist.

In Pennsylvania, New Jersey, and southeastern New York the basement rocks comprise mainly several varieties of gneiss or massive feldspar-bearing rocks of a granular texture and foliated habit, rocks of similar composition but almost or quite free from foliation, very coarse granite or pegmatite, and crystalline limestones. Nearly all these ancient rocks are laminated in greater or less degree, and the different sorts are interlayered on both a large and a small scale in such a way that they usually appear at the surface as relatively narrow bands. These bands have a general northeast-southwest trend throughout the region, and as a rule the dips of the structural surfaces are inclined toward the southeast.

Locally the gneisses carry valuable deposits of iron ore in the form of magnetite, and the same mineral is in some places associated with the white crystalline limestone. This limestone is especially noteworthy, however, because it forms the matrix of the unique deposits of zinc ore occurring in Sussex County, N. J.

Taken together, the pre-Cambrian rocks of this region show a close resemblance to the crystalline complex of the Adirondack Mountains and to the pre-Cambrian of the Green Mountain region, which in turn are like the rocks of the Laurentian area in Canada. They are different in their general make-up from some of the ancient rocks of the Philadelphia district and from the apparent correlatives of these rocks occurring in Maryland and Virginia.

CHARACTER AND GROUPING OF THE ROCKS.

The limestones, being composed essentially of calcite, are readily distinguished from the gneisses made up of silicate minerals in different combinations, but there are so many varieties of gneiss and the different sorts are so intricately mingled that detailed representation of their distribution is quite impracticable. As observed in the field, the most noteworthy differences of appearance presented by the elements of the gneissic complex are those of color, and inasmuch as color distinctions have been found to correspond broadly with fairly definite lithologic differences, they may be used as a guide in classifying the gneisses for the purposes of description and mapping.

All the dark gneisses which owe their color to the hornblende, pyroxene, or biotite which they contain, are grouped together under the name Pochuck gneiss. A second group, the members of which show brown-gray, bronzy, pink, and ocherous tones, is called the Byram gneiss. Here are included a great variety of granitoid or granitelike rocks related to one another and distinguished from the other gneisses by the presence of potash feldspar as an essential ingredient. A third group, the Losee gneiss, includes light-colored granitoid rocks, many of them nearly white, which contain lime-soda feldspar as an essential and characteristic mineral component.

Rocks of intermediate composition do not in general constitute readily definable geologic masses, and as a rule it has not been found practicable to separate them from the other gneisses. However, several masses of coarse granite occurring in the northern part of Pochuck Mountain are so distinct in appearance from the surrounding rocks that their limits may be readily traced. This rock contains subequal amounts of potash and lime-soda feldspar and is like the granite of Mounts Adam and Eve in Orange County, N. Y., which invades the Franklin limestone.

All the rocks which have been mentioned are cut by irregular dikelike masses of pegmatite, but these rocks have not been mapped except within the general area of the white limestone.

The varieties of gneiss are seldom found in large masses free from intermixture with other sorts, but the different facies or varieties occur in tabular masses which are interlayered both on a large and on a small scale. The mingling is so intimate and the proportions of the lithologic facies are so various that even after bringing the varieties together in groups it is impossible to give a really faithful representation of their distribution on a map of small scale. As a matter of necessity, therefore, the bands which are distinguished on the geologic map represent merely the presence of varieties of gneiss resembling the designated type as the most abundant rocks in the area covered by the appropriate color or symbol. Mapping of the crystalline complex on this principle leads to the result that the boundaries shown are to a considerable degree arbitrary. They are therefore not to be considered in the same light as the hard and fast lines which can be drawn between the well-defined formations usually represented on detailed geologic maps. Furthermore, the various boundaries are arbitrary in different degrees, some of them being quite as definite as the boundaries between different sorts of granular igneous rocks, where one of these is intrusive into another, and others being located by personal judgment as to the most fitting line to indicate a general difference in the rocks occurring in adjacent areas. In many portions of the field, with a large-scale map, it would be possible to represent the occurrence of the different sorts of rock in great detail, but however minute the subdivisions might be made it would still be inevitable that the areas distinguished should represent preponderance of varieties rather than the occurrence of invariable rock masses.

STRUCTURE OF THE PRE-CAMBRIAN.

The general structure of the Highlands pre-Cambrian complex rocks is monoclinal. The more or less well-defined layering between the various rock masses strikes on the average from southwest to northeast and dips usually toward the southeast, though rarely toward the northwest. Straight or gently curving structural features are the rule, but in many places individual layers or sets of layers, if followed along the strike or along the dip, exhibit at intervals sharp, troughlike corrugations. These corrugations range in size from mere wrinkles to folds of considerable span. Usually they are very minor features compared with the notably great extent of the nearly straight layering which they modify, but in a few places they are of importance in determining the areal distribution of the different varieties of gneiss. Also, in some of the mines of the region, particularly in the zinc mines at Franklin Furnace and Sterling Hill, the ore bodies have the form of pitching troughs. Within the layers of gneiss, besides a commonly well-marked foliation due to the arrangement of the more or less flattened mineral constituents in parallel planes, there is in many places a distinct streaking or graining which runs diagonal to the strike and dip, in the same direction as the pitch of the corrugations referred to above. Locally the foliation may be observed to almost disappear and to give place to a pitching linear structure, produced by the grouping of mineral grains into pencils. The edges of some individual layers of gneiss exhibit a like pitch. The very general existence of obscure graining in this common direction, though usually not apparent to the eye, is brought out by a topographic feature observable throughout the glaciated portion of the Highlands. The longitudinal profiles of the gneiss ridges are in many places like unsymmetrical sawteeth, with gentle slopes toward the northeast and a more abrupt falling off on the southwest. In many of the magnetite mines the ore layers are divided by pinches and swells into long pod-shaped shoots, nearly all of which, like the corrugations described, dip toward the northeast or east; and, where ore bodies are entirely capped or bottomed by barren rock, the edges of the shoots likewise pitch in the same direction.

Long faults running nearly parallel with the general strike of the crystalline rocks are known to exist mainly from the fact that movements along them have produced the existing insets of Paleozoic formations. Near these breaks the minerals of the gneisses are considerably decomposed, but the faults are ordinarily not traceable beyond the areas of younger rocks, owing to the presence of glacial drift north of the terminal moraine and to the deep mantle of decomposed rock farther south.

Cross breaks have been found in some of the mines, but usually they are not important and few of them are discoverable on the surface.

ORIGIN AND RELATIONS OF THE ROCKS.

The gneisses of the New Jersey Highlands, with few exceptions, correspond accurately in their mineralogical and chemical composition with common types of coarse-grained igneous rocks like the granites and diorites. They differ from the usual igneous rocks in that they possess foliated or linear structures instead of evenly granular textures. The members of the gneissic complex which are present in the largest amounts are light-hued granitoid rocks, here included under the names Losee gneiss and Byram gneiss. There can be little doubt that these rocks have solidified in part out of silicate solutions or molten magmas, which moved while in a soft or plastic condition from the more or less distant regions in which they had originated into the positions now occupied by the resulting rocks. The fact that they comprise invading masses is shown locally by irregular crosscutting contacts, by the manner in which they inclose masses of older rocks, and in places by the development of metamorphic minerals along their borders. That large amounts of preexisting rock material have been more or less completely dissolved and assimilated by the invading magmas is suspected but can not be affirmed.

In all the gneisses foliation is conditioned both by the interlayering of different varieties of rock and by the more or less elongated or flattened form of the component mineral grains and the arrangement of these grains in such a manner that their longer dimensions lie in sets of nearly parallel planes. Lamination of the first sort may be called structural foliation, and of the second sort textural foliation. Textural foliation may be developed during the first crystallization of a rock magma when consolidation takes place under the influence of some straining 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 it had once solidified. Elsewhere in the pre-Cambrian rocks, notably in northern New York and Canada, foliation exists in different stages of development, leaving in certain localities no doubt of the secondary manner in which it has been produced. Throughout New Jersey, however, evidence of crushing in the minerals of the gneisses is almost entirely wanting and appearances strongly favor the belief that the gneissic foliation is original in the invading rocks of the pre-Cambrian complex.

Less abundant than the granitoid rocks, but still of considerable importance in the field at large, is the dark Pochuck gneiss. The rocks embraced under this term have the composition of igneous diorites or gabbros, but whether they have been derived from igneous or sedimentary originals, or, as is thought, in part from both, their present characteristics have in most places been acquired by metamorphism, involving secondary crystallization. In these dark rocks foliation is everywhere present, and parallel to this structure the rocks are injected in all proportions by sheets of light-colored material similar in composition to phases of the Losee gneiss, with which group these sheets are undoubtedly to be classed. In addition to being definitely injected by thin bodies of the Losee rock, the dark gneisses are interlayered with both the Losee and the Byram gneisses on a broad scale, and the white crystalline limestones which occur here and there throughout the Highlands are similarly interlayered with the granitoid gneisses, so that these two sets of rocks—the dark gneisses and the limestones—together seem to constitute a matrix holding the intrusive granitoid rocks in the form of relatively thin but extended plates.

Apparently the dark rocks were already foliated before they were invaded, because the interlayering of the granitoid materials is so regular that the presence of some structural control would seem to have been a necessity. At the time of the injection, and perhaps as an effect of it, the dark rocks must have been reduced to a physical condition such that both in large masses and in thin plates their materials were able to adjust themselves to deforming pressure by solid flow instead of by rupture. During this deformation the early texture of the rock was broken down, important addition or subtraction of elements may have occurred, and a later crystallization ensued contemporaneous with the crystallization of the injected material. Both in the invading and in the invaded rock the process of crystallization went on subject to some widely operating control which, by allowing the mineral grains to grow more rapidly in certain directions than in others, gave them their flattened or elongated shapes and produced the observed foliated structure of the gneisses. The parallelism existing between the plates of rock and the foliation within them suggests as the most probable explanation that the forces causing flowage continued to operate after crystallization had begun, and practically until it was complete, so that the injection of the granitoid material, the pressing out and kneading of the masses of the matrix, and the development of textural foliation in both were phenomena connected in origin with a single cause.

The Franklin limestone locally retains traces of original stratification, showing its sedimentary origin, but the lamination observed within masses of this rock is regarded mainly as a sort of flow structure developed through the crystallization of the limestone masses while they were being molded under the action of deforming stresses and at the same time traversed by mineral-charged waters derived from the invading Losee and Byram magmas.

Though it can not be claimed that determinable facts are sufficient to substantiate fully the relations and history outlined above, yet the occurrence of the different sorts of rock as interlayered masses with generally parallel contacts, the pitch of various structures in a common direction, the interlocking of mineral grains along contacts, and the conformation of the foliation within individual layers with the general lamination of the complex as a whole are believed to warrant the conclusion that the white limestones and the various gneisses with which they are associated, together with the ore deposits which they inclose, came into their present state of crystallinity and received their present forms as geologic masses during a single period of regional deformation.

Subsequent to the crystallization of the gneisses and limestones, though perhaps before the period of general deformation had closed, the rocks were invaded by the irregular dikelike masses of pegmatite which now occur in them.

HISTORICAL SKETCH.

In past years the weight of opinion has been in favor of a sedimentary origin for the typical gneisses of the Highlands region, though it has been rather generally admitted that many of the more massive rocks which are associated with the highly laminated members might prove to have been formed in a purely igneous way. This view of the origin through the metamorphism of sedimentary rocks was advanced in 1836 by Rogers, the first official geologist of New Jersey, and although it was consistently upheld by his successors, Kitchell, Cook, and Smock, the facts from which the conclusion was drawn now seem inadequate, and the conclusion itself appears not to have been based on strict deduction from observed facts. Investigation along this line of approach culminated in a report by Britton, published in 1886, in which the pre-Cambrian rocks of New Jersey (there designated Archean) were divided into three groups, separated primarily on the basis of 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 theory was Nason, who pointed out (1889) that existing knowledge was inadequate for a decision whether the gneisses in the Highlands have been derived from sedimentary or igneous rocks, or even possibly from a mixture of the two. A special study of the rocks in the vicinity of the iron mines at Hibernia, N. J., by Wolff (1893) led to the suggestion of a sedimentary origin for the rocks of this particular district, but the same geologist (1896) regards certain of the granitic rocks occupying extensive areas in the Franklin Furnace region as undeniably intrusive.

Two views have been held regarding the age of the white crystalline limestone of the Wallkill and Vernon valleys. It has been regarded on one side as a metamorphosed form of the blue Paleozoic limestone which occurs in the same region, and on the other as a formation entirely distinct from this rock and of far greater antiquity. The latter view, which has been argued by Wolff and Brooks (1896), is here accepted without qualification.

LOCAL DISTRIBUTION OF THE FORMATIONS.

Pre-Cambrian crystalline rocks, constituting a basement or floor upon which the Paleozoic sedimentary formations were deposited, underlie the whole of the Franklin Furnace quadrangle, but they appear at the surface only in the Highlands district. Though characteristic of that district, these rocks do not form all of its surface, but are locally covered by Paleozoic formations which appear at the surface in strips trending northeast and southwest, parallel with all the most noteworthy features of topographic and geologic structure throughout the general region.

The longest and widest inset of Paleozoic rocks within the Highlands contains formations of Silurian and Devonian age which are younger than any occurring elsewhere east of the Kittatinny Valley. These rocks, extending in a belt from one-half mile to 4 miles wide, from a point near Dover, N. J., along Green Pond, Bearfort, and Schunemunk mountains to Cornwall, N. Y., occupy the southeast corner of the Franklin Furnace quadrangle. Within New Jersey they meet the gneisses which lie to the west of them along a profound fault. In the Wallkill Valley are two narrow blocks of Kittatinny limestone, one 10 miles long and from one-half to three-fourths mile wide, the other 7 miles long and somewhat more than 1 mile in greatest width. A third strip of the limestone, occupying the Vernon Valley below McAfee, continues toward the northeast to the New Jersey-New York line, beyond which it widens into a broad area of lower Paleozoic formations west of which no pre-Cambrian rocks appear.

The various rocks, grouped and set apart in the manner outlined under a previous heading, are disposed upon the surface in relatively narrow northeast-southwest bands, which, like the inset strips of Paleozoic strata within the crystalline area, conform in direction with the principal features of the topography.

The rock groupings which have been represented on the map of the Franklin Furnace quadrangle, and which are described in the following pages, are as follows: Franklin limestone, Pochuck gneiss, Losee gneiss, Byram gneiss, granite, and pegmatite.

FRANKLIN LIMESTONE.

Distribution.—The Franklin limestone forms a band 22 miles long and from half a mile to 2 miles wide, extending from Mounts Adam and Eve, in Orange County, N. Y., in a southwesterly direction to the vicinity of Sparta, N. J. Throughout the 12 miles of this belt which lies within the Franklin Furnace quadrangle, its width between the gneisses which bound it on either side would seem to be rather uniform, but the surface outcrop of the limestone is far from regular, because of the presence of several strips of Paleozoic strata that partly hide the older rock. On the west side of Vernon Valley the width of the white limestone outcrop is less than one-half mile, its eastern side being capped by the blue Paleozoic limestone. At McAfee, where the whole band is seen, it is 1 mile wide, but a short distance to the south the limestone is again partly hidden by two strips of the Paleozoic strata, which probably unite under the covering of glacial drift in the vicinity of Hamburg, as represented on the areal geology map. Toward the south the western boundary of the white limestone against the gneiss is covered as far as Greenspot (Franklin Furnace post-office), where the northernmost surface workings of the zinc mines are situated. Here the total width of the band may be seen, though its continuity is interrupted by the wedge end of another strip of the Paleozoic strata, which a short distance farther south overlap the eastern side of the white limestone and cover both its contact with the gneisses of the Wallkill Mountains and the southern termination of the white limestone belt between Ogdensburg and Sparta.

Several detached masses of white limestone are present within the area of gneisses which lies southwest of Franklin Furnace and west of Wallkill River. The largest of these masses is about 3 miles due east of Newton, extending along the western base of the Pimple Hills from Pinkneyville nearly to Sparta Junction. The area in which this rock comes to the surface is spindle shaped, about 2 miles in length and one-fourth mile across in the widest place. On the west the white limestone passes beneath the overlapping Paleozoic beds. Three-fourths mile southwest of Franklin Furnace the rock is exposed in a club-shaped area, over a mile in length, lying about one-fourth mile west of the main belt. It is very likely that this area has a greater length than is proved by the outcrops. Possibly it connects beneath the mantle of glacial débris with exposures west of Sterling Hill, and these in turn may be part of a continuous band extending to the patch about 1 mile southwest of Sterling Hill, or even to the small outcrop 1 mile farther south. The area of limestone east of Woodruff Gap may extend farther to the southwest than has been represented on the map, but there are no outcrops in this direction. So also the narrow belt which lies just to the south may run out into the swampy ground for some distance, and the next belt to the east may connect beneath the glacial mantle with the outcrops on the edge of the swamp three-fourths of a mile southwest of Sparta. The last-named outcrops are so situated in respect to the long, narrow band of the limestone which lies at the base of Briar Ridge that an actual connection between them seems to be very likely.

Description.—The Franklin limestone is a white, highly crystalline limestone or marble, varying greatly from place to place in texture and composition, and to a less degree in color. As a rule it is coarsely granular, being made up of large anhedra (crystalline grains not possessing the exterior faces characteristic of perfect crystals), which show a very perfect rhombohedral cleavage. Almost everywhere pressure twinning is observed, as indicated by parallel planes of parting distinct from the characteristic cleavage. Some of the rock is very finely granular or even nearly amorphous. The color is usually milky white and the cleavage surfaces of the calcite give the rock a lustrous aspect. Locally it has a pink or yellow tinge and elsewhere it is grayish. Where free from included minerals the limestone ranges in composition from a nearly pure carbonate of lime through magnesian limestone to dolomite. Some of it is rather siliceous, and in a few places thin beds of sandstone have been noted. Differences in composition, accompanied locally by textural changes, are recognized in all the quarries where the rock is worked for lime, and in many places the several varieties occur in layers having every appearance of true strata. Taken as a whole the rock contains a large number of minerals which present considerable interest to the mineralogist. The deposits of zinc ore inclosed in it are of great economic importance, and because of their unique characters are of very great scientific interest. Magnetite veins also are present in this limestone. Among the more common minerals is graphite, occurring in brilliant scales disseminated throughout the more coarsely crystalline rock in such a manner as to produce a foliated appearance. White or yellowish mica (phlogopite), pyroxene (diopside), and chondrodite are also common, and these minerals, like the graphite, are distributed in such a way as to give the rock a gneissic structure.

The white limestone has found a considerable use in the manufacture of lime and for furnace flux in iron smelting, as is more fully shown in the discussion of economic geology. The analyses appended show the presence of both magnesian and pure calcium rocks in the white limestone belt.

Chemical composition of Franklin limestone.

	1.	2.	3.	4.	5.
CaO	51.06	28.31	29.68	53.53	30.95
MgO	3.02	18.04	20.07	1.73	21.06
FeO	----	----	----	----	----
Fe_2O_3 }	.80	1.20	3.50	.50	1.15
Al_2O_3 }					
Na_2O }	----	Trace	----	----	----
K_2O }					
CO_2	43.44	42.08	45.51	43.97	47.51
Graphite }	1.40	9.50	.50	.55	.07
Insoluble }					
Water	----	----	----	----	----
SO_3	----	----	----	----	----
	99.72	99.13	99.26	100.28	100.74

	6.	7.	8.	9.	10.
CaO	51.80	48.40	54.79	51.96	54.42
MgO	1.37	5.25	----	2.92	.93
FeO	----	----	----	----	.56
Fe_2O_3	} .15	.90	.90	.20	{ ----
Al_2O_3					{ None.
Na_2O	} ----	.50	.16	----	{ .86
K_2O					{ .23
CO_2	42.23	43.80	43.06	44.03	41.54
Graphite	} 1.70	{ .27	.75	} .20	{ .17
Insoluble		{ ----	----		{ .97
Water	1.80	.20	.15	----	----
SO_3	----	----	----	----	.02
	99.05	99.32	99.81	99.31	99.70

Nos. 1, 4, and 9 from Ann. Rept. New Jersey State Geologist, 1871, p. 44. Nos. 2, 3, 6, 7, and 8 from Geology of New Jersey, 1868, pp. 403, 404. No. 10 from The stone industry (extract from Mineral Resources U. S. for 1903), U. S. Geol. Survey, 1904, p. 138.

1 and 2. From lands of J. B. Titman, west of Sparta.

3. From a drift tunnel northeast of the New Jersey Zinc Company's mine at Sterling Hill, near Ogdensburg.

4. Ordinary white limestone burned at Franklin Furnace.

5. From furnace quarry at Franklin Furnace. Analysis recorded by Frank L. Nason, Am. Geologist, vol. 13, 1894, p. 160.

6. From Geo. W. Rude's quarry (1868) near Hardystonville, now worked by Windsor Lime Company.

7 and 8. From a quarry on the farm of Peter J. Brown (1868), Vernon Township.

9. From West Vernon (locality not specified). Represents an average specimen.

10. From the Hamburg Lime Company's quarry near Rudeville. Analysts, Ricketts & Banks.

Mineralogy.—The white limestone of Sussex County has for many years been famous for the variety and beauty of the minerals which it contains, and the zinc mines at Franklin Furnace and Sterling Hill have afforded several new mineral species, some of which are not known to occur elsewhere. Ninety-one authentic species have been noted. Fifteen of these were originally described from one or the other of the two localities named, and eleven have thus far been found nowhere else. The three minerals—zincite, franklinite, and willemite—which constitute the ores of zinc occurring in large deposits at Franklin Furnace and at Sterling Hill are not found at any other locality except in minor amounts. A fuller description of the minerals is given in the section on "Mineralogy," by Mr. Palache.

Structure.—Stratification is so obscure in the Franklin limestone that it is not ordinarily noted in the study of surface exposures. In the extensive quarries at Rudeville, and especially in those at McAfee, however, undoubted bedding may be observed, and indications of it can be made out in the quarries near Franklin Furnace. At McAfee several layers of high-grade limestone have been worked for considerable distances along the northeast strike, and one bed which has been followed for more than 1200 feet was found to lie throughout this distance between persistent masses of rock quite different from it in physical properties and practically valueless for the manufacture of lime. At this place the beds, which lie in parallel position, strike northeast and southwest and dip from 60° to 75° SE. Bedding is observed also at the Rudeville quarry of the New Jersey Lime Company (formerly called the Hamburg quarry). Here there is an anticlinal fold (see fig. 1), and the

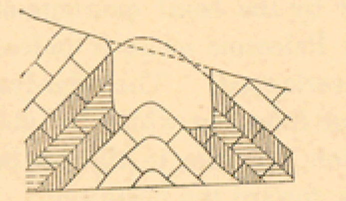


FIG. 1.—Quarry of New Jersey Lime Company at Rudeville, showing anticline of good limestone in siliceous beds.

valuable limestone forms a stratum approximately 60 feet thick, which in the workings may be seen to dip both to the northwest and to the southeast from the place where the quarry was first opened. On both sides the workable rock dips beneath a cap of siliceous limestone (locally known as bastard rock), and in the center of the quarry the bottom of the good rock has been reached. Careful study shows that the arch pitches toward the northeast. In the eastern corner of the excavation a stratum of limy sandstone about 6 inches thick was seen resting upon the good lime rock and grading into the overlying siliceous material. The presence of this sandy bed between the two varieties of limestone seems to prove definitely that these layers are true stratified beds.

One of the most striking exhibitions of stratification is to be seen in an abandoned quarry about one-fourth mile northeast of the one just mentioned, on the property of the Windsor Lime Company. Here two massive beds of good lime rock about 20 feet apart have been worked out for a length of 200 or 300 feet and to a depth of 50 feet or so below the surface of the hill. These two beds are somewhat wavy, but they are essentially parallel, striking, as at McAfee, northeast and southwest and dipping steeply toward the southeast. The rock between them is distinctly bedded, the different layers varying in thickness, texture, and color, and probably in composition, as one of them has an earthy appearance.

The zinc ore bodies have been regarded by some geologists as representing true strata, which either originally contained the metals now found in them or, because of a peculiar composition, were particularly liable to replacement by metal-bearing solutions not capable of similarly affecting adjacent strata of a different sort. Nothing besides the occurrence of the ore bodies in the form of layers can be cited in favor of this view, for there is no provable bedding in the limestones in the vicinity of the ore bodies.

Wherever undoubted stratification can be made out any foliated effect produced by the presence of silicate minerals is almost invariably parallel with the bedding, and throughout the main belt of limestone, as well as in other places where the rock is found in small masses, these streaks of accessory minerals follow the northeast-southwest course of the bands of limestone, which in turn conform with the structural trends in the inclosing gneisses.

Much of the structure in the limestone is probably not bedding, but a secondary feature acquired during the great deformation which the limestones have undoubtedly suffered. Of this superinduced nature is a certain bluish banding which is to be observed in almost all localities where the limestone has been exposed to view by quarrying and which is due to streaks of amorphous carbonaceous matter distinct in character from the graphite. The general effect presented by the structure of the limestones can not be better or more definitely expressed than by mentioning that it closely resembles the structure of the inclosing gneisses.

Age.—The question in regard to the age of the limestone, which was long in dispute, has been settled by the work of Wolff and Brooks, published in 1896. These geologists have shown that the white limestone was metamorphosed to its present condition long before the deposition of the Hardyston quartzite, and that it is therefore entirely distinct from the blue limestone lying stratigraphically above the quartzite formation and could not have been derived from it. Apparent transitions between the white and blue limestones, which had been described by earlier investigators in support of the opposite view, are shown to be confined to localities where the blue limestone has been faulted down against the white rock and thereby metamorphosed to a certain extent. A case of this sort may be seen in the hill east of McAfee. Where normal or unfaulted contacts are observed, the Hardyston quartzite, though locally very thin, is invariably present between the two limestones, being conformable to the bedding of the Kittatinny but not to the structure of the Franklin limestone or to the foliation of the gneisses where these rocks underlie the Paleozoic strata. The general westerly dip of the quartzite and the Kittatinny limestone is quite as noteworthy and persistent as the almost invariable easterly dip of the foliation in the older crystalline rocks. The white limestone contains intercalated masses of gneiss and is injected by numerous bodies of granite (pegmatite), but neither of these rocks is associated with the younger formation. On the other hand, the Hardyston quartzite locally contains fragments derived from these granites, and even fragments of the coarse-grained limestone itself. Those interested in the earlier views on this question and in the details supporting the present conclusions should consult the Eighteenth Annual Report of the United States Geological Survey, part 2, 1898, pages 431–437.

Relations with the other rocks.—In several places in the Franklin Furnace area the white limestone is unconformably overlain by the Hardyston quartzite and the Kittatinny limestone. This relation has been clearly indicated on the economic geology map and the accompanying cross sections. The strips of Paleozoic rocks which lie within the general area occupied by the gneisses and white limestones are bounded on the west by faults, so that on this side their contacts with the older rocks are not normal. On the east side of each of these strips the relations, so far as known, are everywhere those of sedimentary overlap. Contacts may be studied at several points, and the evidence of unconformable deposition of the Hardyston quartzite upon the Franklin limestone can not be doubted in any place where good exposures exist, as in the creek bed below the road at Hardystonville and about three-fourths mile west of McAfee, on the eastern slope of the hill east of the old Pochuck mine. This relation is most clearly exhibited beyond the north end of Pochuck Mountain, along the wagon road leading from Pine Island to Unionville, at a bend about one-fourth mile southwest of the point where this road is joined by the one from Merritts Island. At this place a few inches of entirely unmetamorphosed shale, containing grains of quartz sand and flakes of graphite, may be seen resting upon coarsely crystalline white limestone. Unaltered blue limestone is exposed only a few feet away, and the same rock forms a knoll near by, on the northwest side of the road, whereas to the east white limestone cut by massive pegmatite forms a somewhat higher hill.

At Mounts Adam and Eve, in Orange County, N. Y., near the north end of the Franklin limestone belt, masses of coarse granite invade the limestone, producing considerable metamorphism along their contacts. The pegmatites occurring throughout the belt and in some of the outlying masses are likewise intrusive. Next to them there is at many localities evidence of important metamorphism, though in this respect great differences are observed from place to place, and some of the masses seem to have had little effect on the inclosing limestone. Taken as a whole, the limestones are not more crystalline at the pegmatite contacts than at a distance, and silicate minerals are found generally distributed without any constant relation to the proximity of these invading rocks. It is held, therefore, that the limestones were already highly altered at the time the pegmatites were injected into them.

The earlier metamorphism, which affects both the Franklin limestone and the Pochuck gneiss, is regarded as one of the results of the general invasion of the field by the granitoid Losee and Byram gneisses. In many places where the dark Pochuck rocks are seen to be cut by the Losee gneiss, as along the crest of Pochuck Mountain, layer-like fragments of the matrix have been floated off into the invading magma. What appear to be similar shreds of the dark rock are found throughout the areas occupied by the Losee gneiss, and only less commonly in the Byram gneiss, so that the intrusive relations of both classes of granitoid rocks with respect to the Pochuck gneiss are rather definitely recognizable. With respect to the limestone, the relations are less clear, but the distribution of minor masses of dark gneiss and of limestone in the region west of the main limestone belt and the Wallkill Valley strongly suggests that these rocks, perhaps originally interbedded and considerably folded, were broken and torn apart by the invasion of the Byram gneiss. Several of these small masses of limestone are bordered by layers of dark gneiss which may be regarded as products of contact metamorphism. One of the masses of limestone exposed along the railroad northwest of Sparta is divided longitudinally by a narrow belt of gneiss, which appears to be an injected sheet connected along the strike toward the northeast with the surrounding fine-grained Byram gneiss. Rather numerous belts of lithologically similar material occurring in the limestone of the main belt are probably intrusive sheets, but inasmuch as it can not be certainly shown that they may not have been formed by the metamorphism of material originally interbedded in the limestone, they can not be used as evidence in the present connection. South and southeast of the Franklin Furnace area, in the Raritan and Passaic quadrangles, limestones are found in contact with Losee gneiss, which is probably, though not certainly, intrusive into them.

The relations which have been stated lead to the conception that the dark gneiss and the limestone form a general matrix holding the granitoid rocks as intrusive masses. Their invasion by so great a bulk of magmatic material would afford an adequate explanation of the widespread or regional metamorphism by which they are affected.

Though the Pochuck gneiss and the Franklin limestone are both regarded as older than the granitoid gneisses, the original relations between them are not determinable.

Associated quartzites.—There remain to be described certain beds of siliceous rocks which occur with the white limestones at three localities. The most prominent development of these rocks is at the old Andover iron mine, near the southwest corner of the quadrangle. Here siliceous breccia and indurated carbonaceous shale occur in the form of strata having an aggregate maximum thickness of 80 to 100 feet. These rocks contain irregular masses of iron ore, both hematite and magnetite, and mining operations have revealed them in a continuous northeast-southwest band about 1300 feet in length. In the southwestern pits the strata stand nearly vertical, but in the more northerly workings they show a dip toward the southeast, locally as low as 25°. As a whole, the rocks thus associated form a tabular mass conformable with the gneisses, which are seen in contact with them on the southeast and are exposed at several points a short distance to the northwest. Limestone is not known in actual contact with these rocks, but several narrow bands are present near by, separated from them by layers of gneiss and locally in part by masses of coarse granite or pegmatite. Also a large mass of limestone occurs at the old flux quarries half a mile south of the mines on the road to Andover.

The attitude of these evidently fragmentary or clastic rocks with respect to the gneisses at the Andover mine suggests that the latter may be metamorphosed sediments. Being interlayered with the gneisses, the siliceous rocks are entirely distinct from the Hardyston quartzite, which in part they somewhat resemble. From this formation they are also further distinguished by the fact that they are highly impregnated with iron ore and by the presence in them of irregular dikes or veins of feldspar which seem to be related to the ordinary pegmatites of the region.

The remaining localities of the quartzite are in the main belt of white limestone—one of them at the Simpson hematite mine, 2 miles northeast of Hamburg, and the other a mile farther north, near the top of the eastward-facing slope just west of McAfee station, where two pits have been opened in search of iron ore. At both of these places the rock is a glassy quartzitic conglomerate, dull red in color from the presence of considerable amounts of hematite. At the Simpson mine the quartzite lies in layers separated by shaly material, and, besides the iron oxide which impregnates the sandy beds, masses of pure ore are interleaved with the shale and the indurated sandstone. The exposures are very meager, as the hill is covered extensively by glacial drift, but enough is visible to show that the strata have a southeast dip beneath the limestone, though from the northwest they are closely approached by the basal quartzite of the unmetamorphosed Paleozoic rocks, if indeed they are not actually overlapped. The Hardyston quartzite and the blue limestone which lies above it here dip in a direction opposite to the ore-bearing quartzite—that is, toward the northwest.

At the Cedar Hill mine opening near McAfee a massive red conglomerate, from 40 to 50 feet thick, stands nearly on edge. The rock is intercalated in the white limestone, and although the limestone shows no independent evidence of stratification, the quartzite may be traced with probable continuity for a distance of nearly 500 feet. The rock presents a very fresh appearance, and though highly ferruginous it is too lean to be worked as an iron ore. Considerable iron pyrites is distributed through the rock, and portions of it contain crystalline grains of iron carbonate, one-half inch or so in diameter, which have a pearly color when freshly broken but are rust red on exposed surfaces.

The rocks at the three places mentioned have a general resemblance among themselves, and they are similar in a general way to the rocks which carry the hematite ores at Marble Mountain, near Phillipsburg, N. J. A detailed study of the Marble Mountain rocks and of their relations to the crystalline limestones associated with them would in all probability throw light on the occurrences in the Franklin Furnace quadrangle, which are too scanty in extent to furnish facts leading to any complete theory of their nature.

POCHUCK GNEISS.

General statement.—The name Pochuck gneiss was first employed by J. E. Wolff in describing the rocks of Pochuck Mountain, which lies in the northeastern part of the Franklin Furnace quadrangle. It is here used to include all the gneisses occurring in the Highlands region that contain hornblende, pyroxene, or mica as principal mineral constituents. Some of these rocks are probably of sedimentary origin, and others may be altered igneous rocks, but in general they are so completely metamorphosed that their original nature can not be ascertained. Their relations to the other rocks of the pre-Cambrian region are not fully determinable, but on the whole they appear to be older than the intrusive Losee and Byram gneisses. It seems probable that the metamorphism of the Pochuck gneiss and of the white limestone as well was produced during their invasion by the granitoid rocks in association with which they now occur.

Distribution.—Though the dark gneisses enter in varying amounts into the make-up of a large part of the crystalline complex, they are represented on the map only where they appear as the most abundant rocks in areas of considerable extent. A band entering the quadrangle on the east, near Stockholm, extends southwestward to the vicinity of Hopewell Pond, and west of the Wallkill Valley, in addition to several minor patches, there are two bands—one lying next to the south end of the white limestone, the other extending diagonally across the quadrangle from the southwest to the northeast corner. In very many of the iron mines of the Highlands district the magnetite ores are associated with dark hornblende gneisses.

Description.—Detailed examination of thin sections under the microscope reveals many varieties among the rocks which have been grouped as the Pochuck gneiss, but all varieties are characterized by dark hues attributable to the presence of hornblende, pyroxene, or mica as important mineral constituents. Usually the only light mineral present is oligoclase, but some facies of the rock contain considerable scapolite. Microcline is observed occasionally; andesine and labradorite feldspar but rarely. Quartz, though known, is characteristically absent. Accessory minerals, occurring in relatively small amounts, are magnetite, titanite, zircon, and apatite.

These rocks range from medium to fairly coarse grained, and their texture may be described as foliated granular. The foliation is produced by the more or less elongated or flattened form of the mineral grains and the arrangement of these grains so that their longer dimensions lie in sets of nearly parallel planes. Many facies of the rock containing mica are so eminently foliated that they may be properly called schists.

The textural foliation of these rocks everywhere accompanies and conforms to a larger structural foliation produced by the occurrence of different varieties of the dark gneiss as interlayered plates, which are further separated or divided by parallel sheets of injected light-colored rock. This platy structure or gneissic lamination conforms in turn with the broad structure of the pre-Cambrian complex, striking in general from southwest to northeast and dipping steeply toward the southeast.

The subjoined table shows the approximate composition of several varieties of this gneiss.

Mineral composition of Pochuck gneiss.

	1.	2.	3.	4.	5.	6.	7.
Quartz	-----	-----	33	52	-----	-----	5
Hornblende	-----	-----	8	-----	20	52	2
Pyroxene	36	35	22	-----	22	7	-----
Plagioclase	61	-----	35	46	54	40	52
Biotite	-----	-----	-----	-----	([a])	1	41
Magnetite	2	1	2	1	4	-----	-----
Microcline	-----	58	-----	-----	-----	-----	-----
Scapolite	-----	5	-----	-----	-----	-----	-----
Titanite	1	1	-----	1	-----	-----	-----
	100	100	100	100	100	100	100

[a] Small amount.

1, 2, 3, 4. Gneisses from Stockholm band.
5. Dark gneiss occurring in Losee gneiss $2\frac{1}{2}$ miles northeast of Stockholm.
6, 7. Dark gneiss from Pochuck Mountain.

Stockholm band.—Two strips of the dark rock entering the quadrangle from the northeast unite near Stockholm to form a band there somewhat less than half a mile across. A short distance farther southwest this band attains a width of more than a mile, which it holds almost to its blunt ending north of Hopewell Pond.

The most abundant variety of rock in the Stockholm area contains grass-green pyroxene as the principal dark constituent, though certain layers carry hornblende or mica in company with this mineral. Moderate amounts of scapolite are present in many layers, and quartz is noted in a few places. The composition of the feldspar ordinarily lies between that of andesine and oligoclase, but some layers carry microcline in place of this variety of plagioclase. The approximate mineral make-up of several varieties of gneiss in the Stockholm band is given in the table.

The light-hued gneisses interlayered in the dark gneiss of this band are mainly Losee varieties, though Byram varieties are also present. Southeast of the band many plates of dark micaceous gneiss are inclosed in the granitoid rock and cut by large irregular masses of coarse pegmatite. Similar pegmatite occurs here and there within the area in which the dark rocks predominate.

In the northeastern part of the Stockholm band the foliation and layering in the gneisses strike northeast and dip southeast, in conformity with the structural rule of the district, but toward the southwest, in the wider part of the band, the rocks lie in a broad trough or synclinal fold pitching toward the northeast. The blunt ending of the area north of Hopewell Pond results from this structure. The direction of strike follows the boundary as shown on the map, changing from northeast to northwest and back to northeast. Correspondingly, the dips vary from southeast to northeast, and finally to northwest. Here, as elsewhere in the region, the dark gneisses are apparently invaded by the granitoid rocks, but it is not apparent whether the fold existed prior to the incoming of these rocks or was produced during the intrusion.

Franklin Furnace band.—The dark gneisses occurring between the main belt of limestone and the strip to the west in the valley of Wildcat Branch show mainly hornblendic to highly micaceous facies, but with these rocks are some layers of paler hue containing light-green pyroxene. The indicated western limit of the band is very arbitrary, and rocks other than the dark gneisses are so abundant that the propriety of representing this band on the map might be questioned. The interleaving layers are made up of granitoid material, in places quite like the Losee gneiss, but ordinarily pinkish and more like the Byram rock, microcline being their characteristic feldspar. Near Franklin Furnace the injected plates are narrow and as a rule not extensive. Here the feldspar is pink orthoclase and the rock is more than ordinarily coarse grained, suggesting that it may be related to the pegmatites of the region rather than to the Byram gneiss. Irregular masses of very coarse-grained pegmatite, in all respects like that inclosed by the white limestones, are prominent features throughout the band.

Within the Franklin Furnace band the structures strike northeast and dip southeast, so that the gneiss passes beneath the adjacent Franklin limestone, as is shown by the workings of the zinc mines at Franklin Furnace. Between the two rocks there is a sharply defined and essentially regular surface of contact, which conforms in attitude with the layering in the gneiss. There are, however, no features that would indicate the geologic relation between the gneiss and the limestone. Though the western leg of the deposit of zinc ore outcrops only a few feet from the gneiss-limestone boundary and runs parallel with it for several hundred feet, this conformity of structure is lost where the bend in the ore body begins. The fact that the contact line holds its course toward the southwest shows clearly that the surface between the two rocks does not partake of the synclinal structure which is shown by the ore body. This leads to the belief that the limestones have been deformed independently of the gneisses, and suggests that the existing relations along the contact may have been produced by flowage of the limestone against the gneiss.

Western band.—The prevailing rock in Pochuck Mountain is hornblende-pyroxene gneiss, but layers composed mainly of hornblende and others rich in mica are interleaved with this rock in many places. Scapolite-bearing rock occurs on the eastern lower slopes between $1\frac{1}{2}$ and 2 miles northeast of Hamburg, and the presence of cyanite schist along the eastern base of the mountain has been reported by N. L. Britton, though the present writer observed this rock only in the form of loose bowlders.

In the northeast corner of the Franklin Furnace quadrangle the western band of Pochuck gneiss is divided by a wedge of Losee gneiss. On the east it is bounded by the white Franklin limestone, and on the west by Losee gneiss. Shreds or wisps of the dark rock are found in many places within the Losee gneiss of this part of the district. Interlayering of the dark and light gneisses is a prominent feature along the crest of Pochuck Mountain, and both here and round about the dividing wedge the intrusive nature of the Losee rock with respect to the gneisses of the Pochuck can be readily observed.

Contacts between the dark gneisses of Pochuck Mountain and the white limestone of the Franklin belt are nowhere exposed, but the structures of the gneiss strike parallel with the boundary and dip on the average about 75° SE., so that the rock evidently passes beneath the adjacent limestone.

Beyond the narrow strip of Paleozoic rocks which hides the Pochuck gneiss southwest of Hamburg, northeast of the road leading from the gristmill above Hamburg to North Church, several outcrops may be observed in the narrow angle between the inset band of Kittatinny limestone on the east and the overlap of the Hardyston quartzite on the west. To the southwest, as far as the railroad tracks, there is but one exposure. Beyond the railroad the dark gneisses appear, and along the crest of the ridge opposite Monroe station they are bounded by white gneiss, a strip of which lies between them and the western edge of the pre-Cambrian area. From knobs of bed rock rising out of the sand plain east of Lake Grinnell, it is known that this westerly band of white gneiss continues beneath the glacial drift in the direction of Woodruff Gap. In the knoll northeast of Woodruff Gap (elevation 690 feet), and in the next knoll to the southwest (elevation 713 feet), a considerable amount of light gneiss occurs with layers of hornblende. The 713-foot knoll contains large amounts of pegmatite.

Associated with the Franklin limestone east of the 713-foot knoll are layers of gneiss containing pyroxene and scapolite, which have probably been formed by the metamorphism of sedimentary material. Layers of similar scapolite-bearing gneiss are present at several places in the continuation of the Pochuck band toward the southwest. At the Andover flux quarry, one-half mile south of the Franklin Furnace quadrangle, this rock is intimately associated with a mass of white limestone, and in the vicinity of the Andover and Tar Hill iron-ore mines it occurs in company with narrow plates of limestone and in places seems to pass into this rock by gradation along the strike. Both limestone and quartzite are present in the mine workings, and layers of garnet-bearing gneiss occur around Tar Hill.

The southwestern part of the western band of Pochuck gneiss is very poorly defined against the rocks which lie toward the east, the location of the boundary shown being very arbitrary. On the west, except for the strip of white limestone extending from Pinkneyville to Sparta Junction, the rock is limited by the overlap of Hardyston quartzite.

In the old mine workings north of Sussex Mills the limestone of the Pinkneyville area can be seen to come against the dark gneiss along a clean parting which dips about 50° SE., so that the limestone passes beneath the gneiss. At this place there is no appearance of gradation between the two rocks.

The structures in this portion of the western band strike northeast and dip southeast as a rule, although in the 1048-foot hill south of the New York, Susquehanna and Western Railroad a synclinal structure is observed.

The approximate mineral make-up of two examples of dark gneiss from Pochuck Mountain is shown in columns 6 and 7 of the table given under the heading "Description." (See p. 4.)

Minor areas.—The curved and forked strip of Pochuck gneiss which crosses the New York, Susquehanna and Western Railroad 2 miles east of Sparta Junction is composed mainly of rather coarse grained hornblende gneiss, but certain layers contain green pyroxene and others nearly-colorless pyroxene and a blue-brown mica. Considerable magnetite is present in some specimens.

The peculiar shape of this area reflects the structure of the gneisses, the layers of which are thrown into a northeastward-pitching anticlinal fold. The rock above and below the arch is Byram gneiss, inclosing wisps of the dark rock. This structure may have existed before the granitoid rock invaded the dark gneisses, or it may have developed during the disturbance caused by that invasion; the point is not clear. It seems, however, that the distribution of the Pochuck and white-limestone masses with reference to the granitoid rocks must be interpreted as indicating the intrusive nature of the latter, so that the dark gneisses and the white limestone may be regarded as together constituting a greatly disrupted matrix.

The dark gneisses which enter the Franklin Furnace quadrangle from the southwest at the head of Wallkill River have been arbitrarily mapped as occupying a narrow triangular area northwest of the fault which limits the strip of Kittatinny limestone.

Dikes in the Franklin limestone.—Thin plates of dark gneissoid rock are of common occurrence in the white limestone of the Franklin Furnace belt. In general there seems to be no way to determine their origin, but in a few places it is evident that they are really intrusive dikes. This relation can be clearly seen in the Rudeville quarries, where narrow plates of black rock fork in such a manner as to show definitely that the limestone has been invaded by them. The rock of most of these dikes is made up mainly of hornblende and scapolite, or of hornblende and oligoclase, but pyroxene and mica also occur in some of them. Titanite, magnetite, and pyrite are common accessory minerals. In the old Furnace quarry, southwest of Franklin Furnace, a narrow dike of dark rock contains microcline in place of the ordinary oligoclase.

The texture of the rock is invariably foliated by reason of a more or less tabular development of the hornblende in parallel planes conforming with the walls of the dike.

In Norway scapolite dikes essentially similar to these have been shown to be the result of a chemical alteration of rocks that were originally gabbros. A like alteration may have produced the scapolite-bearing rocks here, but the steps of such a change have not been recognized and it seems quite as likely that during its intrusion the invading material absorbed lime from the matrix and retained chlorine originally present in the magma, in this way acquiring the elements necessary to produce the unusual mineral scapolite.

LOSEE GNEISS.

General statement.—The group of foliated granitoid rocks here called the Losee gneiss includes the "Losee Pond granite" described by Wolff and Brooks.[a] It is named from Losee Pond, 2 miles northeast of Ogdensburg. The rocks of the group are mainly light in color and in many slightly weathered exposures nearly white. They are distinguished lithologically from the varieties of Byram gneiss by containing oligoclase (soda-lime feldspar) instead of microcline or microperthite (potash feldspars). They differ from the Pochuck gneiss in that they contain much quartz and only minor amounts of dark minerals.

The Losee gneiss is regarded as an intrusive igneous rock younger than the Pochuck gneiss and the Franklin limestone. Its relation to the Byram gneiss is not known, but it is cut by granite and by masses of pegmatite.

Distribution.—In this quadrangle there are four fairly well defined areas of the white Losee gneiss and two others less readily set apart. In the band from 1 to 1½ miles wide next to the fault which limits the southeastern area of sedimentary rocks, the Losee gneiss includes many narrow layers of dark gneiss and a large amount of coarse pegmatite. This band is not sharply defined against the Byram gneiss to the northwest, so that the boundary given on the map is an arbitrary one. A second belt, which begins a short distance north of the Hamburg-Stockholm wagon road and runs southwestward through Losee and Morris ponds to the edge of the quadrangle, has a width of one-half mile to 1½ miles, and is known to be 20 miles in length. Though actual contacts between the Losee and the surrounding Byram rocks have not been observed, the limits of this band are closely determinable. In many places, but particularly along the edges of the mass, the white gneiss incloses innumerable layers of Pochuck rock, into which it has been intruded.

West of the Wallkill Valley an ill-defined belt of white gneiss about 1 mile wide lies between the Byram gneiss of Briar Ridge and the western band of Pochuck gneiss. Within this belt are many shreds of Pochuck gneiss and several strips of Byram gneiss. On the map the northern termination of this belt has been represented in an arbitrary way. The narrow strip of white gneiss extending for 5 miles northeast of Woodruff Gap is limited on the west by the Paleozoic overlap. It is supposed that this belt connects beneath the cover of Paleozoic formations with the area of the Losee rocks lying west of the dark gneisses of Pochuck Mountain. A triangular area of the Losee gneiss, greatly broken by strips of Pochuck, is inclosed within the band of dark gneisses in the northeast corner of the quadrangle. Toward the north this area widens, and in the northern part of Pochuck Mountain includes two strips of granite.

Description.—The Losee gneiss is recognized in the field by its lack of strong coloration. It is generally white in natural outcrops, and slightly tinged with green in artificial exposures where the fresh rock is brought to view. The rock is composed mainly of oligoclase (a soda-rich variety of soda-lime or plagioclase feldspar) and quartz. These minerals occur in variable proportions and are accompanied by minor amounts of mica, hornblende, pyroxene, and magnetite. The subjoined table shows the average mineral composition of four thin sections from a band of Losee gneiss lying west of Pochuck Mountain (column 1) and of twelve thin sections from the Losee Pond belt (column 2), as estimated with the aid of the microscope. The corresponding chemical composition is given at the right of the table.

Mineralogical and chemical composition of Losee gneiss.

	1.	2.		1.	2.
Oligoclase	67	59	SiO	71	73
Quartz	27	36	Al²O³	17	15
Microcline	2	------	Fe_2O_3	1	1
Hornblende	------	2.6	FeO	------	------
Biotite	3	1.5	CaO	3.5	3.1
Magnetite	------	------	Na_2O	6.1	6.2
Apatite	1	.9	K_2O	.5	.1
Zircon	------	------		99.1	98.4
	100	100			

Though these estimates of the mineralogical composition apply to the bulk of the rock, there are many variations in the mineralogical make-up from place to place. Locally in the western areas the oligoclase decreases in amount and is replaced by orthoclase and microcline. In other places considerable amounts of garnet are present, and still elsewhere a slight increase in the percentage of biotite, pyroxene, or hornblende is noted. The dark minerals occur singly or associated in more or less sharply defined bands, some of which closely resemble the black Pochuck gneiss, and it seems very likely that although some of the dark layers may be magmatic segregations, others may be partly dissolved shreds torn off from masses of the dark gneiss.

The Losee gneiss consists of more or less foliated, medium- to coarse-grained granular rocks, in texture closely resembling granite. Though foliation is discoverable almost everywhere in the rock, lamination is not a striking feature to the eye because of the usual lack of color contrast in the component minerals. Examined under a magnifying glass or in thin section under the microscope, the foliation is seen to be due to the disk-shaped grains of quartz and their arrangement in parallel position. The layering and foliation both follow the same trend as the boundaries of the belts, and the dip of these structures, as in the other rocks of the region, is ordinarily toward the southeast.

BYRAM GNEISS.

General statement.—The rocks here grouped as Byram gneiss, named from their characteristic occurrence in Byram Township, Sussex County, include several varieties of granitoid gneiss which are lithologically related by the presence of potash-bearing feldspars among their principal mineral components. As thus defined, the formation includes the "Hamburg," "Sand Pond," and "Edison" gneisses, which were separately mapped by Wolff[a] in the Franklin Furnace district; the "Oxford type" of gneiss, described by Nason;[b] and the gneissoid granite of Breakneck Mountain, on the Hudson, described by Merrill.[c]

The composition of the Fordham gneiss of the New York City quadrangle corresponds with that of the Byram gneiss, and eventually the two may be proved to be equivalent. The rock here mapped as "granite" has been separated from the Byram complex mainly because of the exceptionally definite relations it shows to the other rocks of the district.

The geologic relations of the Byram gneiss to the Pochuck gneiss and the Franklin limestone are very obscure, but the Byram appears to invade the other rocks. The structural relationship between it and the Losee gneiss is not known. In common with all the other pre-Cambrian rocks the Byram gneiss is cut by irregular masses of pegmatite. In many places the gneiss incloses minable deposits of magnetic iron ore.

Distribution.—West of the Wallkill Valley the Byram gneiss is the most abundant rock in a belt including Briar Ridge and the central part of the Pimple Hills. On the east it occupies a general belt including the Wallkill, Hamburg, and Wawayanda mountains, though in Sparta and Hardyston townships this belt is divided longitudinally by the Losee Pond band of the Losee gneiss.

Description.—The rocks here classed together are granitoid gneisses composed essentially of quartz and microcline or microperthite (potash feldspars), with variable proportions of hornblende, pyroxene, and mica. Oligoclase (soda-lime feldspar) is usually very subordinate in amount, but here and there it equals the potash feldspar. Accessory minerals are magnetite, zircon, apatite, and titanite. Though considerable amounts of garnet are present in places, the occurrence of this mineral is sporadic. Cyanite occurs in the old mine workings at Edison. There are several facies of the rock which vary greatly in appearance as seen in the field, though almost without exception these facies show greater resemblance to each other than to varieties of the other gneisses with which they are associated. In a broad way the different varieties may be separated into two groups, according to the lighter or darker appearance of the rocks. The darker gneisses are the most widespread, but locally the light-colored varieties are prominently developed. The subjoined table shows the mineralogical composition of specimens from several localities.

Mineralogical composition of Byram gneiss.

	1.	2.	3.	4.	5.	6.	7.
Quartz	2	6	15	19	20	28	34
Orthoclase	------	------	5	------	------	2	------
Microcline	------	34	5	6	70	35	51
Microperthite	43	40	61	52	5	26	------
Oligoclase	44	2	10	9	2	5	8
Hornblende	9	17.5	------	7.5	------	1.5	------
Augite	------	------	2	------	------	------	------
Mica	------	------	------	------	------	------	4
Magnetite			1	2	3		2
Titanite	2	5		4	------	2	
Apatite			1	.5	([a])		1
Zircon				------	------		
Allanite	------	------	------	------	------	.5	
	100	100	100	100	100	100	100

[a] Present.

1. Fine-grained hornblendic phase from banded gneisses composing 1157-foot knob, south of Hamburg-Stockholm road, 2 miles southeast of Hardystonville.
2. Coarse-grained hornblendic phase from massive outcrops on Hamburg-Stockholm road, near locality of No. 1.
3. Augite phase 2 miles northwest of Ford station, on Central Railroad of New Jersey.
4. Medium-grained hornblendic phase from outcrops north of Sand Pond road, northeast of Rudeville, on brow of ridge facing the limestone valley. Foliated structure well developed.
5. Light-colored phase about 1¼ miles southeast of McAfee.
6. Bronzy gneiss containing very little hornblende. Much of this rock is found along the eastern margin of the quadrangle. The locality of the specimen is 1½ miles northeast of Sand Pond.
7. Fine-grained biotite phase of light-colored "Oxford type" about 1¼ miles northeast of Losee Pond, on 1307-foot hill.

In the dark facies of the Byram gneiss the general tone in natural outcrops is ordinarily gray, but on freshly broken surfaces the rock shows a brownish hue, varying in depth according to the proportion of dark minerals present. This brown tone is accompanied by a bronzy effect produced by the luster of the feldspar cleavages. The bronzy rocks are moderately coarse to coarse grained, and in those which contain dark minerals the latter are more commonly hornblende or pyroxene than mica. Much of the rock is comparatively free from dark minerals, but even where these are absent the brownish color remains. A common dark variety contains considerable hornblende in crystals of moderate size grouped together in the form of pencils. These pencils, being arranged parallel to a common axis, give the rock a banded appearance on all sections except transverse to the axis, where the texture is essentially even granular. In the ledge these pencils almost invariably pitch toward the northeast, in conformity with the pitch of the ore bodies in the iron and

[a] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, p. 429.

[a] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, p. 439.

[b] Ann. Rept. Geol. Survey New Jersey for 1889, p. 30

[c] New York City folio (No. 83), Geologic Atlas U. S., U. S. Geol. Survey, 1902.

zinc mines and the lines of corrugation in the gneisses. In other facies of hornblendic rock the dark mineral is so distributed that the texture is merely foliated, or in some places simply granular. The hornblende, pyroxene, and mica facies are widely distributed, but they grade into and are surrounded by larger amounts of rock containing only small proportions of the iron- and magnesia-bearing minerals.

The light varieties of the Byram are yellowish as seen in outcrop, and pink, light gray, or whitish when freshly broken. They are ordinarily somewhat finer grained and less foliated than the dark facies, and usually carry mica rather than hornblende or pyroxene. They are the most abundant rocks in the Pimple Hills and in three prominent knolls lying northeast of Sand Pond. In specimens of the Byram made up mainly of feldspar and quartz, the texture is commonly almost perfectly granular, but in the field some structure is usually to be detected.

The relations between the different facies of the Byram gneiss are regarded as closely resembling those observable in granites and other coarse-grained intrusive rocks. It has not been found possible, however, to determine the relative age of different facies of this granitoid gneiss where they are found in association, and so far as present information goes all the varieties must be regarded as geologically contemporaneous and equivalent.

GRANITE.

Granite occurs in several good-sized masses immediately north of the Franklin Furnace quadrangle, in the upper end of Pochuck Mountain, and farther north in Mounts Adam and Eve, in Orange County, N. Y. Three narrow wedges of the rock, which are shown on the areal geology map near the northeast corner, are merely the south ends of masses which extend toward the northeast for 2 to 4 miles. The rock is a coarse-grained granite, showing a rude foliation throughout the mass, and in many places being quite gneissoid. Kemp has shown that at Mounts Adam and Eve this rock is definitely intrusive into the Franklin limestone.[a] In Pochuck Mountain it invades the Pochuck and Losee gneisses.

The composition of the granite is intermediate between that of the Byram and Losee gneisses, potash and soda-lime feldspars being characteristically present in about equal amounts. These feldspars, with quartz and hornblende, make up the main bulk of the rock, the accessory minerals being zircon, magnetite, titanite, and the rather rare mineral allanite. The rock carries many irregular dikes of coarse pegmatite, similar in composition to the matrix. In some of these dikes large crystals of allanite occur; others contain considerable magnetite, and fluorite is locally observed.

PEGMATITE.

Distribution.—Coarse granite or pegmatite occurs in all parts of the Highlands, inclosed either in the granitoid Byram and Losee gneisses as ill-defined masses appearing simply like more coarsely crystalline portions of the surrounding rock, or in all the gneisses and in the white limestone as definitely invading masses. In mapping the Franklin Furnace area no attempt has been made to show the distribution of the pegmatites in the gneiss area. Where they are inclosed by limestone it is easier to discriminate them, and here they have been represented in a general way, with the omission of many details. In the eastern part of the quadrangle, between the Morris-Sussex county lines and the sedimentary area of Bowling Green Mountain, pegmatite is so thickly mingled with the Losee gneiss that the two rocks have nearly equal bulk. Between this belt and the Wallkill Valley pegmatite is less prominently developed, but it is not absent in any single square mile. West of the Wallkill this rock is present in about the same amounts as in the belt of Franklin limestone. Only the larger bodies within the limestone belt have been mapped. Here and also in the gneisses they are usually elongated parallel with the general trend of the inclosing rock.

Description. — The principal minerals of the pegmatite are the same as those occurring in the granitoid gneisses, viz, quartz, microcline, microperthite, oligoclase, hornblende, pyroxene, and in places magnetite. The hornblende and pyroxene vary greatly in quantity, rarely forming more than half the rock mass. Accessory minerals include garnet, magnetite, apatite, titanite, zircon, allanite, fluorite, locally graphite, and several of the metallic sulphides. In a few places scapolite is an important mineral in the make-up of the pegmatite. Certain of the masses in the limestone have afforded large and beautiful groups of hornblende and pyroxene crystals, and most of the mineral species from the mines at Franklin Furnace and Sterling Hill occur along the walls or near the pegmatite dikes which cut the ore bodies.

Origin and relations with other rocks.—Many masses of pegmatite show such structural relations with the associated rocks or are so distinct in character and composition from the latter that there can be no doubt that they are bodily intrusions of materials derived from a distant source; other masses appear to be merely coarse-grained phases of the granitoid rocks by which they are surrounded. The injected masses are irregular dikelike bodies which follow in a rude way the lamination of the gneiss or limestone, and where numerous add considerably to the layered effect of the crystalline complex. Accordance of structure is, however, everywhere imperfect, and not only can oblique contacts be noted but in places arms or stringers ramify into the gneisses.

As the pegmatite exhibits essentially the same range of composition as the granitoid Losee and Byram gneisses, it seems possible that it was connected with these rocks in origin. Existing evidences that the intrusive pegmatite crystallized somewhat later than the other rocks are favorable to this suggestion rather than otherwise, in view of the well-known fact that in regions where great intrusions of granite have been studied pegmatite has ordinarily been formed among the later products of igneous activity.

In the limestone abundant contact minerals are observed next to some of the intrusions, but are entirely wanting in the vicinity of others. Aside from the principal ore minerals, franklinite, zincite, and willemite, and certain products of surficial weathering, almost all of the great variety of zinc- and manganese-bearing minerals afforded by the zinc mines have come from the pegmatite contacts, and at Mine Hill even the three usual ore minerals have in places been recrystallized under the influence of the intrusive rock.

OCCURRENCE OF ORES IN THE PRE-CAMBRIAN ROCKS.

MAGNETITE IRON ORES.

Occurrence and description.—Magnetite occurs in numerous bodies of minable richness and size, and also as a common though usually minor constituent of all the varieties of gneiss present in the New Jersey Highlands. The amount of magnetite in the general run of the gneisses is comparable to that ordinarily present in granites and related massive igneous rocks, and, though variable from place to place, is in general not enough to draw attention to the rocks because of their iron content. It is a prominent component of many coarse-grained or pegmatitic portions of the gneisses, which seem to have been formed as local segregations out of materials furnished by the enveloping rock. In many of the intrusive pegmatites, however, the mineral is abundant in the rock, along with feldspar, quartz, and in some places hornblende. Magnetite-bearing pegmatites have been locally prospected in searching for richer deposits, but none of them afford ores of smelting grade without some form of concentration.

The only deposits of magnetite thus far mined with commercial success have the form of layers, which are commonly called veins or ore beds. These are interlaminated with the gneisses of the region, or to a less extent they are embedded in the metamorphic crystalline limestones. The ore layers are observed in all thicknesses from a fraction of an inch to 30, 50, or even 80 feet, the usual range in the mines being from perhaps 4 up to 12 or 15 feet. Extensive mining prior to 1887, when the Lake Superior iron ores began largely to supersede those of the Eastern States, had shown the deposits to be disposed in rather narrow belts or ranges, separated by usually wider belts of practically barren gneiss. These ranges are from one-fourth mile to 2 miles wide, and in places 30 miles or more in length. (See fig. 8.) They take the same general direction as the bands of gneiss, and within them the numerous ore veins have a common strike essentially parallel with the trend of the range itself. The courses of all these features, including the foliation in the country gneisses, are from southwest to northeast, and the dips are toward the southeast. Exceptions to this rule are few. In some of the ore belts there are many workable veins lying side by side or overlapping en échelon, and between the thicker layers there are in many places a still greater number that are too thin for profitable exploitation. In general the persistence of the ore layers corresponds with their thickness, the thinnest layers especially being found to die out in rather short distances, whereas some of greater cross section have proved continuous for several thousands of feet.

The ore layers occurring in the gneisses are not confined to any particular sort of rock, and the several sorts of gneiss recognized in the field are all found in the mines at one place or another. Perhaps the most usual country rock is Byram gneiss, though the Losee gneiss is almost as commonly present. Except where they are cased by limestone, the ore layers are generally accompanied by "vein rock" distinct in composition and appearance from the ordinary country gneiss, and usually darker because more hornblendic. Most of this material resembles common phases of the Pochuck gneiss. The dark rock may be a constant feature, may come and go, or in different parts of a mine may be present on both sides of the ore or on one side only. Locally it forms horses within the vein. In places the country rock on opposite sides of an ore body is of very different composition, the ore, with or without the dark vein rock, following the parting between the two varieties.

The thickness of individual veins is variable, and the variations occur with a certain degree of regularity, in such a way that by alternate swells and pinches many of the ore layers are divided into portions thick enough for profitable mining, with intervening portions too thin to be conveniently extracted. This pinch and swell structure is characteristic of the iron-ore deposits not only in the New York and New Jersey Highlands, but in the Adirondack region of northern New York, in the corresponding pre-Cambrian areas of Canada, and also in certain localities in Norway and Sweden. In the veins of the Highlands region the swells or ore shoots are mainly rather regular, having the form of long cylinders, with roughly elliptical cross sections. (See fig. 2.) This shape has led to the

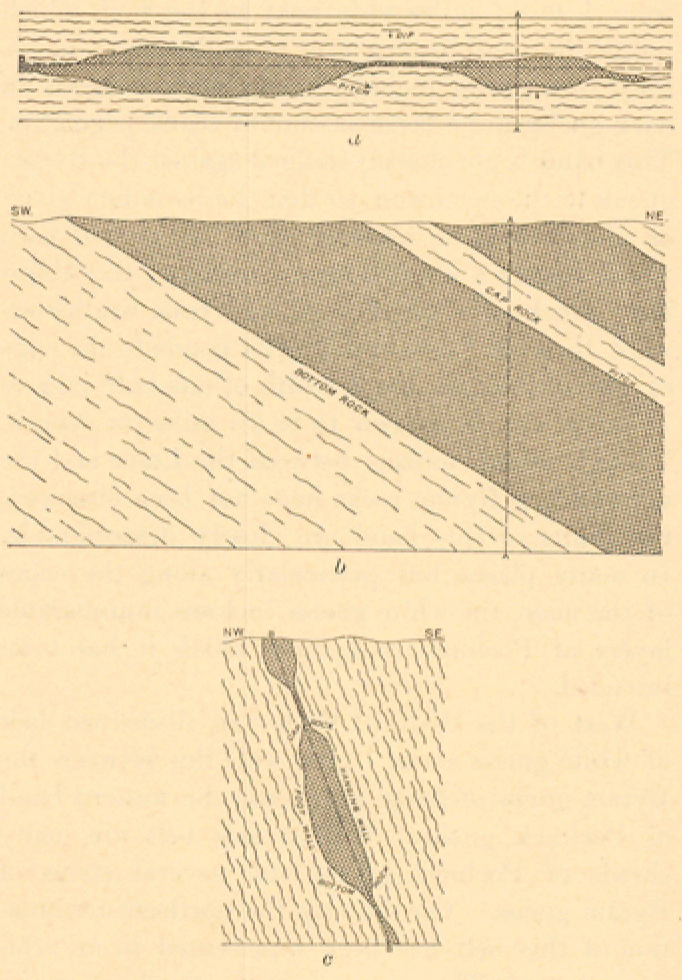


FIG. 2.—Diagram of pod-shaped ore shoots characteristic of the magnetite deposits of the Highlands.
a, Plan of ore lenses, which strike parallel with the inclosing gneiss.
b, Longitudinal section in the plane of the dip of the gneiss.
c, Vertical cross section along the line A-A.

use of the term "ore pods" in descriptions of the shoots of ore. As a rule, to which a few exceptions are on record, it is found that the longest dimensions of the shoots or pods, as they lie in the plane of the ore layer, decline from the horizontal toward the northeast. In other words, the shoots have a northeast pitch independent of the dip of the ore layer. Along the pitch the ore pods are ordinarily persistent for very considerable distances, but as there has been little deep mining their limits have seldom been determined. In several places it may be shown, or fairly inferred, that individual shoots continue for 1000 to 2000 feet, and at the Hurd mine, in Morris County, the length of the main shoot from its outcrop to its underground termination was more than 6000 feet. Measured in the plane of the layer at right angles to their longest axes, the shoots are of variable width, but in many of them the distance from pinch to pinch is not far one way or the other from 100 feet, and the interval between the shoots is perhaps usually not greater than their width. On comparing the length and width of the shoots, it seems that the minable length may be expected to average perhaps from 30 to 60 times the width, though these can not be taken as limiting ratios.

There are few deep mines in the New Jersey Highlands, and the most extensive workings are on the more regular veins, as at the Hibernia mine, in Morris County, where swelling and pinching of the ore belt are not prominent features. For this reason the occurrence of several well-marked swells on a single vein has seldom been shown by continuous working underground. In the main the existence of this relation is proved, however, by studies of surface workings which leave no room for doubt that in several places two, three, four, and probably even a greater number of large ore shoots lie one above another upon the same layer, being connected by thinner masses of ore occupying the pinches. Two such shoots were worked in the Ford and Schofield mines, in the Franklin Furnace quadrangle, and the relation is clearly exhibited in the surface pits on the Mount Hope tract, north of Dover, N. J., where the outcrops of several parallel veins have been opened continuously for a distance of several hundred feet.

In the mines it is usually found that the shoots narrow down rather abruptly in the roof and bottom, but from the workings it is ordinarily impossible to determine the full extent of the ore, as mining ceases when the vein runs down to a thickness of 2 to 4 feet. Some of the ore shoots are cleanly capped or bottomed by rock, or even entirely surrounded by the gneiss. Completely isolated ore bodies of this sort are rather unusual, so far as observation goes, and no instance has been noted where two of them can be definitely referred to the same layer in the country rock. Nevertheless, it seems likely that they have originated in a similar manner to the swells of the continuous layers, the difference being that the pinching is more complete.

As a rule, the ore layers are essentially tabular, their principal irregularity of form being the swells and pinches already described. Gently curving outcrops and variation in the angle of dip show, however, that certain layers are slightly warped, and in a few places the veins turn back upon themselves and present the appearance of having been folded, as do the veins of zinc ore at Franklin Furnace and Sterling Hill. Similar features are to be observed locally in following layers of distinctive composition in the gneisses.

Branching of the veins rarely occurs, but spurs have been noted, in some places diverging upward, and in others downward from the main body of ore. In the Hurd mine at Wharton, which is not to be confused with the abandoned mine of the same name mentioned above, a downward spur was found to terminate about 80 feet below its junction with the main vein, and the mine workings show that for several hundred feet the locus of the fork falls away toward the northeast, in conformity with the pitch of the fairly well marked ore shoots of the vein. Masses of rock like that inclosing the veins are present in many of the ore bodies, the workable width of which is thereby decreased. In general, these "horses" have the same podlike shape and northeasterly pitch as the ore shoots, and though many veins are nearly free from them, in others they are numerous and troublesome. In places solid veins split up into a series of wedges which dovetail with narrow angles into the country gneiss, and many of the ore beds are complex aggregates of thin plates of magnetite alternating with plates of silicate minerals. Deposits of this sort have much the aspect of darker varieties of

[a] Ann. New York Acad. Sci., vol. 7, 1893, pp. 638-654.

the country gneiss, the only essential difference being that their dark mineral is magnetite instead of hornblende or pyroxene.

The gangue of the ore is always made up of the ordinary minerals of the country rock. Hornblende and feldspar, the commonest minerals of the accompanying gneisses, are the most abundant components of the gangue, but replacing or in addition to them quartz, mica, and pyroxene occur locally. Where the ores are cased by limestone, calcite is almost invariably the only nonmetallic mineral present. Between magnetite-bearing gneiss and bodies of high-grade magnetite, on the one hand, and ordinary country rock containing little magnetite, on the other, all intermediate gradations may be observed throughout the field, so that the more one sees of the iron deposits the stronger becomes the conviction that they form an integral part of the gneissic complex, and that even in the purer form they had their origin along with the gneisses, of which they seem to be merely mineralogic phases.

The ores are rarely of Bessemer grade, for as a rule they contain too much phosphorus and in many cases too much sulphur. The phosphorus is present in the mineral apatite, the whitish grains of which may be seen distributed through the magnetite of many of the massive ores that are nearly free from silicate minerals. In certain mines considerable portions of the deposit are rich in apatite, but segregations of this sort are rather rare than common. Sulphur, where present, occurs in the form of iron sulphides, either pyrite or pyrrhotite, the latter being perhaps more common than the former. These minerals locally accompany the magnetite in amounts so considerable that the ores must be roasted to free them from sulphur before they are suitable for smelting. The ore from most of the mines now worked contains only minor amounts of sulphide minerals.

Minerals occasionally found with the ores are titanite, garnet, sillimanite, calcite containing manganese replacing part of the lime, fluorite, molybdenite, chalcopyrite, galena, and sphalerite. Many of the ores contain small amounts of manganese, probably replacing part of the iron in the magnetite, and though a few deposits rather high in titanium are known the latter mineral is not generally present in amounts sufficient to seriously affect the metallurgical treatment of the ores.

The statements that have been made concerning the relations of the layered iron ores to the several sorts of gneiss show that the existence of ore beds depends in no way on the presence of any particular sort of rock. It is also true that no structural conditions peculiar to the ore ranges have been recognized. The most careful work of a geologist furnishes, therefore, no law governing the occurrence of the ore which, if recognized, might be turned to account in determining favorable or unfavorable geologic conditions in any undeveloped tract of land, nor is it possible to define any geologic conditions favoring the presence of large ore bodies within a recognized ore range. In spite of this lack of basis for definite predictions, however, a generally successful outcome may be expected when deep drilling is systematically taken up in the search for ore reserves within known ore ranges. The features of the deposits already worked, considered in the light of the general make-up and geologic structure of the Highlands region, tend strongly to the conclusion that future development will show a general persistence of the iron ores in depth and that for the field at large the lower limit of mining operations will ultimately depend on increasing costs as depth is attained rather than on any decrease in the average size or richness of the ore bodies.

ZINC-BEARING ORES.

Occurrence and description.—The ores which occur at Mine Hill, near Franklin Furnace, and at Sterling Hill, near Ogdensburg, N. J., are chiefly valuable as a source of zinc, but also on account of the manganese and iron which they contain. From them is made a high grade of spelter (crude commercial zinc); zinc oxide, used as a white paint and in the arts; and spiegeleisen, an alloy of iron and manganese used in the production of steel. The ore minerals are principally franklinite, containing oxides of iron, manganese, and zinc; willemite (silicate of zinc), much of it containing some manganese; and zincite (oxide of zinc), with manganese as a minor constituent. In the Sterling Hill ore the minerals above named, with the addition of tephroite, a silicate of manganese, are practically the only metallic minerals, but in the Mine Hill deposit several other zinc and manganese bearing minerals, mainly silicates, are found in considerable amounts, though still not present in the bulk of the ore.

The ore bodies may be called veins, in conformity with local usage, though like the bodies of iron ore occurring in the Highlands they are not really veins in the sense of being distinct fillings of definite fractures in the inclosing rocks. They are layers or stratiform masses consisting of varying mixtures of the three ore minerals and calcite, inclosed or cased by coarsely crystalline white limestone. The ore and country rock are in general not sharply separated by definite walls, but the calcite of the rock is intergrown with that of the gangue, and in many places there is a gradual passage from workable ore through lean material into barren rock without the slightest suggestion of a physical break or parting. Both the inclosing rock and the ore show a rather well marked and persistent lamination that corresponds in appearance and attitude with the platy structure of the gneisses occurring throughout the general region outside of the white-limestone areas. In the ore this foliation is more strongly marked than in the limestone, because of the contrasting colors of the component minerals, but wherever foreign minerals are present in the limestone the laminated effect is obvious. Completeness of foliation depends on variations in the proportions of several constituent minerals segregated in different parts of the vein. The mineral grains on the borders of adjacent layers or plates interlock so that the entire mass is closely knit into a solid whole.

In places in both deposits the entire vein consists of franklinite and calcite, and is comparatively low in zinc content. Elsewhere brilliant-green or dull-brown willemite is added to these minerals, and certain layers show a sprinkling of blood-red zincite, contrasting with the black franklinite, white calcite, and tinted willemite, and making an ore of strikingly beautiful appearance. At Sterling Hill portions of the ore bed, as opened in the old mines, consisted of two distinct layers which were called the zinc and the franklinite veins. The zinc vein was composed mainly of zincite mixed with calcite, though locally carrying considerable willemite or tephroite and in some places franklinite also. The other layer was composed of franklinite and calcite, with willemite or sporadic tephroite. At the bend or elbow of the deposit the zinc vein is missing, but along the hanging wall of the eastern leg several shoots of the rich ore were encountered and one of them was mined for more than 700 feet on the dip of the vein. On the western or back leg, to judge from what may be seen in the abandoned workings, a similar layer, here on the foot wall, was followed for 200 feet or more along the strike and 100 feet down the dip. These are the only instances exhibited in the mines of so definite and persistent a separation of the ore minerals.

Less marked examples were noted in the Mine Hill deposit, in the shallow northeast openings on the western leg of the vein, where a layer carrying zincite in addition to franklinite occurred on one side of the vein, though the other side carried practically none of the richer zinc mineral. Toward the elbow of this deposit the western leg is said to have contained two streaks rich in zincite, but these seemed to have had no constant position in the vein. In the present deep workings no regularity in the distribution of the different ore minerals can be made out, though the ores of varying value are always disposed in the form of plates, which taken together bring out a gneissic structure almost everywhere. The early supposition that there was a persistent division of the Mine Hill deposit led to the separate conveyance of mining rights for zinc ore and franklinite ore, and eventually to troublesome litigation continuing from 1857 to 1896.

The veins of both mines have curved or hook-shaped outcrops, and mining has shown that they are warped bodies of rather simple and somewhat similar form. In the open pits at Sterling Hill the curve or bend of the vein was found to lie parallel to an axis inclined about 50° away from the horizontal toward the east, so that the ore body is a simple trough, resembling a rock stratum folded into a pitching syncline. The average pitch of the keel is probably about 50°. The foot wall of the eastern vein is said to be considerably corrugated, and the ore shoots resulting from this structure pitch toward the east. Along the outcrop the eastern leg is about three times the length of the western, the total length being about 2200 feet. The eastern leg has been opened by shafts and slopes to a depth of about 600 feet, but the elbow was not reached in the underground workings. The total thickness of the deposit ranges from 10 to 30 feet; that of the division rich in zincite from 2 to 10 feet.

Lying inside the trough of the ore but separated from it by a few feet of barren marble or very lean ore is a curving dike of hornblendic pegmatite with concentric walls, about 300 feet long on the western and 700 feet long on the eastern leg, and from 2 to 30 feet wide. Both the ore vein and the dike show a marked thickening at the bend. The wall of this dike on the side next the ore carries the unusual manganese and zinc bearing silicates which the mine affords.

Between the two legs of the vein and opposite the termination of the western leg, the coarsely crystalline limestone is highly charged with franklinite and willemite. Much of the calcite from this part of the mine contains a considerable percentage of manganese oxide replacing part of the lime. The exposed width of the mineralized rock along the north side of the large open pit is 250 feet. Somewhat farther north, on the brow of the hill, the same material is seen to continue nearly 100 feet farther east, quite to the foot wall of the eastern vein, Toward the north the mineralized rock makes a series of dovetails into the country limestone, the line marking its general limit running from a point near the end of the western leg diagonally across to the eastern leg, which it meets about 300 feet from its northeastern termination. Near the points of the dovetails pyroxene and scapolite appear and the amount of franklinite diminishes greatly and the analysis of the latter mineral shows it to contain less than half the ordinary amount of zinc. The metallic impregnation between the legs of the vein dies out beneath the open excavation in ground not at present accessible for examination because covered by mine waste. South of the pit white and blue tinged limestone fills all the space within the elbow of the vein. Here there are no metallic minerals and the limestone is in every way like the usual country rock, even carrying abundant graphite, which, though characteristic of the general run of the white limestone throughout the Franklin Furnace belt, is nowhere observed in any of the ore, however lean.

In the natural state of the ground at Sterling Hill, just where the large open pits are now, the ore veins were crossed by a broad swale 20 to 30 feet deep draining to the Wallkill Valley. Under this basin-like depression was found a deposit consisting in part of loose franklinite gravel, and in part of more or less decomposed franklinite and willemite crystals cemented by calamine and smithsonite. The manner of occurrence indicates that this material was derived from the breaking down of the surficial portion of the main ore body, the minerals of which were freed by solution of the calcite in which they were embedded, and at the same time were themselves partially dissolved to furnish solutions from which the secondary zinc minerals were precipitated. The maximum depth of this secondary product is said to have been about 75 feet. No deposits of the sort existed at Mine Hill, where calamine and smithsonite are found only in a few narrow veinlets in the upper portion of the ore body.

The vein at Mine Hill also is trough shaped; but here the bottom line or keel is less steeply inclined than at Sterling Hill and is considerably curved. The trough has an average pitch of 20° NNE., but toward the lower end of the deposit it first flattens and then rises gently to the termination of the ore body. The total length of the keel is somewhat more than 3500 feet. At Sterling Hill the outcrop of the eastern leg is the longer, but at Mine Hill the reverse is true, the western outcrop measuring in round numbers 2600 feet and the eastern only 600 feet. Both parts of the vein continue underground beyond their outcrops. The north end of the western leg is capped over by blue limestone, and though not yet explored in the upper mine levels may be reasonably expected to extend for several hundred feet beyond the last surface exposure. In the eastern leg the buried portion is much longer than the part which outcrops. Northeast of the trap dike near the last surface exposure (referring to original conditions prior to extensive mining in the present open-cast workings) the ore is capped by the white-limestone country rock, which forms an arching roof above it. This crest pitches more steeply than the bottom of the trough, so that from southwest to northeast, in a horizontal distance of 600 feet, the height of the eastern leg decreases from about 300 to 150 feet. In both the southern and the northern parts of the mine the eastern leg stands in a nearly vertical position; in the central part the top leans toward the west. The western leg dips toward the eastern at an angle of about 55 degrees, the maximum dip length of this leg being about 1350 feet. In the deeper workings the deposit is much thicker along and near the bottom of the trough than on the limbs, and here the largest amounts of rich ore are found.

Irregular dikelike masses of pegmatite cut the ore body in several places, and it is along their contacts that the numerous and unusual zinc and manganese minerals afforded by the mine are found. Unlike the dike at Sterling Hill, these pegmatite masses do not follow the lay of the ore body, but are obviously intrusive in it.

Minor amounts of sphalerite are found at both mines, but the occurrence of this mineral is such as to indicate that it has originated since the main body of the ore was formed, probably in connection with the invasion of the pegmatite masses.

The very general description of the two zinc deposits given above shows them to be distinct from all other known deposits of this metal. Not only is the triple association of iron, manganese, and zinc in ore bodies of workable size unique, but the state of chemical combination in which these metals exist, though common enough in the case of iron and not unusual for manganese, is exceptional for zinc. Ordinarily zinc ores consist of sulphide (sphalerite), or of carbonate (smithsonite) and hydrous silicate (calamine) derived from sulphide in a secondary way by decomposition due to the action of atmospheric waters. Among the mines of the world only two others have been brought to the attention of mineralogists as having afforded any considerable amount of willemite. In one of these the mineral occurs with and is subordinate to sphalerite; in the other it is associated with calamine. Franklinite is reported from a few localities as an unusual mineral, and zincite is a rarity. In striking contrast to the paucity of these particular minerals in the ore deposits of the world at large is the fact that the New Jersey deposits contain each of them in amounts measurable by many thousands of tons.

The difference in the chemical state or combination of zinc in sphalerite and in the minerals franklinite, willemite, and zincite is most readily exhibited by the composition formulas of these minerals. Sphalerite in chemical notation is ZnS, zincite is ZnO, willemite is $2ZnO \cdot SiO_2$, franklinite $(Fe,Mn,Zn)\ O.\ (FeMn)_2O_3$. In the New Jersey ore minerals the zinc is thus combined with oxygen and not with sulphur as in all other occurrences. From the chemical standpoint, therefore, these three ore minerals are closely related among themselves and are in no way allied to sphalerite. The association with the zinc in sphalerite ores of sufficient amounts of iron, lead, cadmium, and in many places copper to affect both the metallurgy of the ores and the purity of the metal derived from them is to be compared with the presence in the New Jersey ores of these elements (except iron) in minute quantities only, which enables the production of a pure grade of commercial metal.

The association of the zinc with manganese and iron, the combination of these metals in the condition of oxide, and the mineralogic similarity between the franklinite and magnetite $(FeO.Fe_2O_3)$ suggest a close analogy between the zinc deposits and those of iron ore occurring throughout the area occupied by pre-Cambrian rocks in New Jersey and southeastern New York. Recorded analyses of the New Jersey magnetic iron ores show them to contain manganese in amounts ranging from a fraction of 1 per cent up to several per cent, and small amounts of zinc have been found in several analyses where special tests have been made to determine its presence or absence. Not only are the zinc and iron deposits thus closely related in a chemical way, but they resemble each other in the form and structure of the ore bodies and in the manner of occurrence with respect to the inclosing rocks. Taken as a whole, these resemblances lead to the view that the ore bodies at Mine and Sterling hills are to be classified with the occurrences of magnetite and regarded as a variety of ore deposit differing from the ordinary type mainly in the unusual amount of zinc and manganese which they contain.

ORIGIN OF THE ORE DEPOSITS.

Two theories have been held hitherto concerning the manner in which the iron ores of the Highlands district were formed. The first, which was stated by H. D. Rogers in 1840, admits a sedimentary basis for the gneisses in which most of the ores occur, but regards the ore bodies themselves as igneous injections. The similar magnetite deposits of the Adirondacks region in New York were regarded by Ebenezer Emmons, in his report of 1842 on "The geology of the northern district of New York," as igneous dikes injected into gneisses partly of sedimentary and partly of igneous origin.

The second theory, first fully stated by William Kitchell in the report of the Geological Survey of New Jersey for the year 1856, places the ores as well as the gneisses in the light of sediments brought into their present condition by complete and wide-reaching metamorphism.

The igneous theory has had no adherents since the conclusions of Kitchell were published and in nearly all the work of the New Jersey Geological Survey it has been assumed that the gneisses and included iron ores have been derived from stratified or sedimentary rocks through processes of metamorphism involving no essential addition of material during the alteration. The question of genesis was reopened in 1889 by Frank Nason, who concluded that the then existing state of knowledge did not afford an adequate basis for deciding between the sedimentary and igneous hypotheses. This view was likewise held by C. R. Van Hise in his summary of literature of the pre-Cambrian rocks of the Highlands region, published in 1892.

The ore deposits of the Highlands region offer in themselves no adequate clues for determining their origin, and the best that can be done in this direction is to assign the deposits to the most probable place in the geologic history of the pre-Cambrian rocks. As the history of these old rocks is obscure, the genesis of the ores can be considered only in very general terms.

The two deposits of zinc, iron, and manganese minerals at Sterling Hill and Mine Hill and a few deposits of magnetite are inclosed by highly metamorphosed sedimentary limestone, whereas most of the magnetite deposits are associated with granitoid gneisses of igneous origin. Both in the limestone and in the gneisses the ore deposits are layers or tabular masses which conform with the general structure of the country rocks. The fact that there are usually no sharp physical breaks between the ore bodies and the wall rocks indicates that the present characters of the ore masses originated contemporaneously with the final crystallization of the associated rocks, so that the deposits must have been introduced either before or during deformation and metamorphism. The crystallization of the limestone was undoubtedly produced during deep-seated deformation and metamorphism. It is conceived that the general alteration of these rocks accompanied their invasion by the igneous rocks and that the deposits of ores which they contain were derived from the same source as the invading magmas. The ores occurring in the igneous rocks must be regarded also as of magmatic origin.

The magnetite ores of the Highlands are believed to have been formed by igneous processes connected with the invasion of the region by the granitoid rocks which are characteristic of the pre-Cambrian area. It seems almost certain that the ores at the Andover mines, in the Franklin Furnace quadrangle, were deposited from solutions as replacements of limestone, shale, and siliceous breccia, remnants of which may still be recognized in the old mine workings. Elsewhere, as in the vicinity of Franklin Furnace, the ores may have been introduced by iron-bearing solutions, or the ore masses may have been injected in the condition of magmatic materials. Some of the ore layers in this vicinity are well within the mass of white limestone; others occur along the parting between this rock and the gneisses which outcrop west of the limestone belt. The ores of the limestone have calcite as their only gangue mineral, but the ores occurring between the two rocks carry abundant feldspar and pyroxene and here and there some garnet. Small and irregular masses of pegmatite that occur with the ore seem to be essentially contemporaneous with it. The fact that the body of zinc ore embedded in the limestone at Mine Hill has the form of a trough, while the near-by parting between the limestone and the gneiss is essentially straight, suggests that the zinc ore had been introduced and that the ore body had been bent into its present shape before the formation of the iron ore began.

The largest and by far the greater number of the magnetite deposits occur in close association with igneous gneisses and it seems necessary to conclude that the ores thus associated are of igneous or magmatic derivation. Some of the ore bodies may be essentially masses of igneous rock which acquired the characteristic tabular form during the general migration of the deep-seated magmas that gave rise to the gneisses of the region; others may represent shreds of limestone or other rock, older than the igneous gneisses, that were soaked and altered by solutions emanating from the invading magmas.

At the Ogden mines, 2 miles southeast of Ogdensburg, irregular stringers of pegmatite and minor bunches of magnetite seem to be of contemporaneous origin, and there can be no doubt that the injection of these materials into the country gneiss is responsible for the great body of low-grade ore existing at this place.

The local occurrence of pegmatite masses containing large amounts of magnetite adds weight to the general conclusion that the ore deposits of the Highlands are of magmatic origin. The pegmatites of the region are coarse-grained granites which represent the latest phase of pre-Cambrian igneous activity. In composition they are closely allied with the granitoid gneisses, and they may be regarded as having come from the same general source as these more ancient rocks. Only a few of the pegmatite masses show noteworthy amounts of magnetite, but the few examples are sufficient to prove that the deep-seated source of iron existed and that the concentration of this metal actually occurred through igneous or magmatic agencies.

The great trough of zinc ore at Mine Hill is known to be entirely surrounded by barren limestone and appears for this reason to represent only a portion of a deposit that was originally of greater downward extent. In the open workings at the south end of the deposit the rock on both sides of the west leg is thinly charged with franklinite, but along the east leg this mineral is disseminated through the rock only on the inside of the trough. The absence of lean ore along the outer side of the east leg suggests that the original deposit has been sheared apart along a displacement which followed the outer wall of the east limb of the trough. Under conditions of great pressure, permitting solid flowage instead of rupture, the attitude of the east limb and the mass of the ore in the bottom of the trough would be fully explained as the result of drag if the rocks which lie east of the ore body had been thrust upward during an important geologic movement.

Several irregular masses of pegmatite were intruded into the ore body after its foliated structure had been acquired, and most of the uncommon minerals of this locality were formed under the metamorphosing influence of this invading rock. That the silicate minerals containing essential proportions of zinc and manganese were formed by metamorphism due to the pegmatite is shown by the fact that they do not occur throughout the ore mass, but only along or near the contacts with the pegmatite. It is believed that the metal-bearing silicates were formed by an interchange of materials between the previously existing ore body and the invading pegmatite, because the minerals which characterize the walls of the dikes where they penetrate the ore are not present where the dikes pass out of the ore mass into the country limestone. Franklinite and willemite, which are the principal minerals of the unaltered portion of the ore mass, occur also among the secondary minerals of the pegmatite contacts, and in this association both minerals are ordinarily well crystallized. It seems evident that they were formed by the rearrangement of materials derived from the original ore.

No direct evidence can be cited to show how the Mine Hill ore body was formed, but it may be fairly assumed that the two similar deposits at Mine Hill and Sterling Hill originated in the same way, and the latter shows features which indicate that the materials of the ore were segregated after the formation of the inclosing rock and not contemporaneously with it. The feature of the Sterling Hill deposit which leads to this conclusion is the great mass of lean ore which lies between the limbs of the synclinal trough of ore. The layer of massive ore could have received its present shape by simple folding if it had originally existed as an intercalated bed in the limestone, if it had been formed by the previous replacement of a definite stratum, or if it had been a tabular vein deposited in a fissure, but it seems impossible to account for the great mass of lean ore which extends across the trough except on the theory that the metallic minerals in this portion of the deposit were segregated after the existing local structure had been produced. The general similarity between the lean ore and the richer material of the definite layer makes it probable that they are closely related in origin, so that it seems reasonably certain that the whole deposit was formed out of invading materials. The lean ore was probably deposited by solutions which permeated and partly replaced the limestone. The richer ore occurring in the massive layer may have been formed in the same way, but this origin can not be affirmed and it may be that the main ore layer at Sterling Hill and the mass of ore at Mine Hill were injected bodily into the limestone after the manner of igneous rocks. If the layer of ore at Sterling Hill originated in this way it would seem that the lean ore of the deposit must have been formed by solutions which accompanied the igneous injection.

The dike of pegmatite inside the ore trough at Sterling Hill does not cross the lamination of the limestone but follows the curve of the ore layer, from which it is separated by 10 to 15 feet of limestone containing a minor amount of franklinite. The concave side of the dike in contact with the mass of barren limestone that fills the southeast end of the trough shows no development of contact minerals, but along the convex side, which faces the ore layer, garnet and zinc bearing pyroxene and biotite occur in several places. This one-sided metamorphism suggests that the zinc which the contact minerals contain was contributed by the ore layer and therefore that the dike was injected after the ore body had been formed.

MINERALOGY.

By Charles Palache.

GENERAL STATEMENT.

Ninety-one well-defined mineral species are known from Franklin Furnace, Sterling Hill, and vicinity; they are named in the following summary, which is arranged in alphabetic order to facilitate reference. Fifteen of these minerals were first described from these localities, viz, franklinite, zincite, tephroite, rœpperite, sussexite, chalcophanite, hetærolite, clinohedrite, glaucochroite, hancockite, nasonite, rœblingite, leucophœnicite, hardystonite, and bementite. Thus far only the four minerals first named have been found elsewhere and these only in small amounts. It is clear that the mineral occurrences here involved are unique, with reference both to the large number of species occurring in them and to the uncommon minerals constituting their principal and secondary components.

MINERALS OCCURRING AT FRANKLIN FURNACE, STERLING HILL, AND VICINITY.

Albite.—See Feldspars.

Allanite: $(Ca,Fe)_2(Al.OH)(Al.Ce)_2(SiO_4)_3$. — Monoclinic. Tabular crystals up to 3 inches across, of dull-black color. Abundant in the coarse granite of the Trotter mine, Franklin Furnace, and in the same rock in various iron mines.

Amphiboles.—Tremolite: $CaMg_3(SiO_3)_4$. White fibers intermixed with calcite and zincite (calcozincite) in secondary veins. Common at Franklin Furnace. Also in white and gray crystals in limestone wall rock of both deposits.

Crocidolite: $NaFe(SiO_3)_2.FeSiO_3$. Bright-blue fibers intermixed with calcite and sphalerite in secondary veins at Trotter mine, Franklin Furnace.

Manganese hornblende (aluminous amphibole rich in Fe and Mn). Monoclinic. Large, complex crystals, very perfect in form, dark green to black in color, occurred in considerable abundance in the ore at the bend of the ore body near the contact with pegmatite at Sterling Hill.

Edenite (aluminous amphibole low in Fe and Mn). Monoclinic. Dark-green crystals, very complexly developed, were found in large number associated with leucaugite in limestone near the ore body at Sterling Hill, in a railroad cut near the adit to the Noble mine. A gray to green variety of edenite in simple crystals or granular is abundant in all the lime quarries near Franklin Furnace and Rudeville, near pegmatite contacts. It is often mistaken for tremolite or actinolite.

Anglesite: $PbSO_4$. Orthorhombic. Minute white crystals implanted on galena at Sterling Hill.

Anorthite.—See Feldspars.

Apatite: $[(Ca,Mn)F]Ca_4(PO_4)_3$. Hexagonal. Crystals large and small. Color white, green, dark blue. Not uncommon in ore, limestone, and coarse granite, especially near granite contacts. With jeffersonite at Sterling Hill in crystals up to 3 inches long. Abundant in the white limestone.

Aragonite: $CaCO_3$. Orthorhombic. White fibrous aggregates occur sparingly in cavities of the ore at Franklin Furnace. Also seen in minute crystals in secondary veins.

Arsenopyrite: FeAsS. — Orthorhombic. Granular masses of dark-gray color found in association with nickel compounds in Trotter mine, Franklin Furnace. Brilliant complex crystals found in the limestone of several quarries at Franklin Furnace.

Asbestos.—See Serpentine.

Augite.—See Pyroxenes.

Aurichalcite: $2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$.—Needles in rosettes or fibrous crusts. Color pale bluish green. Found as a rarity incrusting limestone in the calamine deposit at Sterling Hill.

Azurite: $(CuOH)_2Cu(CO_3)_2$. — Blue granular masses or stains. Found rarely as alteration product of chalcopyrite at both localities. One specimen from Buckwheat mine, Franklin Furnace, showed it intimately intermixed with franklinite grains.

Axinite: $(Ca,Mn,Fe)_7Al_4B_2(SiO_4)_8$.—Triclinic. Brilliant tiny crystals in cavities of massive granular material. Color yellow, pale green, pink, and brown. Intermixed with rhodonite at Trotter mine. Abundant with hancockite and other rare species at one locality in Parker shaft. Both at Franklin Furnace. Clove-brown crystals in minute amount in iron ore of the Gooseberry mine near Franklin Furnace.

Barite: $BaSO_4$. — Orthorhombic. Tiny crystals and platy aggregates. Color bluish white. Filling cavities in loose aggregates of willemite, rhodonite, and axinite crystals in specimens from Trotter and Parker mines, also rarely in Taylor mine, Franklin Furnace.

Bementite: $2MnSiO_3.H_2O$ (?).—Radiating platy aggregates in calcite; coarse platy aggregates apparently pseudomorphous after tephroite. Color pale yellow to brown. Found in Trotter mine, Franklin Furnace. Composition uncertain and now under investigation.

Biotite: See Micas.

Calamine: $H_2(Zn_2O)SiO_4$. — Orthorhombic. Aggregates of platy crystals; stalactitic; fibrous: powdery; intermixed with "tallow clay;" isolated crystals implanted on limonitic quartz. Color white, gray, rarely blue. In great abundance and an important ore at Sterling Hill as alteration product, with smithsonite of the zinc ore body. Rarely at Franklin Furnace in secondary veins as alteration product of sphalerite.

Calcite: $CaCO_3$, with varying amounts of Mn, Zn, and Mg replacing Ca.—Hexagonal. Rare in crystals; granular, coarse to fine, the grains almost invariably showing twin striations. Color white to pale pink; weathered surface dark brown to black when manganiferous. The gangue mineral of both ore deposits, principal constituent of wall rocks, and chief filling material of secondary transverse veins.

Varieties: Spartaite, manganocalcite, calcimangite—names that have been used for more highly manganiferous varieties; calcozincite, a mechanical mixture of calcite, zincite, and fibrous tremolite or serpentine, filling transverse fissures.

Caswellite.—See Micas.

Cerusite: $PbCO_3$. — Orthorhombic. White crystals and thin films incrusting galena at Sterling Hill.

Chalcophanite: $(Mn,Zn,Fe)O.2MnO_2.2H_2O$.—Synonym hydrofranklinite. Hexagonal. Tabular and rhombohedral crystals; foliated and stalactitic masses. Color brownish or bluish to iron black. Abundant in the calamine deposit of Sterling Hill associated with other decomposition products of franklinite. Not known elsewhere.

Chalcocopyrite: $CuFeS_2$. — Tetragonal. Granular masses of brass-yellow color, found rarely in granite and ore body at Franklin Furnace. In secondary veins with other sulphides at Sterling Hill.

Chloanthite: $NiAs_2$.—Isometric. Small octahedral crystals and massive. Color brilliant silver-white to gray. Found in small amount with niccolite in Trotter mine, Franklin Furnace.

Chondrodite: $Mg_3[Mg(F,OH)]_2(SiO_4)_2$. — Monoclinic. Granular masses, yellow to brown in color, are found in the limestone of the southernmost lime quarry at Franklin Furnace and very generally throughout the limestone belt. Supposed chondrodite in rude crystals in ore from Sterling Hill seen in several collections is tephroite.

Clinohedrite: $H_2(CaZnO)SiO_4$. — Monoclinic. Complex crystals; massive granular. Color white to pale amethystine. Found only in a few specimens from Parker shaft, Franklin Furnace, associated with green willemite, garnet, hancockite, and other pneumatolytic minerals. Not known elsewhere.

Copper: Cu.—Isometric. Crystals very rare, usually thin leaves or irregular lumps. Color red. Found rarely in crevices of willemite ore in masses up to a pound in weight, from the Parker shaft, Franklin Furnace.

Corundum: Al_2O_3.—Hexagonal. Crystals and irregular grains. Color gray, blue, and red. Not found within either ore body, but sparingly in the limestone wall rock very near the ore. Loose crystals of clear red color were found in the débris of the calamine deposit of Sterling Hill. Also found at numerous localities near Franklin Furnace in isolated pockets in the white limestone.

Crocidolite.—See Amphiboles.

Datolite: $Ca(B.OH)SiO_4$.—Monoclinic. Crystals rare; generally massive. Color white, glassy. Fills interspaces of willemite and clinohedrite crystals, and lines cavities of hancockite at Parker shaft, Franklin Furnace.

Desaulesite.—See Serpentine.

Descloizite: $(Pb,Zn)_2(OH)VO_4$.—Orthorhombic. Tiny yellow crystals of this rare vanadium compound were seen on a single specimen, coating decayed jeffersonite, from Sterling Hill.

Dolomite: $(Ca,Mg)CO_3$.—Hexagonal. Gray granular rock with cavities lined with rhombohedral crystals forms a band in the limestone between the veins at Buckwheat mine, Franklin Furnace. Much of the limestone wall rock and part of that within the ore deposits is more or less dolomitic.

Edenite.—See Amphiboles.

Epidote: $Ca_2(Al.OH)(Al,Fe)_2(SiO_4)_3$. — Monoclinic. Small crystals and granular masses. Color dark to light green. Sparingly present in the granite of both localities near its contact with the ore body and also in the iron mines south of Franklin Furnace.

Feldspars. — Orthoclase and microcline: $KAlSi_3O_8$. Albite: $NaAlSi_3O_8$. Oligoclase: $(Na,Ca)AlSi_3O_8$. Anorthite: $CaAl_2Si_2O_8$. Orthoclase, microcline, and oligoclase are normal constituents of the pegmatite. At the contact of the pegmatite with the limestone the microcline is in places developed in large, bright-green crystals, as at the Trotter mine, Franklin Furnace, and at Sterling Hill, where it is dull white in color. Isolated crystals of microcline are found in the limestone, demonstrating that a considerable migration of material has taken place where the two rocks came together. Albite occurs in clear glassy white crystals in the porous dolomite rock of the Buckwheat open cut, Franklin Furnace. Anorthite was found in crystals embedded in limestone at the southernmost quarry at Franklin Furnace.

Fluorite: $(Ca,Mn)F_2$.—Isometric. Granular masses. Color purple, rose colored, red. Locally abundant at Franklin Furnace as matrix of ore minerals of rare species from the Parker shaft, and of the nickel minerals in the Trotter mine. Locally abundant in the white limestone at all the quarries. Blue cubical crystals were found in cavities of the blue limestone at Franklin Furnace.

Fowlerite.—See Rhodonite.

Franklinite: $(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$. — Isometric. Octahedra, rarely dodecahedra, embedded in limestone; grains or rounded crystals, many of them showing pitted surface due to resorption by the inclosing rock; massive granular. The most abundant ore mineral in both Franklin Furnace and Sterling Hill deposits. Generally intimately intermixed with willemite and zincite to form the banded granular ore. In veins where these primary minerals and rhodonite have recrystallized the crystals are found—rather rarely and with very brilliant luster at Franklin Furnace, more abundantly and of huge size (up to 6 inches on an octahedron edge) in the early workings at Sterling Hill. First described from these localities and very rare elsewhere.

Friedelite: $H_7(MnCl)Mn_4(SiO_4)_3$.—Hexagonal. Platy rhombohedral crystals and scaly, massive. Color pale red. Known only from a single specimen from Buckwheat mine, Franklin Furnace, as a coating on surface of a crevice in massive franklinite-willemite ore.

Gahnite or zinc spinel: $(Zn,Fe,Mn)O.(Al,Fe)_2O_3$. — Isometric. Octahedra, rarely cubes and dodecahedra. Color greenish black, dark green, blue. Abundant in very large and perfect octahedra at Sterling Hill, especially on the west side of the east leg of the ore deposit, in limestone near the pegmatite contact. At Franklin Furnace fairly abundant at Trotter mine. Rare cubical habit found only on crystals from west wall of Taylor mine.

Varieties: Dysluite, local name for dark-green crystals from Sterling Hill; automolite, old local name for yellowish altered crystals from Franklin Furnace. (See also Spinel.)

Galena: PbS.—Isometric. Granular masses. Color lead-gray. Found sparingly at both localities, more especially at Sterling Hill, embedded in pegmatite and in jeffersonite near the contact. Also in secondary veins cutting the ore body at Sterling Hill.

Garnet, variety polyadelphite: $(Ca,Mn)_3(Fe,Al)_2Si_3O_{12}$.—Isometric. Large crystals showing dodecahedron and trapezohedron, color black, brown, and red; also brown and yellow massive forms. Common at all contacts of granite and ore body at Franklin Furnace. Rare at Sterling Hill. Little is known of the composition of the varieties in detail, but all tested show presence of manganese. At the Gooseberry and other iron mines was found black garnet in large brilliant dodecahedra and red and cinnamon-colored massive granular varieties. These show only slight traces of manganese.

Glaucochroite: $CaMnSiO_4$.—Orthorhombic. Imperfect crystals. Color bluish green. Occurs embedded in nasonite in rare specimens from Parker shaft, Franklin Furnace. Not known elsewhere.

Goethite: $Fe_2O_2(OH)_2$.—Orthorhombic. Minute acicular crystals of dark-brown color surrounding reniform globules of hematite in cavities of porous dolomite from Buckwheat open cut, Franklin Furnace.

Graphite: C.—Hexagonal. Iron-black scales; spheres composed of radiating plates. Found in limestone of wall rock at both localities. Abundant in the white limestone of all the quarries about Franklin Furnace and in the iron ores found in limestone.

Greenockite: CdS.—Hexagonal. Powdery incrustation on shaly limestone. Color bright yellow. Found in small amount at the Hamburg mine, Franklin Furnace. It is associated with sphalerite, from which it has probably been derived.

Hancockite: $H_2(Pb,Ca,Sr,Mn)_4(Al,Fe,Mn)_6Si_6O_{26}$. — Monoclinic. Minute crystals and massive. Color red to reddish brown. Found only in the Parker shaft, Franklin Furnace, in small amount associated with other rare zinc and lead silicates of pneumatolytic origin. Not known elsewhere.

Hardystonite: $Ca_2ZnSi_2O_7$. — Tetragonal. Massive granular and coarse columnar. Color white. Abundant in parts of the ore deposit near the Parker shaft, Franklin Furnace, in banded granular ore with franklinite, willemite, and rhodonite. Not known elsewhere.

Hematite: Fe_2O_3.—Hexagonal. Coarse granular with rhombohedral parting; massive, fine granular; fibrous and reniform. Color black to red-brown. Several large masses of black granular hematite, mistaken for franklinite, were found in the Parker shaft, Franklin Furnace. Not an uncommon alteration product of franklinite, both ocherous and as coloring matter of red jasper. Minute reniform masses were seen in the cavities of the porous dolomite rock in the open cut at the Buckwheat mine.

Hetærolite: $ZnO.Mn_2O_3.H_2O(?)$.—Radiated fibrous coatings with botryoidal surface. Color dark brown. Intimately associated with chalcophanite at the calamine deposit of Sterling Hill. Composition under investigation. Not known elsewhere.

Hornblende.—See Amphiboles.

Hydrozincite: $ZnCO_3.2Zn(OH)_2$.—Flaky incrustations. Color pearly white. Found in small quantity lining cavities in smithsonite in secondary veins near Trotter mine, Franklin Furnace. Derived from sphalerite.

Jeffersonite.—See Pyroxenes.

Lead: Pb.—Isometric. Films or irregular grains. Color gray or black. Extremely rare in crevices of willemite, caswellite, and several lead silicates from the pneumatolytic zone in Parker shaft, Franklin Furnace.

Leucophœnicite: $H_2(Mn,Zn,Ca)_7Si_3O_{14}$. — Monoclinic? Grains and minute crystals. Color purplish red. Associated with willemite, garnet, franklinite, and many other minerals in the pneumatolytic contact zone in Parker shaft, Franklin Furnace. Not known elsewhere.

Limonite: $Fe_4O_3(OH)_6$.—Massive or ocherous. Color brown and yellow. Common as a decomposition product of iron minerals, especially in association with the calamine deposit of Sterling Hill.

Löllingite: $FeAs_2$. — Orthorhombic. Crystals and granular masses of steel-gray color. Found in limestone with gahnite and also intimately admixed in small amount with franklinite ore in the Buckwheat mine, Franklin Furnace.

Magnetite: $FeO.Fe_2O_3$.—Isometric. Octahedral and dodecahedral crystals; granular massive; disseminated in limestone. Color black. Occasionally found at Franklin Furnace associated with or replacing franklinite in the main ore body; abundant in the magnetite ore bed underlying the zinc deposit on the west vein, and locally in small masses between the legs of the vein. Abundant in all the iron mines. Found in pegmatite only at Sterling Hill.

Malachite: $(CuOH)_2CO_3$. — Green fibers or stain. Found rarely as alteration product of chalcopyrite. Recorded from both localities.

Manganophyllite.—See Micas.

Manganosite: MnO.—Isometric. Granular. Color blackish green. Intimately intermingled with zincite and franklinite in a single specimen believed to have come from the Taylor mine, Franklin Furnace.

Menaccanite: $(Fe,Ti)_2O_3$. — Hexagonal. Rounded black crystals, embedded in limestone with spinel, were found in the Windsor lime quarry at Rudeville. Not surely known from the vicinity of the zinc deposits, although recorded in old lists.

Micas.—Muscovite: $H_2KAl_3(SiO_4)_3$. In grains and flakes, found rarely in the white limestone.

Biotite: $(H,K)_2(Mg,Fe)_2Al_2(SiO_4)_3$. — Abundantly developed in the contact zones in both localities, especially in the pneumatolytic zone of the Parker shaft, Franklin Furnace. Most of it that has been tested is manganesian and should be counted to the variety manganophyllite.

Manganophyllite (manganesian biotite) is indistinguishable from biotite except by chemical tests showing the presence of manganese. It is abundant at Franklin Furnace.

Phlogopite (magnesian biotite) is abundant at many granite contacts. It is especially developed in the limestones at many localities in beautifully sharp crystals of white, pale-golden, or brown color. It is not sharply distinguished from biotite.

Caswellite (altered and hydrated biotite) is dull, lusterless biotite which has undergone more or less complete alteration. It is more properly a pseudomorph than a mineral species.

Microcline.—See Feldspars.

Millerite: NiS.—Hexagonal. Hairlike yellow needles of millerite were found in minute amount in cavities of the porous dolomite rock occurring in the Buckwheat open cut, Franklin Furnace.

Molybdenite: MoS_2.—Hexagonal. Scales and platy crystals. Color bluish lead-gray. Found embedded in scapolite and limestone in the east wall rock of the open cut of the Buckwheat mine, Franklin Furnace. Sparsely in the ore of the Gooseberry iron mine and in the pegmatite at Sterling Hill. Very large crystals at Edison iron mine, Ogdensburg.

Muscovite.—See Micas.

Nasonite: $Pb_4(PbCl)_2Ca_4(Si_2O_7)_3$. — Massive, fine fibrous, or platy. Color white. Very rare, with hancockite and other lead silicates, in pneumatolytic zone in Parker shaft, Franklin Furnace.

Niccolite: NiAs.—Hexagonal. Rude hexagonal crystals and massive. Color pale copper-red. Several hundred pounds of this mineral were found at one point in the Trotter mine, Franklin Furnace, near but not in actual contact with the pegmatite. Pseudomorphs after the niccolite crystals found in the same mass consist of a green nickeliferous silicate of uncertain composition known as desaulesite. (See Serpentine.)

Oligoclase.—See Feldspars.

Orthoclase.—See Feldspars.

Phologopite.—See Micas.

Psilomelane.—Hydrous manganese oxide. Massive, amorphous. Color black. Found with other decomposition products of franklinite at the calamine deposit at Sterling Hill.

Pyrite: FeS_2.—Isometric. Cubes, pyritohedra, and octahedra; granular. Color yellow. Found in small amount with sphalerite in secondary veins cutting the ore body at Franklin Furnace. Large and very symmetrical and complex crystals found in the limestone of both the active quarries at Franklin Furnace.

Pyrochroite: $Mn(OH)_2$.—Hexagonal. Rhombohedral crystals; platy aggregates. Color black (pink or greenish when first exposed to the light). Occurs in secondary veins in franklinite ore, containing also zinc and manganese carbonates, fibrous willemite, zincite, garnet, etc., at two localities at Franklin Furnace. Manganite (?) found with the sussexite at Hamburg mine belongs in this species.

Pyroxenes.—Jeffersonite: $(Ca,Mg)(Fe,Mn,Zn)(SiO_3)_2$. Monoclinic. Well-formed dull crystals; massive granular. Color dark green to black. Very abundant wherever granite intrusions are found in the ore bodies, both in the granite and the limestone or ore. Very large crystals at Sterling Hill, more commonly massive at Franklin Furnace.

Zinc schefferite (same formula as jeffersonite). This name is applied to a coarse granular or foliated variety, white to light brown in color, having much the appearance of orthoclase, owing to the very perfect basal parting. It occurs intimately intermixed with franklinite and willemite in ore from Parker shaft, Franklin Furnace. Isolated crystals in limestone, pale brownish in color and rich in manganese, from Sterling Hill, belong near this variety.

Leucaugite: $CaMgSi_2O_6$ with $(Mg,Fe)(Al,Fe)_2SiO_6$. Large, well-formed crystals of dirty-white color associated with edenite in limestone in a railroad cut near the adit to the Noble mine, Sterling Hill, are found to be an aluminous augite low in iron and are hence called leucaugite. The large rough crystals near Double Rock on the west vein at Franklin Furnace are probably similar. The pyroxenes of these localities have not yet been thoroughly studied.

Pyrrhotite: Fe_7S_8.—Hexagonal. Irregular grains and large masses. Bronze color. Found commonly in the white limestone south of Franklin Furnace together with amphibole and fluorite, and in the scapolite dikes cutting the limestones. The larger masses of pyrrhotite appear to be deeply corroded crystals, but in no specimen was a crystal outline observed.

Quartz: SiO_2.—Hexagonal. Crystals rare; massive. Color white. Except for its occurrence as a constituent of the intrusive pegmatite, quartz is a rare mineral at both localities. Secondary veins filled with massive quartz and carbonates are occasionally found at Franklin Furnace, and rare crystals occur in cavities of the porous dolomite of the Buckwheat mine. A few loose crystals were found in the débris of the calamine deposit at Sterling Hill. Jasper colored red by hematite is not uncommon about Franklin Furnace as float material, but its source is not known.

Rhodochrosite: $MnCO_3$. Manganese replaced by varying amounts of calcium, zinc, and magnesium. Hexagonal. Drusy rhombohedral crystal aggregates; massive granular. Color pale pink to white. Common in secondary veins cutting the ore bodies of both localities. It is not reported as occurring at the calamine deposit at Sterling Hill.

Rhodonite: $MnSiO_3$. Manganese replaced by varying amounts of zinc, iron, and calcium. Triclinic. Crystals, large and small, commonly with rounded angles and pitted faces due to resorption; lamellar; coarse to fine granular. Color bright to pale pink. Occurs abundantly in all parts of the Franklin Furnace deposit where granite intrusions are found. Most commonly developed in the limestone, alone or admixed with franklinite and willemite; at many places a considerable constituent of the granite in its contact facies. Very rare at Sterling Hill.

Variety: Fowlerite; a name given to the variety rich in zinc.

Rœblingite: $H_{10}Ca_7Pb_2Si_5S_2O_{28}$.—Massive, in nodular masses; compact. Color white, porcelain-like. Very rare, with hancockite, axinite, etc., in pneumatolytic zone in Parker shaft, Franklin Furnace. Not known elsewhere.

Rœpperite: $(Fe,Mn,Zn,Mg)_2SiO_4$. — Orthorhombic. Rough or rounded crystals. Color pink, black on exterior. Found very abundantly at one place in Sterling Hill, locally taking the place of willemite and employed as an ore. Very rare at Franklin Furnace. Known only from these localities.

Rutile: TiO_2.—Tetragonal. Minute black lustrous crystals attached to corundum from the calamine deposit at Sterling Hill. Found in small amount with tourmaline in the white limestone quarries near Franklin Furnace.

Scapolite: $Ca_4Al_6Si_6O_{25}$ with $Na_4Al_3Si_9O_{24}Cl$.—Tetragonal. Columnar masses. Color greenish white. Found in irregular masses in the limestone of the east wall of the Buckwheat open cut, Franklin Furnace. Well-formed crystals were found in the Gooseberry iron mine. A constituent, with hornblende, of igneous dike rocks cutting the white limestone.

Variety: Algerite. Slender, curved prismatic crystals embedded in limestone were described by this name. They were found only in loose blocks of limestone near Franklin Furnace. Analysis shows that they are altered scapolite, perhaps related to pinite.

Serpentine: $H_4(Mg,Fe,Mn)_3Si_2O_9$.—Columnar, asbestiform, and massive. Color white to dark green. Generally forms secondary veins together with calcite and locally with zincite. This mixture has been called calcozincite and is often mistaken for sussexite. Also as an alteration product of rhodonite, both as pseudomorphs and massive: it is then rich in manganese and of brown color. To this variety the name hydrorhodonite has been applied. Also formed as an alteration product of edenite.

Variety: Desaulesite. Massive. Color bright apple-green. Nickeliferous variety of serpentine forming pseudomorphs after niccolite and also formless aggregates. It occurred in small amount at Trotter mine, Franklin Furnace. Composition uncertain.

Siderite: $FeCO_3$.—Hexagonal. Granular aggregates. Color yellowish brown. Found occasionally at Franklin Furnace, filling secondary carbonate veins.

Smithsonite: $ZnCO_3$. — Zinc replaced by varying amounts of manganese, calcium, and magnesium. Hexagonal. Fibrous; massive granular; earthy. Color white, gray, and brown. Occurs as filling of secondary veins cutting ore body at Franklin Furnace, both massive and as fibrous crystalline filling. Forms a white coating on fracture planes of zincite. Abundant in drusy crusts and earthy in the calamine deposit at Sterling Hill.

Sphalerite: ZnS. — Isometric. Octahedral crystals: granular masses. Color white, yellow, and brown. Occurs in granular masses up to several inches in diameter in granite of both localities; also embedded in jeffersonite and garnet in the contact zone. Most abundant in secondary vein cutting ore body at Franklin Furnace, in fine-granular massive form, as flattened octahedral crystals with willemite, or as rounded grains with calcite. Brilliant crystals in cavities of porous dolomite in the Buckwheat mine. Fairly abundant but does not constitute an ore.

Variety: Cleiophane, an old name for the pure-white brilliant crystals and grains found at both localities, which are almost absolutely free from iron or other chemical impurity.

Spinel: $(Mg,Fe)O.Al_2O_3$. — Isometric. Octahedra. Color gray, green, brown, and black. Found sparingly with corundum in limestone wall rock and in granite near contacts at both localities. (See Gahnite.) Black iron spinel crystals abundant with chondrodite in the limestone of the southernmost quarry at Franklin Furnace; and in many colors at many isolated localities in the white limestone throughout its extent, especially near Sparta.

Sussexite: $H(Mn,Mg,Zn)BO_3$.—Silky fibrous. Color white with tinge of pink or yellow. Filling seams in franklinite ore at Hamburg mine and very rarely in Buckwheat open cut at Franklin Furnace. Rare here and not known elsewhere. Fibrous asbestos is often mistaken for it.

Talc: $H_2Mg_3(SiO_3)_4$.—Monoclinic. Platy aggregates. Color gray to green. Found chiefly as pseudomorphs, after spinel at Franklin Furnace and after calamine at Sterling Hill.

Tephroite: Mn_2SiO_4.—Manganese replaced by more or less zinc and magnesium. Orthorhombic. Rarely in crystals; massive granular, or platy masses. Color ash-gray, yellow, and brown. Locally abundant at both localities as constituent of the granular ore associated with franklinite, zincite, and willemite; forming an ore of importance. At Sterling Hill only rare crystals of considerable size embedded in limestone and long mistaken for chondrodite. First described from these localities.

Thorite: $ThSiO_4$.—Tetragonal. Grains of brownish-yellow color, very rarely in granite of Trotter mine, Franklin Furnace.

Titanite: $CaTiSiO_5$.—Monoclinic. Crystals up to 1 inch in diameter, light to dark brown, found sparingly in granite of both localities and rarely in the limestone near the contact. Also found in the iron mines and in dark-brown lustrous crystals in the limestone quarries.

Tourmaline (magnesium tourmaline): R_9Al_3 $[B.OH]_2$ Si_4O_{19}.—Hexagonal. Prismatic crystals of light-brown color. Only one or two found, in the calamine deposit at Sterling Hill. Not otherwise known at either ore body. Abundant in large and complex crystals, brown and green in color, at the limestone quarries at Franklin Furnace and Rudeville.

Tremolite.—See Amphiboles.

Troostite.—See Willemite.

Vesuvianite.—Complex Ca and Al silicate. Tetragonal. Minute crystals and irregular patches of brown color, determined by form to be vesuvianite, occur very sparingly in the pneumatolytic zone in Parker shaft, Franklin Furnace. Brown tourmaline is often mistaken for vesuvianite and accounts for the frequent mention of this mineral on Franklin mineral lists.

Willemite: $(Zn,Mn)_2SiO_4$. — Hexagonal. Prismatic crystals; disseminated rounded grains; massive granular; fibrous. Color white, pale green, yellowish green, yellow, red, and brown. Abundant in all parts of the ore body at Franklin Furnace, making up with franklinite, zincite, and calcite the mass of the granular ore. Also frequently found in secondary veins, in part as fine fibrous aggregates, in part as well-developed crystals, white and water-clear, pale green, and topaz yellow. At Sterling Hill it is also widely disseminated in the granular ore, but is apparently not so abundant as at Franklin Furnace. It is also found here in sharp-cut isolated crystals in limestone occurring in lean bands of ore between the two legs of the ore body. In all its occurrences in limestone the crystals are apt to show effects of resorption in rounded and deeply pitted outlines. At the calamine deposit at Sterling Hill crystals were found surrounded by a coating of black manganese oxide and a halo of calamine needles, both formed at the expense of the willemite.

Varieties: Troostite, tephrowillemite — both local names for varieties of willemite rich in manganese. Neither is a distinct variety.

Zincite: (Zn,Mn) O.—Hexagonal. Crystals very rare; granular, coarse and fine; scaly; powdery. Color red. Generally in small amounts irregularly distributed through the granular franklinite-willemite ore. Found at both localities but apparently more abundant formerly at Sterling Hill. Where recrystallized in secondary veins it forms large, brilliant masses or very rarely distinct crystals. Many such large crystals, formerly found at Sterling Hill, were deeply corroded and rounded by resorption. Known as a mineral only from these localities.

Zinc schefferite.—See Pyroxenes.

Zircon: $ZrSiO_4$.—Tetragonal. Small crystals of dark-brown color occur sparingly in the granite at the Trotter mine, Franklin Furnace. Remarkably large and brilliant crystals were found near the Hill iron mine south of Franklin Furnace.

PARAGENESIS OF MINERALS OF THE ZINC DEPOSITS.

Introductory statement.—The principal mineral constituents of the ore deposits, both at Franklin Furnace and Sterling Hill, are four in number—franklinite, willemite, zincite, and calcite. Tephroite occurs locally in minor amounts. The first three are the ores of the metals zinc, manganese, and iron, for which the deposits are worked; the fourth is the sole abundant gangue.

Normally these minerals are intimately intermixed in granular form, the grains of the ore minerals are in general noticeably rounded, and the interlocking calcite grains form a paste or matrix to the whole. Generally also a marked banding is visible in the mass of the ore, due to the greater or less concentration of one or more of the ore minerals in adjacent layers, roughly parallel to the walls of the deposit.

Locally the same minerals occur in larger and much more perfect crystals embedded in coarse granular calcite in the form of irregular veinlike deposits within the main ore body. These occurrences are regarded as due to recrystallization of the normal constituents under the conditions described below.

An explanation of the probable mode of origin of this unique mineral deposit will be found elsewhere in this folio. For the purpose of the present discussion of the mineralogy the five minerals named are regarded as primary constituents of the ore. Most of the other mineral species are believed to have been produced by agencies which in various ways modified the primary deposit and, according to their various effects, formed characteristic groups of secondary minerals. The modifying agencies most clearly recognized are three in number—granite intrusions, transverse fissuring followed by vein filling, and superficial processes of oxidation and hydration. The minerals characteristic of each of these processes, so far as they can be discriminated, will be grouped together in the following paragraphs.

Pegmatite intrusions.—Intrusive bodies of granite-pegmatite are present at numerous localities in both deposits. At their contacts with the ore deposits many new minerals have been developed by the chemical rearrangement of the primary constituents and also by the introduction of new materials from the pegmatite magma. The constituent minerals of the pegmatite also become so intimately admixed with the ore minerals that they may well be included in this discussion of the mineralogy of the deposits.

(*a*) Minerals of the pegmatite: The petrographic description of the pegmatite will be found on page 6. The minerals found in it are allanite, apatite, epidote, galena, magnetite, microcline, oligoclase, orthoclase, sphalerite, thorite, titanite, and zircon. Calcite and some of the minerals produced by the metamorphism of the ores, such as rhodonite, manganese pyroxene, and spinel, are often intermixed with the true granitic minerals.

(*b*) Minerals resulting from contact metamorphism: Rhodonite, polyadelphite (zinc-manganese garnet), jeffersonite (manganese pyroxene), schefferite (zinc pyroxene), manganese hornblende, manganese mica, phlogopite, spinel, gahnite (zinc spinel) and possibly galena, sphalerite, and löllingite are believed to represent, for the most part, chemical rearrangements of the constituents of the original ore minerals through reactions induced by the intrusion of the pegmatite. They are generally characterized by their content of manganese and zinc and are found at or near the immediate contact of the granite. Rhodonite and the manganese-bearing pyroxene and garnet are the most abundant and striking products of this action and are largely developed, though rhodonite is somewhat rare at Sterling Hill. The small amounts of sulphides found sporadically in intimate association with them are doubtless derived from the granite in which they occur more abundantly.

(*c*) Minerals resulting from pneumatolytic action: Two localities are known at Franklin Furnace where the granite, in addition to its contact effect, has introduced abundantly new chemical agents, producing a zone of pneumatolytic mineral formation. In one of these zones developed in the workings of the Parker shaft, the mineralizing agents were chiefly boron, fluorine, and lead; the minerals found here, in addition to most of those mentioned under *b*, include nearly all the rare new species described from Franklin Furnace in recent years. The list is as follows: Apatite, axinite, barite, biotite, clinohedrite, copper, datolite, fluorite, glaucochroite, hancockite, lead, leucophœnicite, nasonite, rœblingite, vesuvianite, willemite in unusual crystallizations, and franklinite. Hardystonite may belong here but is of uncertain origin.

The second locality was in the Trotter mine. Here the elements fluorine, boron, arsenic, sulphur, and nickel were the active chemical materials introduced and in the midst of the contact region was formed a sharply bounded deposit characterized by the presence of arsenopyrite, axinite, barite, biotite chloanthite, fluorite, niccolite, and sphalerite.

Sussexite, a boron compound, is probably due to a similar cause active in yet another part of the ore deposit, at the Hamburg mine.

Vein filling of secondary fissures.—The primary ore bodies are traversed abundantly at both localities by veins of two types.

(*a*) Veins filled by recrystallization of the primary minerals with calcite matrix have been earlier mentioned. They furnish the majority of specimens showing well-crystallized franklinite, zincite, and willemite; rhodonite is also associated with these minerals.

(*b*) Veins filled by carbonates, sulphides, oxides, and other derived products from the primary minerals are mostly narrow, many of them being sharply banded parallel to their walls, and are clearly deposited by solutions which derived their mineral contents from the inclosing ore body. They are characterized by great diversity of mineral contents; examples are the quartz-sphalerite veins so abundant at the Trotter mine; veins of calcite, rhodochrosite, and smithsonite, locally with fibrous willemite or other uncommon habit of that mineral as seen at many places in the Taylor mine; and the vein of porous gray dolomite containing in its cavities a great variety of well-crystallized minerals, visible in the open cut of the Buckwheat mine. Veins of this character are not known at Sterling Hill. The minerals known from these veins are albite, barite, calcite, chalcopyrite, crocidolite, dolomite, friedelite, garnet, gœthite, hematite, millerite, pyrite, pyrochroite, quartz, rhodochrosite, serpentine (asbestos), siderite, smithsonite, sphalerite (particularly the colorless variety cleiophane), willemite (especially the fibrous and radiated varieties), and zincite, in rare crystals.

These veins are nowhere known to cut the granite, but are believed to have been formed after the intrusion of that rock. It is very probable, however, that the fissuring which preceded their formation and the active circulation of the solutions which deposited them were results in large measure of the granite intrusion.

Minerals due to superficial oxidation and hydration.—The most notable example of mineral formation due to the agencies of superficial oxidation and hydration is the extensive deposit of calamine which was long mined at Sterling Hill. The minerals composing it were essentially calamine, limonite, chalcophanite, hetærolite, and psilomelane—the first representing the zinc, the second the iron, and the remainder the manganese contained in the original franklinite, zincite, and willemite.

The minerals of the following list are of minor importance, found locally as coatings on or transformations of older minerals: Anglesite, cerusite, descloizite, greenockite, smithsonite, hydrozincite, auricalcite, azurite, malachite, hematite, aragonite. Pseudomorphic replacements are found in bementite (probable after tephroite); caswellite, after biotite; desaulesite, after niccolite; talc, after spinel; and manganese serpentine after rhodonite and after spinel.

MINERALS OF THE FRANKLIN LIMESTONE OUTSIDE OF THE ZINC DEPOSITS.

Outside of the limits of the zinc deposits the white limestone is exposed in numerous quarries and railroad cuts in and near Franklin Furnace and Sterling Hill, and it is characterized by the sporadic occurrence of a group of minerals most of which are foreign to or extremely rare in the zinc deposits themselves. At some localities these minerals are in close proximity to granite bodies which may have caused their formation; but in others this cause can not be proved to have been active, and the minerals must be regarded as a result of the general metamorphism and recrystallization of the limestone. They present a marked contrast to both the primary and the metamorphic minerals of the zinc deposits in the entire absence of either zinc or manganese as constituent elements. This group comprises amphibole (tremolite and edenite), anorthite, apatite, arsenopyrite, corundum, chondrodite, fluorite, graphite, leucaugite, magnetite, menaccanite, molybdenite, phlogopite, pyrite, pyrrhotite, rutile, scapolite, spinel (both iron and magnesian varieties), titanite, and tourmaline.

MINERALS OF THE IRON-ORE DEPOSITS.

The magnetite deposits found near Franklin Furnace and formerly worked as ores of iron are described in the section on economic geology. The group of minerals found in these deposits is similar in some respects to that just enumerated for the limestones; like the latter it is devoid of the zinc and manganese minerals, although both elements are present in minute amounts in the magnetite. The minerals found here, most of them except magnetite in relatively small amounts, are allanite, apatite, arsenopyrite, axinite, biotite, epidote, garnet, magnetite, molybdenite, phlogopite, pyrite, pyroxene, rutile, scapolite, iron spinel, titanite, and zircon. Some of these are directly traceable to the granite which everywhere occurs in intimate association with the iron deposits.

PALEOZOIC SEDIMENTARY ROCKS.

By H. B. Kümmel.

CAMBRIAN SYSTEM.

The rocks of the Cambrian system here considered are part of a great belt of similar strata extending without interruption from New York to Alabama. In this and adjoining regions they are for the most part made up of thick limestone with much thinner layers of shale, sandstone, and quartzite at their base. Farther south the clastic rocks increase greatly in thickness and the limestones form proportionally less of this system. Along the entire length of this belt the Cambrian rocks rest unconformably upon the eroded and truncated edges of the underlying formations; and everywhere there is evidence in the composition of the basal beds that their materials were derived almost entirely from the subjacent rocks.

HARDYSTON QUARTZITE.

The Hardyston quartzite derives its name from the village of Hardystonville, in Hardyston Township, Sussex County, near which there are good exposures. In virtue of its stratigraphic position it is probably to be correlated with the Poughquag quartzite of Dutchess County, N. Y., and the Chickies quartzite of Pennsylvania.

It varies considerably in composition and thickness. Typically it is a quartzite, at many places conglomeratic and containing pebbles of quartz, feldspar, granite, gneiss, and slate. Most of these pebbles are less than an inch in diameter, but some measure 2 to 4 inches. Locally the formation is a calcareous sandstone, more or less friable, steel-blue when fresh, but weathering to a rusty-brown, porous limonitic rock. It is usually but not invariably feldspathic. In some localities its arkose character is so marked that it is not readily distinguishable from a coarse granite. Beds of slate occur in its upper portion.

Within the area of this quadrangle its thickness ranges from a few feet to 30 feet or more, but in adjoining regions thicknesses of 200 feet are known to occur. 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.

It is the oldest fossiliferous rock in the quadrangle and forms the base of the Cambrian, resting upon the eroded surface of the earlier formations. It is present wherever the contact between the pre-Cambrian and Cambrian rocks is exposed, except where there has been faulting. It is shown on the map in long, narrow bands along the normal basal contacts of the Cambrian, at the western base of Pochuck Mountain and the Pimple Hills; along the eastern contact of the Hamburg belt of limestone and the eastern contact of the northwest fork of the Hamburg belt; and along the contact of the Kittatinny limestone with the Byram gneiss near the Sand Hills. Along the western base of the Hamburg Mountains (south of Franklin Furnace) and of the Wallkill Mountains the glacial drift is heavy and there are no outcrops, but the existence of the Hardyston is locally shown by quartzite débris, although elsewhere along this line the rock structure is such as to imply its absence through faulting. At several localities there are small isolated masses of quartzite surrounded by the Franklin limestone, but, as shown on page 4, they are not to be referred to the Hardyston.

There are good exposures in the railroad cut northwest of Hamburg, along the brook at Hardystonville, in the railroad cut north of Franklin Furnace station, and at numerous points along the outcrop between Howell Pond and Iliff Pond. In the railroad cut near Hamburg the actual contact with the underlying granite is exposed, but in the cut at Franklin Furnace the upper calcareous sandstone beds are shown with some layers of slate.

A species of *Olenellus* has been found in considerable numbers in the weathered calcareous beds of the upper portion at widely separated localities (between Hardystonville and Franklin Furnace and south of Iliff Pond within this quadrangle), and on this basis the formation is regarded as of Georgian ("Lower Cambrian") age.

KITTATINNY LIMESTONE.

Overlying the Hardyston quartzite is a thick magnesian limestone which takes its name from the Kittatinny Valley, of which it forms in part the floor. It grades downward into the quartzite, the transition layers being interbedded shales and limestones. Above, it is limited by an unconformity at the base of the Jacksonburg ("Trenton") limestone.

Three subordinate belts of this formation (near Ogdensburg, Hamburg, and Sand Hills) lie within the pre-Cambrian areas and are cut off on the west by faults; the main belt (along Wallkill River) divides into two prongs near the center of the quadrangle, owing to a fold and a longitudinal fault which repeats the limestone. The extreme north end of a fifth area enters the quadrangle near Branchville. Outcrops are numerous within all the limestone areas, so that its various phases may be readily studied. The outcrops are uniformly rough and irregular, giving a warty aspect to the surface.

It is generally blue or bluish-gray, in places drab, black, or rarely red, and has commonly been called the blue limestone, in contrast to the white (Franklin) limestone. At various horizons layers or nodules of black chert are abundant, and some beds in the basal portion are oolitic. Most of the formation occurs in massive layers, locally 3 or 4 feet thick, but thin layers of limestone alternating with shale or thin-bedded sandstone are present near the top. In some places a distinct cleavage at right angles to the bedding is developed. The formation is estimated to have a thickness of 2500 to 3000 feet. Chemically it is magnesian limestone, a series of thirty or more analyses of widely separated samples showing from 14 to 21 per cent of magnesia. Some beds near the top of the formation, however, carry less than 3 per cent of magnesia.

The fossil fauna of the Kittatinny limestone, so far as known, is not extensive and is found at but few localities, but it suffices to establish the Cambrian age of the greater part of the formation. The principal fossil locality for this formation in the quadrangle is at O'Donnell & McManniman's quarry in Newton, where the following species have been identified by Stuart Weller:

Foraminifera?	Olenellus?
Lingulella stoneata.	Ptychoparia newtonensis.
Orthis newtonensis.	Anomocare parvula.
Microdiscus?	Dikelocephalus newtonensis.

The last-named species is the most abundant member of the fauna, which shows a general similarity to some of the Saratogan ("Upper Cambrian") faunas of the upper Mississippi Valley. *Orthis newtonensis* is found also in an old quarry one-half mile west of Long Pond.

These fossils as a whole are of Saratogan type and the beds containing them are probably in the upper half of the formation, although their exact position can not be determined. No Acadian ("Middle Cambrian") fossils have been found, but as the *Olenellus* fauna of the Hardyston quartzite is considered to be of Georgian ("Lower Cambrian") age, and as no evidence of a break in sedimentation has been observed, an Acadian fauna would naturally be expected to occur somewhere in the formation. In one locality (southwest of this quadrangle) a fauna of Ordovician (Beekmantown) age has been found in beds near the top of the Kittatinny limestone. This formation, therefore, where complete, represents a period extending from the middle or upper part of the Georgian to the lower part of the Ordovician, inclusive.

ORDOVICIAN SYSTEM.

In this region there is no sharp line of demarkation between the rocks of the Cambrian and those of the Ordovician system. This relationship is not, however, abnormal, for it prevails all along the great Appalachian Valley. As already indicated, the base of the Ordovician lies somewhere below the top of the Kittatinny limestone, but its exact position can not be readily determined.

The rocks of the Ordovician system are here chiefly shale, slate, and sandstone, although some limestone occurs in the lower portion. They accordingly 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 extend from northern New York to Alabama and together with the Cambrian rocks underlie the Appalachian Valley.

JACKSONBURG LIMESTONE.

Above the Kittatinny limestone and separated from it by a break in sedimentation indicated by a calcareous basal conglomerate is a dark-blue or black fossiliferous limestone, correlated with the Lowville, Black River, and lower Trenton limestone of the New York section and hitherto classed as "Trenton." The conglomerate is made up of poorly worn fragments of the underlying magnesian limestone embedded in a relatively nonmagnesian matrix and ranging 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 limestones, some layers of which contain as much as 95 per cent of calcium carbonate. They are usually separated by about 30 feet of more shaly beds, and calcareous shales occur also at the top of the formation. This sequence, though common, is not of universal occurrence. At Jacksonburg, Warren County, N. J., the type locality, shales and thin-bedded shaly limestones 19 or 20 feet thick occur at the base of the section and are overlain by 102 feet of limestone, the top of the formation not being seen. The shaly limestones are suitable for use in Portland cement, but they are not utilized within this area.

In this quadrangle the thickness of the Jacksonburg limestone is about 135 to 150 feet, so that in outcrop it forms a narrow band between the Kittatinny limestone and Martinsburg shale wherever they are in normal sequence without faulting. The conglomeratic phase is best exposed in the small area east of Branchville; the higher layers are well shown at numerous points between Monroe and Beaver Run, southwest of Mulford station, and 2 to 3 miles north of Lafayette.

The limestone contains an abundant fauna, ninety-eight forms having been described by Weller from outcrops within and adjoining this quadrangle. The most characteristic forms are the following:

Streptelasma corniculum Hall.
Prasopora simulatrix Ulrich.
Rafinesquina alternata (Emm.).
Plectambonites sericeus (Sow.).
Strophomena incurvata (Shep.).
Dalmanella testudinaria (Dal.).
Dalmanella subæquata (Con.).
Zygospira recurvirostris (Hall).
Protowarthia cancellata (Hall).
Bucania punctifrons (Emm.).
Hormotoma salteri Ulrich.
Isotelus gigas De Kay.
Bumastus trentonensis (Emm.).
Calymene senaria Con.
Pterygometopus callicephalus (Hall).

At the type locality the lower strata for a thickness of 58 feet carry a Lowville and Black River fauna, and the higher beds have a lower Trenton fauna. The principal fossiliferous localities within this quadrangle are seven-eighths of a mile a little north of west from Beaver Run, one-fourth mile east of Beaver Run, three-fourths of a mile due east of Branchville, at the north end of Drake Pond, and one-half mile northwest of Iliff Pond.

MARTINSBURG SHALE.

There is a somewhat abrupt transition through 100 or 200 feet from the comparatively pure limestone of the Jacksonburg to the overlying beds of shale, slate, and sandstone which have heretofore been known as the "Hudson River slate" and which are now correlated with the Martinsburg shale of West Virginia and hence take that name.

The formation ranges from the finest grained mud shale and slate to fine sandstone. The former beds on the whole are black and more abundant in the lower part, whereas the sandstone beds are dark bluish gray, many of them calcareous, and occur more commonly higher in the formation. In amount the fine-grained rocks are more numerous than 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 in thickness. Owing to their greater resistance, these thicker beds form outcropping ledges, but the finer beds are more commonly broken down by the frost and covered with their own débris. Locally 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. The cleavage has generally (but not exclusively) an eastward dip at high angles to the dip of the strata. In disintegrating, the finer-grained rock breaks chiefly along these cleavage planes and also along joint planes, but much more rarely along lines of bedding. At some horizons in the lower portion of the formation the planes of cleavage are so straight and parallel and the rock so even textured that commercial slates have been obtained in considerable quantities. For the most part, however, the cleavage planes are slightly curved or not quite parallel, so that the rock splits irregularly. Inasmuch as the 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 be referred to as a slate. 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 and it may be more. It constitutes the surface formation over a large part of the Kittatinny Valley, occurring in this quadrangle east of Branchville Junction, in a long, narrow syncline faulted on the west side, lying between the two large limestone areas, and in normal succession west of the limestones in a wide belt extending to the upper slopes of Kittatinny Mountain, where it is overlain by the Shawangunk conglomerate. It occupies so large an area and is exposed at so many places that it is hardly necessary to specify particular localities where it can be studied. The slate quarries north of Lafayette and west of Long Pond, a flagstone quarry at Sussex, and a railroad cut near Washingtonville may be mentioned as affording good exposures.

Four species of graptolites — *Diplograptus foliaceus*, *Diplograptus angustifolius*, *Lasiograptus mucronatus*, and *Corynoides calycularis*—have been collected by Weller from a small quarry three-fourths of a mile east of Branchville. They are characteristic of the Normans Kill fauna of New York and their occurrence in the lower portion of the Martinsburg shale makes the beds in which they occur equivalent in age to the middle portion of the typical Trenton limestone of central New York. No data have been observed in New Jersey 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 this region, *Schizocrania filosa* and graptolites characteristic of the Utica shale of the Mohawk Valley have been found in beds close to the overlying Shawangunk conglomerate.

SILURIAN SYSTEM.

The rocks here referred to the Silurian form only the upper part of that system as elsewhere developed. The absence of the lower portion in this 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 late in Silurian time beds of coarse conglomerate were laid down, followed by sandstones, shales, and limestones. These conditions of deposition prevailed with but slight changes of elevation into Devonian time.

SHAWANGUNK CONGLOMERATE.

The Shawangunk conglomerate takes its name from Shawangunk Mountain in New York, the northerly continuation of Kittatinny Mountain of New Jersey. It is chiefly a coarse quartzite and conglomerate composed of small white-quartz pebbles embedded in a siliceous matrix. Its color is generally steel-blue, but some beds have a yellowish tinge, and reddish layers occur near the top. Layers of black shale a few inches in thickness are locally intercalated between thick beds of conglomerate and grit, but they are not readily to be observed except in freshly quarried sections. Between this formation and the Martinsburg shale there is a gap representing the upper part of the Ordovician and all of the Silurian below the Salina of the full New York section, but there is no marked divergence of dip and strike where the two formations outcrop in proximity, and the actual contact is nowhere exposed in New Jersey. The overlying beds are red sandstone and shale, and the transition from these to the Shawangunk is made through a series of alternating red sandstone and gray conglomerate, so that the upper limit of the Shawangunk is not sharply defined. Its thickness is probably from 1500 to 1600 feet. It forms the crest of Kittatinny Mountain and presents steep rocky slopes on the southeast side facing the valley; but beyond the summit there are few outcrops.

So far as known, the formation is barren of fossils in New Jersey, but at Otisville, N. Y., a eurypterid fauna has been found in the black shale intercalated with the conglomerate. In the Otisville section this fauna, which elsewhere appears only and briefly at the base of the Salina, repeats itself many times through a thickness of 650 feet. Above the Shawangunk are several thousand feet of shale as well as some limestone, all of which underlie the Decker limestone, the upper part of the latter being correlated with the Cobleskill limestone of central and western New York, which there immediately overlies the Salina. It is evident, therefore, that the Shawangunk conglomerate represents only the early part of the Salina epoch.

HIGH FALLS FORMATION.

The red sandstone and shale which immediately overlie the Shawangunk conglomerate and outcrop in the extreme northwest portion of the quadrangle have until recently been regarded as the equivalent of the Medina sandstone of New York and have been so called. From their position in reference to the Shawangunk, which is now known to belong near the base of the Salina, it is evident that they are much younger than Medina. Moreover, they lie below a limestone which is correlated with the Cobleskill of the New York section, and since the Cobleskill occurs just above the Salina group, the High Falls rocks must belong in that group, along with the Shawangunk below and some shales and limestones above which do not appear in the New York area. The name High Falls has been applied to the red shales that overlie the Shawangunk conglomerate in Ulster County, N. Y., and is adopted here in place of Medina, which is not applicable.

The lower beds consist of a hard red quartzitic sandstone intercalated with some green or gray sandstones and softer red shales which become more abundant in the upper part of the formation. There is little tendency in these beds to the slaty structure which is so striking a characteristic of the Martinsburg shale. Only a small part of the entire thickness, which is estimated to be about 2300 feet at Delaware Water Gap, appears within this quadrangle. The formation is not known to contain fossils, but its age is fixed by its stratigraphic position.

GREEN POND CONGLOMERATE.

The southeast corner of the quadrangle contains a small portion of that isolated belt of Paleozoic rocks which runs through the middle of the pre-Cambrian Highlands of New Jersey and which is developed in Bowling Green and Green Pond mountains and the adjacent valleys. The whole north end of Bowling Green Mountain lies in this quadrangle, but only a small strip, less than a mile in length, of Green Pond Mountain, is included therein.

The Green Pond conglomerate forms the crest and northern slopes of Bowling Green Mountain, where it is seen overlying the gneiss, with a covered interval of but a few feet between. It also forms the mass of Green Pond Mountain, where it is well exposed in nearly vertical cliffs west of Green Pond and whence it takes its name. It consists of coarse siliceous conglomerate interbedded with and grading upward into quartzite and sandstones. The pebbles of the conglomerate range from one-half inch to 3 inches in diameter and consist almost entirely of white quartz, but some pebbles of pink quartz, black, white, yellow, and red chert, red and purple quartzite, and a very few of red shale and pink jasper occur. Many of the white quartz pebbles have a pink tinge on their outer portion. The quartz pebbles were probably derived from the pre-Cambrian crystalline rocks; some at least of the cherts came from the Kittatinny limestone; and the Hardyston may have yielded some of the quartzites; but the sources of the pebbles of red and purple quartzite, red shale, pink jasper, white, yellow, and red chert are unknown.

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

The beds are almost uniformly quartzitic in texture, and on account of their hardness form the long, narrow, steep-sided ridges that characterize the Green Pond Mountain region. Locally, however, in regions adjoining this quadrangle, the basal portion of the conglomerate is friable and disintegrates readily, owing probably to the presence of a greater or less amount of calcareous material derived from the Kittatinny limestone upon which it locally rests. The quartzite, which is interbedded in the upper portion of the conglomerate and rests upon it, is in general of a purple-red color, but some layers present various shades of pink, yellow, brown, and gray. Some of these beds are massive and show no laminæ, but in others the thin stratification planes can be readily made out. The conglomerate beds are in many places very thick with but a slight trace of any bedding.

Southwest of this area, in the isolated hills southwest of Rockaway River, the rock is much softer and is a friable sandstone rather than a quartzite, and some of the beds are so completely distintegrated that they have been dug for sand and gravel for many years.

In Bowling Green and Green Pond mountains the conglomerate unquestionably rests directly upon the pre-Cambrian gneiss, although the actual contact is not seen. The gneiss, however, is exposed in the valley along the outlet of Green Pond, close under the conglomerate at the north end of Green Pond Mountain, and close to the conglomerate in Bowling Green Mountain. It is apparently overlain conformably by the red Longwood shale, but nowhere in New Jersey have the two been seen in actual contact.

The thickness of this formation has been measured on numerous section lines across Green Pond, Copperas, and Kanouse mountains, where the approximate position of the inclosing formations could be determined and where frequent measurements of the dip of the strata could be made. West of Green Pond the conglomerate beds dip from 45° to 78° NW., indicating a probable thickness of 1500 feet. The average of measurements elsewhere is about 1200 feet.

As organic remains are unknown in this 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. Although in this quadrangle it rests upon the gneiss, in closely adjoining regions it is found upon the eroded Kittatinny limestone and less certainly upon the Martinsburg shale. The first rock exposed above the Longwood shale of the Green Pond Mountain region is a fossiliferous limestone containing a fauna of Salina age identical with that found in the first fossiliferous limestone overlying the High Falls sandstone west of Kittatinny Mountain. But whereas the beds in the Delaware Valley referable to the Salina have a thickness of 3000 feet or more, those of the Green Pond Mountain region do not average more than 1400 to 1500 feet. It is still an open question whether the Paleozoic strata of the Green Pond region were once continuous with those of Kittatinny Mountain across the intervening valley and highlands, a distance of 15 miles, or whether the Green Pond region represents a separate basin shut off on the northwest from the larger Paleozoic sea, although communicating with it to the northeast. The fact that its sediments are now cut off on the northwest by a profound fault is indicative that they once extended much farther in that direction. More refined work far beyond the limits of this quadrangle is necessary to determine this question.

LONGWOOD SHALE.

Immediately above the Green Pond conglomerate and conformable with it is a soft red shale, in which an irregular cleavage is usually so highly developed that the bedding planes can be determined only with difficulty. The rock, however, does not have a slaty structure. This formation, which derives its name from Longwood Valley, in the Lake Hopatcong quadrangle, forms a narrow belt at the northwest foot of Green Pond Mountain and along the northern margin of Bowling Green Mountain, but owing to the covering of glacial deposits outcrops are rare except just south of Milton, where the thickness is apparently about 200 feet. The formation is not known to contain fossils, but as it rests directly upon the Green Pond conglomerate and is overlain by a limestone carrying a Salina fauna, it is probably of Salina age. Its stratigraphic position is in general the same as that of the High Falls formation, but the two may not be exactly synchronous.

DECKER LIMESTONE.

A dark-gray impure siliceous and shaly limestone overlies the Longwood shale in the Green Pond Mountain region but is nowhere seen in contact with it, and in this quadrangle its outcrops are concealed by drift. It is not more than 50 feet thick, but no single exposure shows this entire thickness. The beds exposed contain fossils which permit their correlation with the lower portion of the Decker ("Decker Ferry") limestone on Delaware River and the upper Salina beds of New York. The principal fossil localities are not within this area.

DEVONIAN SYSTEM.

Of the Devonian strata occurring in the isolated belt of Paleozoic rocks near Green Pond Mountain only the lower formations outcrop in this quadrangle. These are chiefly sandstones and shales of great thickness, grading upward into a thick-bedded massive conglomerate which is very similar in lithologic character to the Green Pond conglomerate, but which does not occur within the area here described. Lithologically these Devonian sediments stand in marked contrast to the highly fossiliferous Devonian limestones and calcareous shales which occur beyond the quadrangle, 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 merely 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 Devonian formation in this area, is a thick-bedded, fine-grained conglomerate below and a greenish sandstone above, having a thickness of about 215 feet. The basal portion is composed of white quartz pebbles from one-fourth to one-half inch in diameter, usually set somewhat loosely in a siliceous matrix, so that the rock is of open texture and friable. Locally, however, the interstices are filled with a siliceous cement and the rock is decidedly quartzitic. These coarser beds grade upward into a hard, greenish, thin-bedded sandstone, which in turn passes into a black argillaceous shale (Pequanac shale) carrying a Hamilton fauna. The sandstone forms a narrow belt parallel to the outcrops of the Longwood shale but separated from it by the Decker limestone, and is the "New Foundland grit" of the New Jersey Geological Survey reports. Good exposures occur just northeast and east of Petersburg, at New Foundland, just east of the quadrangle; and in the valley west of Kanouse Mountain, farther northeast. Its name is taken from the exposures at the last-named locality. Although fossils are not rare, yet as a rule they are obscure and many of them are greatly distorted, so that identification is impossible. At the two localities (beyond the limits of the quadrangle) where recognizable forms have been found in this formation, an Onondaga fauna has been recognized, and these beds may be interpreted as the shoreward correlatives of the Onondaga limestone.

In the upper Delaware Valley, northwest of the Franklin Furnace quadrangle, a number of formations occur between the Decker limestone and the Onondaga limestone, but in the Green Pond region no intervening beds have been recognized. However, as the outcrops of the Decker limestone and the Kanouse sandstone are everywhere separated by a narrow space, it is possible for these missing formations to be represented in greatly attenuated forms.

PEQUANAC SHALE.

The rocks forming the Pequanac shale are black to dark-gray, somewhat slaty, thick-bedded shales which become more sandy in their upper portion. They are nearly everywhere strongly cleaved, so that the bedding planes are not always readily discernible where the rock is of uniform texture. They overlie the Kanouse sandstone with apparent conformity but the contact has nowhere been observed. They are the youngest sedimentary rocks within the quadrangle, and underlie the large drift-covered area north of Petersburg. The thickness is unknown but is estimated as high as 1000 feet. Fossils found elsewhere determine the Hamilton age of these rocks. The formation takes its name from its extensive development along upper Pequanac River and is the "Monroe shale" of the reports of the New Jersey Geological Survey.

POST-ORDOVICIAN IGNEOUS ROCKS.

By J. E. Wolff.

NEPHELITE SYENITE.

Distribution.—The largest mass of igneous rock occurring in the sedimentary area of this quadrangle is that formed by the nephelite syenite of Beemerville and its associated dike rocks. This mass lies about 2 miles northwest of the village of Beemerville, just under the crest of Kittatinny Mountain, on the northeast slope. The rocks form a wooded ridge rising steeply from a bench produced on the general slope by the gently dipping Martinsburg shale, and separated from the outcrops of the Shawangunk conglomerate which form the crest of the mountain by a shallow depression. The mass of rock is 2 miles long and about a quarter of a mile across at the widest place, narrowing slightly at both ends. It trends northeast, parallel to the strike of the associated sedimentary rocks and to the cleavage of the Martinsburg shale.

Geologic relations.—This mass of rock occurs along the contact between the Shawangunk conglomerate and the Martinsburg shale, which have a northwest dip of 20° to 30°. The upper level of the ridge produced by the igneous rock is slightly below the plane of the base of the conglomerate, if the latter were projected outward from its present outcrop; but at both north and south ends the ridge of syenite dies out at the base of conglomerate cliffs, which cut off its further extension and join the Martinsburg shale. On the lower side of the ridge of igneous rock the shale is in places almost in contact with it and is penetrated by branches from the main mass. Satisfactory contacts with the overlying rock, especially such as would show whether the igneous rock passes into the mountain under the conglomerate have not been seen.

The syenite has been described as a huge dike emerging at the present contact between the two sedimentary formations; it might, however, be equally well an intrusive sill or a bulging laccolithic mass along the contact. The last supposition would accord best with the bulging form of the outcrop in the middle and the thinning at the ends where the two inclosing formations come together. On the other hand, the two smaller bodies of this rock (described under the heading "Nephelite dike rocks") are, like the large mass, parallel to the cleavage of the slate, and as they are intrusions, by analogy the same form might be supposed for the large body. Perhaps the rock cuts the lower part of the slate as a dike but spreads out laterally along the bedding near the conglomerate contact. If the rock forms a sill or laccolith the thickness between the walls is about 600 feet at a maximum, if a vertical dike it is about 900 feet wide.

Lithologic character.—The rock forming the body of the igneous mass varies within wide limits both in the proportion of the constituent minerals and in the coarseness of grain. The color of the syenite ranges from light to very dark gray, and in some weathered varieties the rock is slightly reddish. It is generally without any definite structure, except that many of the large crystals of orthoclase are arranged in parallel planes. The constituent minerals are orthoclase, nephelite (elæolite), augite (including ægirite), and biotite as principals, and titanite, melanite (a black garnet), apatite, zircon, sodalite, magnetite, and pyrite as accessories. The variation in the relative amounts by weight of the minerals will be seen by the two analyses given below. The rock of No. 1 was obtained toward the north end of the large mass; that of No. 2 toward the south end.

Mineral composition of nephelite syenite.

	1.	2.
Nephelite	74.2	9.8
Orthoclase	9.5	72.3
Ægirite-augite	8.7	15.4
Titanite	5.3	2.0
Biotite	1.8	.2
Apatite	.5	.2
	100.0	100.0

Under the microscope the biotite is seen in hexagonal plates, and the augite, titanite, apatite, and other accessories are grouped together in bunches of crystals that are inclosed in the large crystals of orthoclase. Many of these are more than an inch in length. They have irregular boundaries and form numerous Carlsbad twins. Where the feldspar predominates over the nephelite it incloses the latter in hexagonal crystals, but where the nephelite predominates the two form a coarse granular aggregate. The centers of some of the larger augite crystals are reddish, the outer zones green (ægirite-augite), and the periphery deep green (ægirite). Secondary cancrinite, calcite, and fluorite are common.

Contact metamorphism.—The Martinsburg shale has been hardened and mineralogically altered for a considerable distance southeastward from the line of the syenite and north and south of its termination. The principal change observed microscopically is the development of biotite and magnetite in the cement. At some places near the contact the shale is penetrated by small dikes of the syenite and contains between the clastic grains of quartz and feldspar clumps of biotite, ægirite, and titanite derived from the eruptive rock. In places the clastic material has disappeared and a fine-grained banded rock is found, composed of polygonal grains of orthoclase and ægirite, with some apatite and titanite—a sort of orthoclase-ægirite schist.

NEPHELITE DIKE ROCKS.

The nephelite syenite proper is cut by dikes, some of which are exposed in place, but there are also abundant loose blocks found on the surface of the ridge unconnected with actual outcrops. Most of these blocks are probably derived from dikes, but others may be due to local variations in the main syenite mass.

Another group of dikes occurs in the Martinsburg shale within a radius of 3½ miles from the main syenite area. They strike parallel to that area and nearly all of them were intruded parallel to the slaty cleavage.

Leucite tinguaite.—The most of this rock is found in dikes associated directly with the main syenite mass. A few dikes are found, however, as far as 3 miles from the syenite. The material of the dikes and loose blocks is usually of a dark greasy-green color and a general dense texture. It contains some phenocrysts of nephelite, orthoclase, or rounded 24-sided crystals that were originally leucite but are now mixtures of orthoclase and nephelite. Under the microscope the groundmass, which contains the larger crystals just mentioned, shows smaller crystals of augite, biotite, and apatite, and a network of acicular green crystals of augite or ægirite, lying in a colorless background composed of irregular areas of orthoclase, nephelite, and in places some analcite. The analysis of the leucite tinguaite is given beyond; the mineral proportions are about as follows:

Mineral composition of leucite tinguaite.

Pyroxene	22
Nephelite	36
Orthoclase	38
Titanite, apatite, etc	4
	100

These dikes correspond to rocks often called nephelite or leucite tinguaite, nephelite porphyry, etc. Some varieties are exceedingly rich in biotite, magnetite, apatite, titanite, and augite, the feldspar and nephelite becoming subordinate, and correspond to the facies of the elæolite syenite of Brazil called "jacupirangite."

Nephelite syenite.—There are two large dikes of porphyritic nephelite syenite in this quadrangle—

one 2 miles east of Plumbsock and the other a mile west of Wykertown. The first is about 150 feet wide and 500 feet long, the second 120 feet wide and 700 feet long. The dike near Plumbsock contains phenocrysts of orthoclase, nephelite, and augite in a groundmass of irregular areas of orthoclase inclosing prisms of nephelite, acicular crystals of ægirite, and large crystals of titanite. The Wykertown dike is finer grained and under the microscope shows phenocrysts of biotite which have been corroded around the edges and replaced by ægirite, crystals of augite which are red in the center and green at the periphery, and crystals of apatite and melanite in a background of orthoclase and nephelite. The mineral composition of this rock is as follows:

Mineral composition of nephelite syenite dikes.

Orthoclase	31.1
Nephelite	24.0
Ægirite-augite	29.2
Biotite	6.2
Melanite	6.4
Apatite	1.7
Titanite	.9
Magnetite	.5
	100.0

Bostonite.—A number of dikes occur together south of Plumbsock as long bands parallel to the cleavage of the slate. Some of them are at least 1500 feet long and from 20 to 100 feet wide. They are fine-grained gray rocks, in their least decomposed state, and contain phenocrysts of feldspar and locally of nephelite in a groundmass with flow structure composed principally of slender lath-shaped crystals of feldspar. The feldspar is probably in large part anorthoclase, but there is some orthoclase and albite, and there may have been originally a little biotite and augite; the rocks are too decomposed for the certain identification of all the minerals. They are composed mainly of alkali feldspar and correspond to the acidic dike rocks called bostonite.

Breccia.—Eruptive breccia composed of fragments of various sedimentary rocks cemented by dike material occurs in several places within the dike region. The largest mass occupies a round hill about half a mile east of the north end of the syenite ridge. The hill is about 200 feet above the bench at the base and about 1500 feet in diameter. The Martinsburg shale outcrops on the north and west sides, but the south slope and center of the hill show outcrops of a breccia in which fragments of various foreign rocks are intimately mixed with a dark-green eruptive rock containing large plates of biotite. The foreign rocks range from bowlders down to fine sand and include gneiss, granite, limestone, Martinsburg shale, and a porphyritic eruptive rock with phenocrysts of orthoclase. The presence of this great mass of fragments of the underlying rocks, some of which (the gneisses) must have been carried up nearly a mile vertically, suggests explosive action in a narrow volcanic neck.

The eruptive material that cements these fragments is generally decomposed to a granular mass of calcite with only scattered remnants of the original minerals, but in one occurrence within the main syenite mass it is fairly fresh and is composed, as shown in thin section, of large rounded crystals of biotite, reddish and green ægirite-augite, and rounded aggregates of apatite, titanite, and magnetite, contained in a groundmass of granular green augite and small plates of biotite, some grains of orthoclase and acid oligoclase with much secondary calcite. This material corresponds to basic dike rocks of the camptonite family which have been called ouachitite.

Camptonite.—Dikes occur in a third group outside of the main dike zone and differ from the others both in composition and in occurrence. With reference to the main syenite mass they are radial and not parallel to its trend. Two such dikes (probably disconnected parts of the same dike) occur in the Kittatinny limestone west of Hamburg and several in the Franklin limestone farther east. The great dike at the Buckwheat mine is the best known of these, it is 20 feet wide and can be traced for a long distance. Eighteen small parallel dikes were found near it in the limestone. There are also several at the Rudeville limestone quarries.

These dikes belong to the camptonite family and are of the same general character, being dark greenish-black rocks in which plates of biotite are conspicuous and which vary somewhat in coarseness of grain. Under the microscope the rocks are seen to be holocrystalline, with large hexagonal plates of deep-red biotite, which contain numerous inclusions of apatite and magnetite; prisms of pale-red augite, some of which are green toward the periphery and are bordered by ægirite; and large prismatic crystals of titanite. These colored minerals are contained in a background composed of irregular areas of albite and orthoclase, partly mixed with analcite. The same minerals in places form round radial aggregates or spheroids some of which probably represent the secondary replacement of original leucite.

The mineral composition by weight of the dike rock at Franklin Furnace is as follows:

Mineral composition of camptonite dike, Franklin Furnace.

Albite	23.5
Orthoclase	12.5
Augite	40.0
Titanite	5.5
Apatite	1.0
Biotite	8.0
Magnetite	9.5
	100.0

This appears to contain more feldspar than the analysis in the table (No. 6) would allow.

GENERAL RELATIONSHIPS OF THE ERUPTIVE ROCKS.

The following chemical analyses represent some of the principal types of the igneous rocks:

Chemical analyses of igneous rocks in Franklin Furnace quadrangle.

	1.	2.	3.	4.	5.	6.	7.
SiO_2	53.56	50.36	50.00	45.18	41.37	40.71	40.47
Al_2O_3	24.43	19.34	20.03	23.31	16.25	19.46	11.86
Fe_2O_3	2.19	6.94	.98	6.11	16.93	7.46	17.44
FeO	1.22	------	3.98			6.83	------
MgO	.31	------	.69	1.45	4.57	6.21	3.1
CaO	1.24	3.43	3.41	4.62	12.35	11.83	16.8
Na_2O	6.48	7.64	8.28	11.17	4.18	1.80	1.9
H_2O	9.50	7.17	8.44	5.94	3.98	3.26	4.21
H_2O at 110°	.93	[a]3.51	.10	[a]1.14	.45	1.53	[a]3.6
H_2O + 110°			1.50				
TiO_2	------	------	.99	------	------	------	------
P_2O_5	------	------	.21	------	------	------	------
MnO	.10	.41	.50	------	------	.18	------
BaO	------	------	Abs.	------	------	------	------
FeS_2	------	------	.54	------	------	------	------
Cl	------	------	Trace	------	------	------	------
CO_2	------	------	.22	------	------	.74	------
	99.96	98.80	99.87	98 92	100.08	100.01	99.38

[a] Loss.

1. Nephelite syenite, Beemerville mass.
2. The same, northern part.
3. Leucite tinguaite dike, south end.
4. Nephelite tinguaite (elæolite porphyry), central part of main mass.
5. Basic dike (ouachitite), southern part.
6. Camptonite dike, Franklin Furnace.
7. Basic dike (ouachitite), round hill east of syenite ridge.

It will be noticed that the tinguaite dike of No. 3 does not differ much chemically from the more basic syenite of No. 2, but the other dikes show 10 per cent less silica and about half the content in alkalies, with a great increase in the lime, magnesia, and iron. If a fresh example of the purely feldspathic acidic dikes (bostonite) were available for analysis it would probably show over 60 per cent of silica and the remainder principally in alumina and the alkalies. The geologic association of the syenite with these various dike rocks suggests a common origin from one underground reservoir of melted rock (magma), of which the larger mass of syenite represents perhaps the average composition, and the acidic and basic dikes the complementary chemical extremes of a differentiation which progressed with the lapse of geologic time. This genetic connection is confirmed by certain chemical and mineralogical peculiarities common to the series. The existing analyses are too incomplete for a detailed discussion, but the general fact is evident that all the rocks are abnormally rich in the alkalies. The similarity in chemical constitution of the magmas from which the individual rocks crystallized is best shown by some peculiarities in the composition of the minerals which are common to all. For instance, the large crystals of augite which are red in the center (titanium augite?), green toward the periphery (ægirite-augite), and deep green at the border (ægirite) are common to the main and subordinate syenite masses, to the ouachitite dikes, and to the distant camptonites, and show that the chemical peculiarities of the magma by which this change took place in the growing crystals was common to all forms of occurrence. The large crystals of titanite, the biotite, and the leucite are more or less common to all types—in short, these eruptive rocks form a so-called petrographic province.

Geologic age.—Although none of the eruptive rocks penetrate the Shawangunk conglomerate or any younger formations in the quadrangle, the relations of the syenite to the Shawangunk indicate a later period of eruption. Many of the dikes are parallel to the slaty cleavage or to joints in the sedimentary rocks so that they must be younger than the period at which those structures were formed—that is, post-Devonian and probably much later.

QUATERNARY SYSTEM.

By R. D. Salisbury.

INTRODUCTION.

To the Quaternary period of geologic time is referred most of the unconsolidated material lying on the bed rock described in the preceding pages. This material is commonly known as drift. It is partly of glacial and partly of fluvioglacial origin, and is made up of clay, sand, gravel, and bowlders, locally separated from one another, but more generally commingled in varying proportions and without apparent order or arrangement. It is in places so thick as to effectually conceal the bed rock beneath, and in other places so thin and discontinuous that the underlying rock outcrops at short intervals. Within the area of this quadrangle the latter condition is the more common.

The drift of this region is but a small part of a great sheet of drift covering about half of North America. It owes its name to the obsolete idea that its materials were drifted by water from their original sources to their present position. It is now known, however, that the drift is primarily a deposit made by an extensive sheet of ice, a glacier of continental dimensions, which once occupied the drift-covered area.

GENERAL DESCRIPTION OF GLACIAL PHENOMENA.

DRIFT-COVERED AREA.

The accompanying map (fig. 3) shows approximately the area of North America formerly covered by ice, and now covered by drift. It also shows that northern New Jersey lies near the southern margin of the great drift sheet.

Fig. 3.—Map of North America, showing the area covered by the ice sheet of the Pleistocene glacial epoch at its maximum extension, the three main centers of ice accumulation, and the driftless area within the border of the glaciated region.

The condition of the northern part of the continent when the ice sheet was at its maximum was comparable to that of Greenland today. The larger part of the 500,000 square miles which this island is estimated to contain is covered by a vast sheet of snow and ice, hundreds and probably thousands of feet in thickness. In this field there is constant movement, the ice creeping slowly out toward the borders of the island, tending always to advance until its edge reaches a position where it is wasted by melting and evaporating as rapidly as it advances. The total area of the North American ice sheet at the time of its maximum development has been estimated at about 4,000,000 square miles, or about ten times the estimated area of the present ice field of Greenland.

GROWTH OF THE ICE SHEET.

The ice sheet which covered this great area was of slow growth. Its beginnings are believed to have been snow fields on the east and west sides of Hudson Bay. With increasing rigor of climate, the cause of which is not certainly known, these snow fields became larger, just as mountain snow fields become larger during periods of low temperature or of heavy precipitation of snow. As they increased in size, all the snow except that at the surface was converted into ice, so that the great fields, like all great perennial snow fields of the present time, were really great ice fields, but thinly covered with snow. As soon as the ice attained sufficient thickness to deform or flow under its own weight, movement was begun. This movement was glacial movement and the ice in motion was glacier ice.

From the separate centers the ice and snow fields extended themselves in all directions, partly as the result of movement and partly as the result of the marginal accumulation of snow. The ice sheets spreading from these centers ultimately became confluent, and invaded the territory of the United States as a single sheet which, at the time of its greatest development, had the area shown in fig. 3.

The map also shows that the edge of the drift-covered area is somewhat lobate. The lobation is, indeed, more pronounced than this small map shows.

RECURRENT GLACIATIONS.

In the preceding paragraphs the ice sheet has been referred to as if it developed once, and then melted from the face of the land. But a great mass of evidence is now in hand showing that the history of glaciation was not so simple. One ice sheet developed and then melted partly or wholly, only to be succeeded by another, which in turn was partly or wholly dissipated before a renewal of glacial conditions caused a third advance of the ice. Within the United States the number of pronounced advances of the ice was not less than five, though the ice did not reach the same limit in successive advances, and probably did not retreat to the same position during the epochs of deglaciation. There is reason to believe that the region with which we are here concerned was covered by ice at least twice, though nearly all of the accessible drift was deposited by the last ice sheet and the waters associated with it.

WORK OF AN ICE SHEET.

The work effected by an ice sheet is twofold. In the first place, it erodes the surface over which it advances, widening and deepening valleys which are parallel to its direction of movement, cutting off hilltops, and smoothing down roughnesses of all sorts. In the second place, it sooner or later deposits the débris which it gathers in its movement and carries forward in its basal parts. Glaciation therefore tends, first to cut the surface down by erosion, and then to build it up by deposition; but the two processes rarely affect the same spot in an equal degree. The result is that the configuration of much of the surface is considerably altered by the passage of glacier ice over it. If the drift is thick it may level up an uneven surface of rock, or it may be so disposed as to increase the relief instead of diminishing it. If the drift is thin its effect on the topography is less pronounced. Where the relief of the rock surface beneath the drift is great, the drift has relatively little influence on the topography.

The deposits occasioned by glaciers fall into two distinct classes, those made by the ice itself and those made by the waters derived from the ice. The ice deposits are unstratified and unassorted; the water deposits are stratified and assorted. The unstratified drift constitutes moraines.

CHARACTERISTICS OF GLACIAL DRIFT IN GENERAL.

From the method by which it was gathered, it is evident that the drift of any locality may contain fragments of rock of every variety occurring along the route followed by the ice which reached that locality. The variety of materials in the drift may therefore be great.

Another characteristic of the drift is its physical heterogeneity. As first gathered by the ice, some of the materials of the drift were fine and some coarse. The ice tended everywhere to grind and crush the débris it carried, reducing it constantly to a finer and finer state. Much of the softer material, such as shale, was crushed or ground to powder, forming what is popularly known as clay; other sorts of rock, such as soft sandstone, were reduced to sand; and masses of more resistant rock escaped comminution and remained as bowlders. From clay and sand on the one hand to bowlders on the other, all grades of coarseness are represented in the glacial drift.

Still another characteristic of glacial drift, and one which clearly distinguishes it from all other formations, pertains to the shapes and markings of the stones it contains. Many of them have planed and striated faces.

TYPES OF DRIFT.

Ground moraine.—The ground moraine constitutes the great body of the glacial drift. *Bowlder clay*, a term descriptive of its constitution in some places, and *till* are other terms commonly applied to the ground moraine. It consists of all the unstratified drift which lodged beneath the ice during its advance, all that was deposited back from its edge while its margin was farthest south, and most of that deposited while the ice was retreating. From this statement it is seen that the ground moraine of an ice sheet should be essentially as widespread as the ice itself. Locally, however, it failed of deposition, and many areas of bare rock, mostly small, occur within the great tract which the ice covered. As it constitutes the larger part of the drift, the characteristics already enumerated as belonging to drift in general are the characteristics of the till. The character of the till in any locality depends on the sorts of rock over which the ice passed in reaching that locality. Where it passed over much sandstone the till is likely to be sandy, and where it passed over much shale the till is apt to be clayey. If the formations passed over were resistant and so situated that the ice could erode them effectively, the resulting till is likely to be rich in bowlders; if the formations passed over were soft, bowlders are few.

In general the till of any locality is made up predominantly of materials derived from formations close at hand. Within the area of this quadrangle, for example, probably less than 10 per cent of the material came from areas north of the New Jersey boundary. This leads to the conclusion that deposition must have gone on beneath the ice during its movement, even back from its margin.

Terminal moraine.—The marginal portion of the ice sheet was more heavily loaded in proportion to its thickness than any other. Here the thinned and thinning ice was constantly losing its transporting power, and at its edge this power was gone. As the ice was continually bringing débris to its edge and leaving it, the average rate of drift accumulation must have been greater beneath and at the edge of the ice than elsewhere.

Whenever, at any stage of its history, the edge of the ice remained essentially constant in position for a long period of time, the corresponding submarginal accumulation of drift was great, and when the ice melted, the former site of the stationary edge was marked by a belt of drift thicker than that adjacent. Such thickened belts of drift are terminal moraines. It will be seen that a terminal moraine does not necessarily mark the terminus of the ice at the time of its greatest advance, but rather its terminus at a time when its edge was stationary, or nearly so, for a considerable period.

In composition, terminal moraines are very similar to the adjacent ground moraines, though large bowlders and stratified drift are rather more abundant in the former than in the latter. The

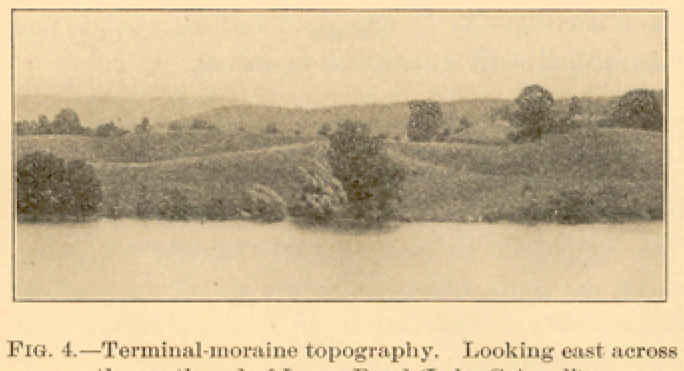


FIG. 4.—Terminal-moraine topography. Looking east across the north end of Lanes Pond (Lake Grinnell).

most distinct feature of a terminal moraine is its topography. This, more than any other one feature, distinguishes it from the ground moraine. Although the topography varies from point to point, its most distinctive phase is marked by hillocks and hollows, or interrupted ridges and troughs, following one another in rapid succession, as illustrated in fig. 4. The relief is in places scores of feet within short distances. The depressions inclosed by the elevations are the sites of marshes, ponds, and lakelets, wherever the material constituting their bottoms is sufficiently impervious to retain the water falling and draining into them.

The manner in which the topography of terminal moraines was developed is worthy of note. In the first place, the various parts of the ice margin carried unequal amounts of débris. This alone would have caused the moraine of any region to be of unequal height and width at different points. In the second place, the margin of the ice, though maintaining the same general position during the making of a moraine, was yet subject to many minor oscillations. Some of these oscillations were seasonal and some covered longer periods of time. If the ice retreated and advanced repeatedly during a considerable period of time, always within narrow limits, and if during this oscillation the details of its margin were frequently changing, the result would be a complex or "tangle" of minor morainic ridges of various heights and widths. Between and among them there would be depressions of various sizes and shapes. Thus, it is conceived, many of the peculiar hillocks and hollows which characterize terminal moraines may have arisen. Some of the depressions probably resulted from the melting of ice blocks left behind when the ice retreated.

Stratified drift.—A large part of the drift is stratified, showing that it was deposited by water. This is not strange when it is remembered that the total amount of water which operated on the drift was scarcely less than the total amount of ice, for the larger part of the ice was ultimately converted into water, and to this was added the rain which fell on the marginal part of the ice.

Stratified drift may be formed in various ways. It may be deposited by water alone, or by water in cooperation with the ice. The water may be running or standing. When the ice cooperated with the water, it was generally a passive partner.

The most extensive deposits made by water arising from glacier ice are laid down either as the water issues from beneath the ice, or as it flows away. At the immediate edge of the ice sheet, therefore, certain deposits were made. The margin of the ice was probably irregular, as the ends of glaciers now are, and as the waters issued from beneath it they left some of their débris against its irregular front and in its reentrants and marginal crevasses. When the ice melted, these marginal accumulations of gravel and sand assumed the form of hillocks. Such hillocks of gravel and sand are *kames*. The streams emanating from the ice carried some gravel, sand, and silt beyond the edge of the ice, and deposited them in the valleys through which the drainage passed, just as other overloaded streams deposit such material under like conditions. Such deposits are *valley trains*. Where the water was not confined in valleys, but spread more or less widely over a plain surface, it developed plains of gravel and sand, often called *outwash plains*. If the water issuing from the ice flowed into lakes or the sea, as sometimes happened, *deltas* were developed from the material it carried. Most of these types of stratified drift are illustrated in this quadrangle.

All the deposits made by water issuing from the ice at the time of its maximum advance were likely to remain after the ice melted. Likewise all similar deposits made while the ice was retreating were likely to be preserved. On the other hand, all deposits made by water at the edge of the ice or beyond it during its advance were likely to be overridden and buried or destroyed by the farther advance of the ice. Thus a part only of the stratified drift actually deposited is finally preserved. When it is remembered that there were several ice epochs, and that in each the edge of the ice was subject to considerable oscillations, it is evident that the relation between the stratified and the unstratified drift may be very complicated.

GLACIAL PHENOMENA OF THE FRANKLIN FURNACE QUADRANGLE.

The drift of this quadrangle was deposited chiefly or wholly by the ice of the last glacial invasion which affected it. Much of the older drift had been removed by erosion before the advent of the last ice sheet, and what remained was buried by or worked over into the mantle of drift which that sheet left.

DIRECTION OF ICE MOVEMENT.

The direction of the ice movement is known both by the trend of the striæ on the bed rock, and by the distribution of the various materials of the drift relative to their sources. From the data afforded by these two classes of evidence it is known that the movement of the ice corresponded in general direction with the trend of the Kittatinny Valley, though the correspondence was not perfect. Throughout most of the valley the movement of the ice was less toward the west than the trend of the valley; moreover, the ice tended to diverge on either side from the main direction of movement in the axis of the valley, advancing more to the east (or less to the west) in the eastern part, and more to the west in the western part. As a result of this divergence of movement the edge of the ice here as elsewhere tended to become lobate. The general direction of movement is shown in fig. 5. The

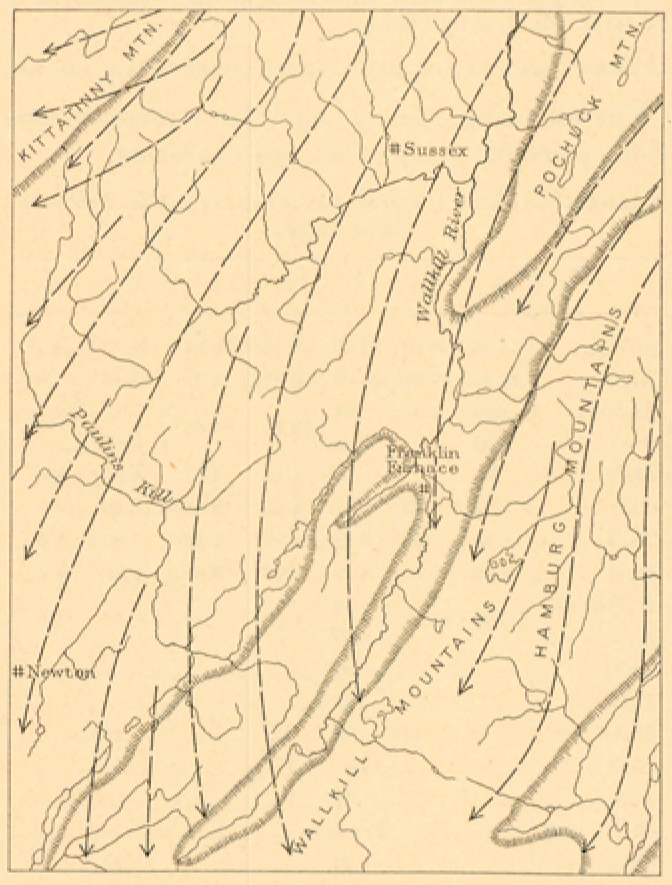


FIG. 5.—Sketch map of Franklin Furnace quadrangle, showing general direction of ice movement.

axis of the partly differentiated lobe lay in the Kittatinny Valley, and was doubtless determined by it. The easterly divergence from the axis was so pronounced that this portion of the ice mass advanced up the slope of the Highlands obliquely. The westerly divergence was less pronounced, probably because of the abrupt mountain wall which faced the valley on the northwest. Kittatinny Mountain restrained the ice which crowded against its base, but near the top of the mountain the ice escaped the restraint of the mountain front and made an abrupt turn to the west. The record of striæ shows that the average direction of movement was S. 35° to 40° W., but that, owing to the axial divergence referred to, it ranged from west, or even 2° or 3° north of west at the summit of the mountain, near the northwest corner of the quadrangle, to S. 18° W. in the eastern part of the valley. Local topography caused many local variations from the normal directions. West of the Kittatinny Mountain crest the direction of movement was more westerly than in the valley and less westerly than on the crest. In the Highlands the general direction of movement was about the same as the average trend in the valley, namely, S. 35° to 40° W., but owing to the great relief of the region, there are many departures from this direction.

The distribution of drift material gives less specific but not less important general information with reference to the course of ice movement. Numerous bowlders of Shawangunk sandstone and conglomerate are scattered over the Kittatinny Valley, being especially abundant near its northwestern border. These bowlders seem to be out of harmony with the general direction of movement of the ice, which tended rather to shift material westward from the mountain crest. Their explanation is to be found in the following considerations: (1) Many of the bowlders were probably in the valley before the ice came, having descended from the mountain crest to its eastern base as the result of gravity, weathering, stream work, etc. The ice then shifted them southwestward along the base of the mountain. (2) Farther north the ice moved in a direction less nearly parallel with the trend of the mountain and, crossing the ridge from the northwest to the southeast side, brought the bowlders to the valley. Many of the Shawangunk bowlders doubtless came from the continuation of Kittatinny Mountain in New York. (3) It is possible that the bowlders may have been left in the valley before the incursion of the last ice sheet by the ice of some earlier glacial epoch, which followed a different course.

A mile and a quarter northwest of Beemerville small outcrops of nephelite syenite occur at short intervals for $1\frac{3}{4}$ miles along the eastern face of the mountain, between the Shawangunk ledge above and the slate and shale below. Fragments from these outcrops are readily recognizable in the drift. As this rock occurs in no other part of the State, and as its outcrops are of small extent, the distribution of its fragments in the till shows the direction of ice movement. The syenite has been found in the drift more than 20 miles south and southwest of the outcrop. The area within which it has been seen is approximately bounded by a line drawn south by southwest from the outcrop to a point $1\frac{1}{4}$ miles east of Washingtonville, thence southwestward to a point a little east of Hewitt Pond, thence westward to the foot of the mountain,

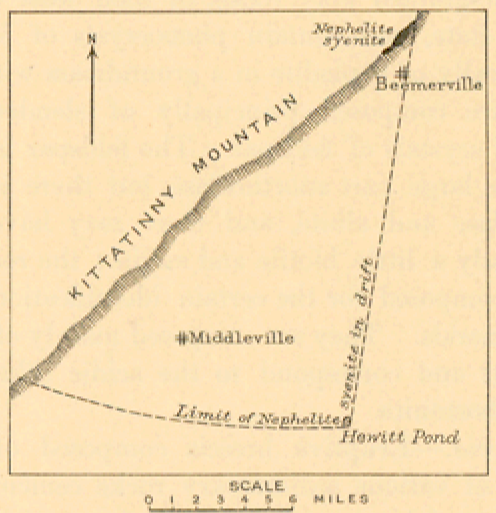


FIG. 6.—Sketch map showing fan-shaped area of distribution of nephelite syenite bowlders from the outcrop at Beemerville.

and thence northwestward along the Kittatinny escarpment. (See fig. 6.) A considerable part of this area is west of the Franklin Furnace quadrangle. The pieces of syenite in the drift decrease in size with increasing distance from the parent ledge, in the vicinity of which some of them are 4 or 5 feet in diameter. It is significant that stones from this outcrop were not carried farther south. The rock is not especially resistant (for igneous rock) and it is hardly to be doubted that its fine waste went farther than the fragments which are now recognizable. The distribution of the syenite is an illustration of the general fact that masses of rock that is not exceptionally resistant do not suffer extensive transportation in the lower part of an ice mass before being ground to fineness. The distribution of the syenite illustrates also the spreading of the ice. Near the ledges the fragments are confined to a narrow zone within which the bowlders are relatively abundant. West of Beemerville, this zone is not more than a mile wide, but 4 miles south of the southernmost syenite ledge the zone is about 4 miles wide and in the latitude of Washingtonville its width is 9 miles. Judged by the distribution of the syenite, the direction of ice motion must have ranged from S. 12° W., to S. 46° W. These figures fall within the limits of the numerous striæ recorded in the valley.

A few bowlders of the same sort of rock were also noted in a locality so significant as to deserve separate mention. The syenite outcrops are 100 to 150 feet below the summit of the Shawangunk ledge. Along the road across the mountain northwest of Beemerville, many bowlders of syenite were noted a quarter of a mile west of the nearest outcrop and at an elevation 100 feet higher. If they came from the northernmost outcrop instead of from the nearest one, their direction of motion was S. 48° W. and their height only about 30 feet above their source; but to reach their present position they must have passed over a hill about 100 feet higher than the ledge whence they were derived.

A number of syenite bowlders, one 3 feet in diameter, were found on the eastern slope of the mountain three-fourths of a mile from Beemerville, 1 mile S. 62° W. to S. 69° W. of the northernmost outcrop. Northwest of the outcrop some striæ bear S. 93° W., or 3° north of west. These striæ and others near by, together with the presence of syenite bowlders west of the crest of the mountain, prove that in this vicinity at least the direction of ice motion at the crest was more westerly than the trend of the mountain, and that ice from the lower part of the eastern slope of the range passed up over the crest to the western slope. It will be noted that the distribution of the syenite in the drift is in harmony with the direction of the striæ.

THICKNESS OF THE ICE.

As the ice moved from the Kittatinny Valley toward the Highlands on the southeast and toward Kittatinny Mountain on the northwest, it follows that the surface of the ice must have been higher in the valley than on the mountains. Moreover, as the Highlands were about 600 feet higher than the valley and were themselves overridden by a thick body of ice, it is clear that the depth of the ice in the valley must have been very great. The elevation of the lowest part of the valley in the quadrangle is somewhat less than 400 feet, and that of the highest part of the mountain to the west about 1650 feet. It is probable, therefore, that the ice in the valley was 1300 feet, at least, thicker than that on Kittatinny Mountain. The vigor of the glaciation on the mountain shows that the thickness of the ice there must have been considerable, and it is probable that the ice in the valley, at least toward the north, was not less than 1500 feet thick, and it may have been considerably thicker.

DISTRIBUTION OF STRATIFIED AND UNSTRATIFIED DRIFT.

In general, it may be said that the unstratified drift, or till, appears at the surface on the mountain lands on either side of the valley, and on the hills and ridges of the valley itself, and that the stratified drift is confined largely to the subvalleys of the great valley; but to these general statements there are numerous exceptions, for till appears in parts of the lower valleys, and doubtless underlies the stratified drift at places where it does not appear at the surface. Stratified drift, on the other hand, locally appears well above the valley bottoms, and even constitutes considerable hills (kames), as about Hamburg.

The drift, on the whole, is not thick. Outcrops of rock are numerous over most of the area where till lies at the surface; they are much fewer in the areas of stratified drift.

DRIFT OF KITTATINNY VALLEY.

Underlying Formations.

As shown by the areal geology map, this valley is underlain by shale and limestone disposed in belts which are nearly parallel with one another and with the general trend of the valley. The topography of the limestone belts is so different from that of the shale belts, and the difference is of such importance in the disposition of the drift, that some account must be taken of it at the outset.

Limestone belts.—In the limestone belts the surface of the rock is very uneven, and numerous ledges and knobs of rock project through the drift. Many of the outcrops rise abruptly above their surroundings, being particularly obtrusive where surrounded by plains of stratified drift, above which they rise like islands in a lake. Though many of the limestone knolls are bare, some of them are partly covered by till; but even in these the character of the soil in places shows the proximity of the rock below. Even where there are no considerable ledges, the limestone shows itself in numerous small, angular, warty projections. As the beds have a notable dip, the outcrops are usually ranged in lines along the strike of some resistant layer. Between adjacent knolls of limestone the drift is locally deep, showing that the relief of the rock surface is much greater than that of the present surface.

The outcrops of limestone are almost invariably rough, angular, and weathered. No striæ are found on them, and but few of them indicate, even by their forms, that they were ever glaciated. From the shape of the bosses of gneiss and schist in the Highlands, and from the smoothed and rounded shapes of limestone mounds seen here and there in section under a considerable thickness of drift, it is evident that the ice left the knolls and ledges distinctly glaciated. It must therefore be concluded that postglacial weathering has almost completely obliterated the traces of ice work, so far as the exposed ledges of limestone are concerned. Few other regions afford more impressive illustrations of postglacial weathering. The warty topography characteristic of the limestone belts is well developed just west of Hewitt and Long ponds, near the southwest corner of the quadrangle; at several points a mile or two north of Lafayette; near the north end of the swamp northeast of Lafayette; and in a belt extending northward for 3 miles from a point somewhat south of Harmony Vale schoolhouse. A good view of this topography may be had along the road from Hamburg to Beaver Run, and again northeast of Papakating Church.

As the limestone belts in general are low, a considerable part of their area is covered with stratified drift, which is generally of considerable thickness. Over by far the larger part of the remainder, the drift (usually till) is thin or absent. In a few localities the till is so thick as to conceal the rock and to give rise to smooth and undulatory slopes.

Shale and slate areas.—The topography of the shale areas is very unlike that of the limestone belts, the difference being due primarily to the different behavior of the two sorts of rock when exposed to weathering. Limestone is more resistant to mechanical agents of erosion, and shale and slate to chemical agents. Before the last glacial epoch the limestone belts had been generally reduced below the level of the shale belts.

The tops of the higher shale hills and ridges are remnants of an erosion plain developed much later than the Kittatinny peneplain already mentioned. This valley plain in turn has been dissected by stream erosion to varying amounts, giving rise to different topographic results. (1) In some places the old plain is still distinct. Within the quadrangle this phase is best seen in the vicinity of Beemerville. (2) Many of the minor streams flow for considerable distances parallel to the strike of the beds before joining the main subvalleys. Such streams have cut the plateau into ridges parallel with one another and with the strike of the beds, giving the surface a fluted appearance. Topography of this type can be seen north of Wykertown, east of Beemerville, and in the narrow shale belts southwest of Sussex (Deckertown). The ridges are crossed by numerous deep, narrow gaps, through which the smaller streams make their way to the larger. (3) In still other regions the old valley plain is so much cut up by longitudinal and transverse valleys that it presents only the appearance of a confused assemblage of rounded hills, whose tops approach a common level.

When the ice withdrew smooth knolls of polished shale and slate must have been exceedingly common. Between them and on their lower slopes was a little till, but their tops and upper slopes were in many places nearly bare, though strewn with foreign bowlders. Not uncommonly these bowlder-strewn rounded knolls of shale are so numerous and so irregularly disposed as to resemble, especially at a distance, the knolls and hillocks of a strongly marked terminal moraine. This resemblance is increased where the till between the knolls is so disposed as to form undrained hollows. Since the ice withdrew solution has had little effect on the shale, but changes of temperature and other agents of weathering have developed a mass of shale débris, most of which remains where it was formed, concealing the solid rock without notably altering the topography. Smooth and flowing outlines are therefore as characteristic of the shale hills and ridges as jagged, angular outlines are of the limestone belts.

The Till.

Till on the limestone.—So far as it shows at the surface, the till on the limestone of the Kittatinny Valley is confined chiefly to the higher parts of the area underlain by this rock. Even here it is not invariably present, for many of the knolls and ridges of limestone are bare. As stated elsewhere, the stratified drift fills the lower depressions in the irregular surface of the limestone, and the till is found mainly on the lower parts of the remaining surface. It is most abundant between the knolls and ridges of rock and on their lower slopes, though locally it covers their crests also.

The till varies in character with its variation in thickness. Where thin, much of it so closely resembles the residual earths arising from the decay of the rock that it is impossible to distinguish it from them except by the presence of stony material of foreign origin. The color of such till is commonly reddish brown, ranging to orange and chocolate. The stony matter is largely angular blocks of limestone, and it is in many places impossible to say whether they were really ice carried or weathered from the outcrops after the ice departed. Glaciated stones are rare, and the till is not notably calcareous. Such soluble elements as it once had have been leached out. Where the till is thick, on the other hand, its color is lighter, indicating less perfect oxidation; it is calcareous at depths of 2 to 4 feet from the surface; glaciated stones are abundant; and the proportion of stones foreign to the limestone is greater.

Much of the till of the limestone areas is stony, the bowlders and stones being derived from the Shawangunk and High Falls formations of the Kittatinny Range, and from the Ordovician and Cambrian formations of the valley. In some localities gneiss bowlders also are abundant. On the whole, the Shawangunk bowlders are the most conspicuous. They are usually more or less worn, something like a third of them showing distinct evidences of glaciation either by striæ or by planation surfaces. Bowlders of gneiss are notably rare, as might readily be supposed from the direction of ice movement, which was not such as to bring bowlders from the Highlands into the valley. They are found in the lee of Pochunk Mountain, where their presence was to have been expected, and are most numerous near the mountain.

The abundance of bowlders and other drift material from the principal formations of the valley is natural, but the bowlders from other formations present a less simple problem. For the quartzite bowlders which are thought to be Cambrian, there seems to be no adequate source, for rock which could have yielded them has few outcrops in New Jersey, and these are not extensive. For the Shawangunk and High Falls bowlders there are adequate outcrops, though, as already pointed out, the distribution of these bowlders is not everywhere what would have been expected from the position of the outcrops and the direction of ice movement. It should be noted that the preponderance of Shawangunk bowlders does not mean an equal preponderance of drift material from this formation, for the rock is hard and masses of it are capable of prolonged wear without comminution. If half the bowlders of the valley are from this formation, it may not mean that more than 2 or 3 per cent of the drift has the same source.

Owing to the great unevenness of the surface of the limestone, the thickness of the till upon it varies greatly within narrow limits. Depths of 25 to 30 feet may occur in many places, but the areas over which such thicknesses prevail are certainly small. As it is difficult to obtain accurate information as to the maximum thickness, an estimate of the average thickness is apt to be too small rather than too great; but such data as are at hand indicate that the average thickness of till on that part of the limestone which rises above the level of the stratified drift may be between 5 and 10 feet, and probably nearer the former figure than the latter. Considerable areas of the limestone are covered by humus deposits. This is the case, for example, between Newton and Branchville Junction, where the surface is ill drained.

The till on the limestone in the Vernon and Wallkill valleys contains very much more material derived from the Highlands than that in the main valley farther west. This is because the ice which reached these valleys had crossed the rock formations of the Highlands and brought material from them.

Exposures of till on the limestone are relatively few and shallow. Such as occur are found mainly along the roads and railways and about quarries. Among the best are those in the railroad cuts between Franklin Furnace and Hardystonville and those at the Rudeville quarries. The till has been oxidized to a depth of 2 feet or so, and the layer thus affected is dark brown, the color commonly assumed by the decayed products of the crystalline limestone.

A single bowlder of such size as to be worthy of mention has been observed on the limestone. It lies near the road 2 miles northeast of Lafayette. It is of limestone and is about 15 feet in diameter.

Striæ are rarely seen on the limestone except where the rock has been recently uncovered. Even in such situations they endure but a short time.

Possible drumlins.—The till is extremely thin over most of Mine Hill north of Franklin Furnace, and many ledges of crystalline limestone and intrusive igneous rock outcrop, but northeast of Mine Hill and south of Hardystonville the till is thicker. Between Franklin Furnace and Hamburg it is massed in five elliptical hills which may be drumlins. In those having the more typical form the longer axis is two to two and a half times as long as the shorter, ranging from one-third to three-fourths of a mile. The heights are 44, 57, 80, 100, and 128 feet. The longest hill is also the highest, but the second longest is the lowest, so that there is no constant relation between length and height. The slopes of these hills are smooth and regular, and in their outline there is nothing to indicate that the rock is near the surface. Their longer axes are parallel to one another and approximately parallel to the direction of ice movement. In all these respects they resemble drumlins; but the trend of their longer axes is nearly the same as the strike of the limestone ridges, so that their position can not be regarded as proof that they are drumlins. They may be hills of rock only veneered with till. Another such drumloid hill occurs in the northeast corner of the quadrangle.

Till on the shale.—Where the shale forms hills and ridges, there is relatively little till, and this is increasingly true in proportion as the hills and ridges are narrow. Where they are broad, the till is more abundant. However, the till of the shale areas is, on the whole, thicker than that of the limestone belts, its average thickness being perhaps not far from 10 feet.

The shale hills and ridges are essentially bare in many places, for example, (1) along the east base of Kittatinny Mountain, especially north of Beemerville, (2) on the belt of shale hills between Wykertown and Woodbourne, (3) on the belt of hills southeast of Papakating Creek, and (4) over a belt extending northeastward from Davis Pond. Farther northeast on this fourth belt the till is thicker, but shale outcrops nowhere cease to be numerous, and locally there are considerable areas where the shale is scarcely covered. Apart from the areas mentioned, the surface of the shale is generally concealed by the till. Thicknesses of 20 to 30 feet are not uncommon, as in the area between Branchville and Plumbsock.

Composition.—The till is in general made up principally of material derived from the shale and slate beneath. As this material is not very resistant, the drift is usually clayey and compact. The pieces of shale and slate which it contains are abundantly stratified.

Except on the borders of the limestone belts, the till is not usually calcareous. Where calcareous matter is present, it rarely shows itself for 3 feet or more below the surface. The bowlders are partly from the local formation and partly from the Shawangunk and High Falls formations. Limestone bowlders are relatively rare. Exposures in the till are not numerous and are confined chiefly to the shallow road and railway cuts and to the excavations in the vicinity of the villages. A few striæ are known in the southern part of the area, and very many in the northern.

The Recessional Moraine.

A recessional moraine has an irregular and somewhat interrupted development between Ogdensburg and Washingtonville. It continues westward from the quadrangle to Kittatinny Mountain, and is correlated with morainic patches in the Delaware Valley. The width of the moraine averages about half a mile, but ranges from a quarter of a mile to a mile. This moraine is, on the whole, more stony and bowldery than the adjacent ground moraine and contains some stratified material. The topography is well seen at various points, among them the following: (1) Rather more than one-fourth of a mile north of Ogdensburg, on the slopes of the mountain; (2) at the road crossing near the Ogdensburg zinc mines; (3) east of Lanes

Pond, where the distinctive topography is best seen from the west side of the pond; (4) west of Lanes Pond, where the relief is strong; (5) near Sparta station, on the Delaware, Lackawanna and Western Railroad; (6) on the road south of Lafayette; and (7) about Washingtonville. Exposures in the moraine are to be seen along the railway near the Ogdensburg zinc mines and along the Lehigh and Hudson River Railway west of Lake Grinnell.

Other patches of drift of morainic habit are not pronounced within the area of this quadrangle, but one such patch crosses the valley a mile northeast of Augusta, south-southwest of the Frankford plains.

Stratified Drift.

It has already been noted that the stratified drift is confined principally to the minor valleys of the great valley. It is found in the valleys of Paulins Kill, Wallkill River, Papakating Creek, and Clove and Pequest rivers, and at a few points outside the valleys.

In most of these situations it is irregularly disposed. In many of them it appears to have been deposited against the sides of the valleys while ice still occupied their centers. Drift deposited in such positions constitutes kame terraces, their upper surfaces and especially their valley slopes being marked by kame hillocks and associated depressions. In other places the stratified drift occurs in the form of plains, indicating free drainage through the valleys when it was laid down; elsewhere it constitutes kames, the most conspicuous being near Hamburg; and in still other places it has the form of deltas, the largest of which is the North Church delta, adjacent to the great kames just mentioned.

Drift in the valley of Paulins Kill.—The stratified drift of the Paulins Kill valley lies locally in the form of broad terrace plains which show little influence of the ice, as for example, at Branchville and Augusta, and east and northeast of Augusta. In other places, as between Augusta and Lafayette, it assumes the kame or kame-terrace habit. Terrace patches more or less isolated, but not by erosion, indicate the presence of ice while their material was being deposited.

Deltas, kames, etc., in the valley of Papakating Creek.—From the terminal-moraine patch northeast of Augusta to its junction with the Wallkill, Papakating Creek is bordered by kames and kame terraces. Typical deposits laid down in the presence of stagnant or nearly stagnant ice occur near Armstrong (pitted plain and confused mass of kames), near Papakating (large massive kames), and southeast of Woodbourne (kame terraces). Northwest of Northup, at an elevation of about 525 feet, is a glacial delta, built in a temporary lake or pond, which was partly confined by ice walls. The origin of the plain is indicated by its topography rather than by its structure, for the latter is not exposed. In addition to the stratified drift already noted, there are lower terraces of clayey constitution. For most of its course Papakating Creek is bordered by a wide alluvial plain.

That the gravel deposits of this valley were made when the ice filled its center and lower parts at many points is shown (1) by the topography of the deposits, the valley slopes of the terraces being due to deposition, not to erosion; (2) by their position high on the sides of the valley; (3) by the wide and somewhat swampy flood plain, not of postglacial development; (4) by the outcrops of bare rock and the presence of till in the bottom of the valley below the stratified drift, where their surroundings are such as to forbid the supposition that erosion has removed overlying deposits of gravel and sand; and (5) by the existence of well-marked kames in the valley at elevations of 450 to 480 feet, whereas the general aggradation level of the valley deposits is considerable higher.

The Papakating Valley drains northward. As the ice retreated northward down this valley, the glacial drainage must have been either contrary to the slope of the land or toward and under the ice (very improbable suppositions); or a lake must have been formed in the valley in front of the ice, the overflow escaping to the south. The surface of the stratified drift declines southwestward, showing that the drainage was in that direction. With the exception of the delta near Northup, the topography of the stratified drift of the valley does not indicate that ponds had any considerable development. They probably existed, but for a short period only.

The history of ice retreat and gravel deposition in the valley of Papakating Creek appears to have been somewhat as follows: (1) A stage of comparatively rapid retreat of the ice edge from the position of the moraine northeast of Augusta to a point a little above Papakating, followed by the formation of the gravel deposits between these points at elevations of 525 to 530 feet; (2) a probable second stage of rapid retreat, followed by a pause, during which were laid down the valley deposits from a point a little above Papakating to the vicinity of Woodbourne, represented by the aggradation level ranging from 450 to 540 feet. The rise from 450 to 540 feet in so short a distance may be accounted for by the abundance of material brought down by West Branch of Papakating Creek. As will be seen later, deposits at harmonious levels extend up the valley of West Branch for some distance above Woodbourne.

Kame terraces in the valley of West Branch.—North of Beemerville kame terraces, presenting the various types of topography characteristic of deposits made against ice, border the broad alluvial plain of West Branch of Papakating Creek. At the Beemerville cemetery the stratified drift forms a flat-topped plain, but farther north the kame-terrace topography is strongly marked. These terraces are from 760 to 780 feet above sea level. Another and lower set (720 feet) of kame terraces occurs near Plumbsock. East of Plumbsock similar terraces extend, with but slight interruption, almost to Woodbourne. West of the brook entering West Branch about halfway between Plumbsock and Woodbourne there are two terraces, one at 660 feet and the other 30 feet lower. The upper level is represented by narrow terraces and isolated mounds; the lower is more continuous. Both were developed while ice remained in the valley, and the deposits of the upper level antedate those of the lower. East of Woodbourne terraces of stratified drift have an elevation of 560 to 570 feet—100 feet below the upper level of the Plumbsock area, but harmonious with that of the terraces southeast of Woodbourne (540–550 feet), in the valley of the Papakating.

These several levels of stratified drift in the valley of West Branch do not grade into each other, and their great discordance is proof of independence of origin. They may or may not have been contemporaneous, but they were not made by waters flowing freely down the valley. Although the kame-terrace topography is not strong, the evidence is complete that ice clogged the valley while the terrace gravels were being laid down.

Drift in the valley of Clove River.—Gravel deposits occur more or less continuously on one or both sides of the Clove River valley for several miles north of Sussex (Deckertown). They generally reach down to the alluvial plain, but here and there form small terrace-like patches well above the alluvial plain. Evidence is not lacking that the deposits of this valley, like those of all the other valleys of the region, were made when more or less ice remained in it. The discontinuity of the terraces, the occurrence of some of them high on the valley sides, the topography of their valley slopes, and the deep sinks and the kame hills which affect them in some places form the basis for this inference. Well-defined kame terraces and topographic forms characteristic of deposits made against ice occur along the Sussex-Montague turnpike $1\frac{1}{4}$ miles above Sussex, at the Clove cemetery $2\frac{1}{2}$ miles above Sussex, and a third of a mile above the cemetery. Isolated mounds and small terraces occur at numerous other points along the stream, either in the bottom of the valley or high on its sides.

Near Sussex there are several exposures of lacustrine clay in a terrace a few feet above the river. Near the old mill pond, there were formerly pits where clay was dug for the manufacture of brick. The character of the clay indicates that it was deposited in standing water. Its explanation is to be found in obstructed drainage. Clove River discharges into the Wallkill, and after the lower part of the Clove Valley was free from ice, the valley of the Wallkill farther north was still occupied by it, and the waters were ponded in the vicinity of Sussex, as well as in other portions of the upper Wallkill drainage basin.

The stratified drift of this valley is well exposed near the schoolhouse 2 miles north of Sussex, where the material is mostly shale, slate, or sandstone derived from the local formation. Many of the pebbles are incrusted with lime carbonate.

Drift in the Pequest Valley.—But little of the Pequest drainage system lies within the area of this quadrangle. The glacial drainage which entered this basin came through two valleys—one leading southwestward from Branchville Junction, or perhaps from Harmony Vale, and the other southwestward from North Church. Only a portion of the latter valley now drains to the Pequest, showing that the course of the glacial drainage did not correspond with that which now exists.

The stratified drift lying in the valley which extends from Hewitt Pond on the southwest to North Church on the northeast is singularly and instructively disposed. It is a unit in the sense that it appears to have been in process of deposition at about the same time. Much of it, at least, was laid down while the terminal moraine just north of Lanes Pond was being formed. The most striking feature of this valley is the string of long, narrow ponds and swamps extending from Hewitt Pond to Lanes Pond, a distance of about 10 miles. In the narrow part of the valley, below Pinkneyville, the ponds are larger and more numerous than in the wider part. Even where the valley is narrowest, these ponds are generally surrounded by stratified drift. In one or two localities the rock slope of the valley forms a part of the shore of the pond, but this is the exception rather than the rule. The gravel about the ponds generally has the form of narrow terraces, with undulatory tops 20 to 25 feet above the water. Many of the steep terrace slopes also are undulatory. When the stratified drift was deposited a series of ice blocks probably lay in this valley in the depressions now partly filled by the waters of the ponds and the humus of the swamps. Between these blocks of ice, and between the ice and the valley walls, the stratified drift which now forms the terraces bordering the lakes was deposited by the waters of the melting ice. The knobs and hollows on the face of the terrace reflect, in some measure, the irregularities of outline of the blocks of ice. The sites of the largest of these blocks are now marked by the remarkable series of ponds and marshes in the valley. Some idea of the extent of the glaciofluvial filling may be gained from the fact that Long Pond has a reported depth of more than 100 feet.

The broad area northeast of Pinkneyville, covered with gravel and sand, is known as Germany Flats. The larger part of this area is a terrace plain, the surface of which is interrupted by irregular and more or less connected depressions, 20 feet or so below the general level, occupied by swamps or ponds. Kame terraces, comprising kettles, winding ridges, and narrow terraces bordering the rock hills, are well developed about White Lake and Hewitt, Long, and Drake ponds. Steep slopes surrounding the depressions show in many places the irregularities impressed upon them by the ice against which they were built. This topography is well shown in the vicinity of Woodruff Gap, on the slopes above the swamp followed by the railroad. It may also be seen at almost any point between Sparta Junction and Lake Grinnell. Except for minor irregularities, the surface of the stratified drift of this valley declines from an elevation of about 660 feet at the recessional moraine at Lanes Pond to about 580 feet at Hewitt Pond. That part of the plain which lies south and southwest of White Lake is 15 to 20 feet higher than the part immediately west of the lake, the two levels being separated by an escarpment of 15 to 25 feet, which faces northward. It is probable that the edge of the ice was at the line of the escarpment during the deposition of the stratified drift to the south, and that after the ice had retreated somewhat to the north, the lower terrace was formed.

West of Sparta Junction, and also northwest of Woodruff Gap station, limestone knolls project up through the gravel. In other places the rock outcrops at levels below the plain In some of these places, at least, the rock was never covered by the gravel and must have been protected by ice when the gravel was deposited.

The general southward slope of the terraces of this valley shows that they were formed by glacial drainage flowing southwestward. The present drainage of the valley is in several directions. Southwest of Pinkneyville Iliff, Long, and Hewitt ponds drain into the Pequest. In the southern third of Germany Flats, from Howell Pond, which has no outlet, to Sparta Junction, the drainage is to the northeast, contrary to the general slope of the terraces. The middle third of Germany Flats is drained by two streams flowing southwestward. Near Sparta Junction they unite with the one from the southwest that drains the southern third of the flats, and the stream formed by their union flows northwestward, out of the Germany Flats valley, into Paulins Kill at Branchville Junction. The northern third of the plain, including White Lake and Lanes Pond, drains northeastward into the Wallkill. Here the present drainage is in striking discord with that of glacial time. The present streams were located, not by the slope of the surface of the terraces, but by the slope of the lowest passages along the valley at the time the ice melted. The drainage of to-day would doubtless have corresponded with that of glacial time if masses of ice had not lain along the axis of the valley while the deposition of the gravel and sand was going on. The melting of the ice at a later time modified the southward slope which existed while the ice masses remained, and the streams then adjusted themselves to the new slopes.

Between the north end of Lanes Pond and Monroe there are some massive kame terraces. They are best developed on the east side of the stream, and in places attain an elevation of 80 to 100 feet above the bottom of the valley. Their maximum altitude is about 660 feet, corresponding approximately with the maximum height of Germany Flats. The line which separates the kame-terrace area from the moraine on the west side of Lanes Pond is somewhat arbitrary, as that part of the moraine is made up largely of sand and gravel, and topographically the two areas are not sharply differentiated.

The bulk of the gravel in the Pequest system was derived from the Martinsburg shale close at hand. Limestone pebbles and cobbles are abundant in some exposures, but the larger stones are mainly from the Shawangunk and High Falls formations, especially the Shawangunk. The gravel is generally well waterworn, but striated cobbles are not entirely absent. Here and there masses of till are included in the gravel, though such occurrences are rare. In size the material ranges from fine sand to coarse gravel, layers of extreme diversity being in many places closely associated. The materials are likely to be coarser and less well assorted where the topography is irregular. Over much of the area the surface soil is clayey. The greatest known thickness of the gravel is 45 feet, at which depth its bottom was not reached. There are good exposures along the railway east of Long Pond, west of Iliff Pond, and near Gunderman's mill, at the north end of Lanes Pond. Cuts near Lake Grinnell shows a large proportion of limestone and an abundance of gneiss, but shale is a minor constituent. In the vicinity of the recessional moraine the material is in general coarse. Great masses of the gravel have been cemented by calcium carbonate into firm conglomerate about the north end of Lake Grinnell.

Drift in the valley of the Wallkill.—The Wallkill Valley contains a relatively small amount of stratified drift. The portion below Franklin Furnace was not the line of discharge for any large amount of glacial drainage. At Sparta there are large, massive kames rising 60 to 110 feet above the stream. Much of their material is coarse and but slightly waterworn, some of the stones still retaining striæ. At Ogdensburg a huge triangular embankment of stratified drift crosses the valley, its base resting against the east bluff. Its crest has an altitude of about 660 feet and is 100 feet above the valley to the south. The free end of the embankment does not now reach the western side of the valley, and the evidence seems to indicate that it never did, or at least not at the level of the present crest. This embankment of drift is believed to have been deposited in a huge crevasse in ice which had lost its motion before the deposition took place. The material is plainly stratified, and on the whole assorted, although large bowlders occur at all depths. The gravel of the embankment is composed chiefly of gneiss and limestone, with a considerable amount of sandstone from the Martinsburg.

West of Hardystonville and extending beyond North Church is a glacial delta (fig. 7). It is a flat-topped plateau of sand and gravel 1¾ miles wide and five-eighths of a mile long, with an average elevation of 630 feet. Its southern and eastern margins are lobate, with characteristic delta fronts, which in places are 100 feet high. The lobes of the plain are clearly outlined and the reentrant angles well defined. The surface of the delta is plane, but rises gently northward, grading in this direction into a series of kames. The conditions controlling the deposition of the delta must have been very different on opposite sides. On the south it was built into water standing at an elevation of 620 to 630 feet. On the north the delta material was deposited against the irregular front of the ice which bounded the lake on this side. Except for the delta, shore features are absent, and the life of the lake must have been short. With drainage to the north blocked by ice, the water about North Church would find its lowest outlet to the southwest via Lanes Pond and Woodruff Gap to Paulins Kill, whose level was a little below that at which the North Church Lake was held. The obstruction which held the lake up to the level of 620 to 630 feet was probably the recessional moraine about Lanes Pond, the site of the pond being then occupied by an ice block. In the upper Wallkill Valley, the Ogdensburg embankment may have hemmed it in on the south, or the waters may have extended up the valley to the vicinity of Sparta. The clay near Hardystonville, already mentioned, was probably deposited in this lake.

Fig. 7.—Delta at North Church, deposited in an ice-dammed lake in the Wallkill Valley.

Northeast of the North Church delta plain, and separated from it by a narrow valley in which there is little drift of any sort, is a conspicuous area of kames that is noteworthy both for the large size of two of the kames and for its pronounced kame topography. The two massive kames are flanked by many smaller ones. The larger of the two rises 140 to 150 feet above its surroundings on its southern side. Its slopes are regular and symmetrical, unmarked by minor irregularities. On its northern flank, just southwest of the Hamburg station of the Lehigh and Hudson Railway, is a small but complex area of pronounced hillocks and kettles. This particular spot affords an exhibition of the most striking kame topography in this region. The kettles are nearly circular and their rims are practically unbroken. The hillocks are equally perfect in their dome-shaped outlines. The relief is in many places 40 feet, and if measured from the top of the largest kame to the bottom of the nearest kettle, it is nearly 100 feet. This kame area is continued northeastward across the river, in the southern part of Hamburg. It is marked by massive hills of stratified sand and gravel, in which bowlders are more or less common, associated with irregular depressions and kettles. The new schoolhouse at Hamburg is on one of these hills. These massive kames indicate the position of at least a temporary halt of the ice during its retreat. This area extends toward McAfee, and is more or less continuous with deposits of stratified drift between McAfee and the State line.

North of the pronounced kames about Hamburg, and extending thence to Sussex (Deckertown), there is a well-defined belt of kames along the valley of the Wallkill. This kame belt affords the best opportunity known in Sussex County for studying the effect of differing character in the surrounding rock on the constitution of the stratified drift. It is bordered both on the east and west by limestone hills, save for a mile near its north end, where the gravel lies on shale. Exposures at intervals of a mile give an opportunity for determining the change in the constitution of the drift in passing southward from the shale area to the limestone.

A mile southeast of Sussex about 95 per cent of the pebbles under 1½ inches in diameter consist of shale, and shale cobbles make up about 65 per cent of the coarser material. A mile or more farther south, and three-fourths of a mile south of the contact of shale and limestone, shale constitutes only 75 per cent of the finer material and a much smaller proportion of the cobbles than at the other exposure. The loss in shale is made up almost entirely by a gain in limestone, the other constituents being about the same. At a third exposure, a mile south of the second, more than 50 per cent of the finer material is shale, and 25 to 30 per cent of the cobbles over 3 inches in diameter are of limestone, whereas at the first exposure the limestone cobbles do not constitute over 11 per cent of the whole. At a fourth pit, a mile south of the last and likewise on limestone, 50 to 65 per cent of the cobbles are limestone, as are also half of the pebbles from one-fourth inch to an inch in diameter, though the shale still constitutes more than 50 per cent of the finest gravel. Within less than 3 miles, therefore, after leaving the shale, the material of the stratified drift changes from gravel in which fully 95 per cent of the finer and about 65 per cent of the larger fragments are from the Martinsburg shale to that in which 50 to 65 per cent of the cobbles and 50 per cent of the small pebbles are of limestone.

About a mile east of Sussex is an elevated sand and gravel plain, similar in many respects to the North Church delta. Its greatest dimension, 1 mile, is from northwest to southeast, and its shortest, a quarter of a mile, is from northeast to southwest. Its elevation is about 535 feet, nearly 100 feet less than that of the North Church delta and about equal to that of the kame terraces southeast of Woodbourne. From the south it rises by a steep slope 80 to 100 feet above the low land at its border. Its southern margin is lobate, and the lobes resemble delta fronts. In two places the projecting lobes of the plain were built out to kames, which they partly buried. On the top the delta form is less distinct. Instead of being flat or gently sloping, it is affected by sinks 25 to 40 feet deep, and one knoll rises 10 feet above the general level. The inequalities are less strongly developed near the front of the plain than farther back from the edge. In this respect, as in its steep and lobate front, it is like the North Church delta. No exposures reveal the structure, but the form of the southwestern slope indicates that this part of the plain was built into a temporary lake. The immediate presence of the ice is probably responsible for the form of the surface of the delta, and its slight extent indicates that the lake into which it was built had but a brief existence. There seems to be little chance for a lake to have existed here unless it was held in at the south, as well as at the north, by ice; for the water would need to rise only to the level of 501 feet to overflow the divide between Papakating Creek and Paulins Kill. With the present configuration of surface, therefore, no lake could have existed at Sussex above a level of 501 feet, unless held in at the south by ice. The absence of an outlet channel over the divide makes it improbable that a lake discharged in this direction.

A long, narrow kame belt northeast of the Sussex delta stands in much the same relationship to that delta as the Sussex-Hamburg belt does to the North Church delta. The northern kame belt is separated from the northeast end of the Sussex plain by an alluvial flat, beyond which it extends without interruption to a point 3½ miles northeast of the delta. In width this belt ranges from 300 to 600 yards. It is composed of a succession of massive kames, surrounded and connected with one another by smaller hillocks. Locally it becomes terraciform, but this is not its usual habit. Its greatest relief is more than 50 feet, but the relief between the crests of hillocks and the bottoms of adjacent kettles is rarely more than 30 feet. Topographically, this kame belt is nearly everywhere clearly separated from the shale knolls on either side.

East of the Wallkill there are no continuous deposits of stratified drift north of Hamburg, though isolated kames and kame areas are present here and there. Some of them lie between 1 and 2 miles north of Hamburg, at elevations ranging from 400 to 535 feet.

At Independence Corner there are small but well-marked kame terraces, at elevations between 540 and 560 feet. The gravel does not cover the lower slope of the hill, but is limited below by the 480-foot contour. At lower levels the rock is nearly bare, and was probably covered with ice while the gravel of the terrace above was being deposited. The gravel here is mainly of gneissic origin, and is not well rounded nor well assorted.

From half to three-fourths of a mile north of Independence Corner a huge spurlike embankment of sand and gravel projects from the hillside into the valley of the Wallkill. The main part of the embankment is triangular in outline, the base being against the hill and the apex extending northwestward for half a mile. Seen from a distance, its crest line appears even and nearly horizontal, but at closer range its surface is found to be broken by shallow depressions. The slopes of the southern flank are not distinctly undulatory, but the northern slope retains the peculiar topography given it by the ice against which the gravel was deposited. This embankment probably marks the position of a huge crevasse in the ice which occupied the bottom of the Wallkill Valley, while drainage came down between the ice and Pochuck Mountain. From the free end of the embankment a narrow belt of kames extends for nearly half a mile to the southwest, their direction being at right angles to the main mass.

Drift in the Vernon Valley.—In the Vernon Valley there are several areas of kames and kame terraces which represent deposition at different stages of the ice retreat. Near Hamburg several massive bowlder-strewn kames rise to heights of 560 feet and more, being 60 to 100 feet above their surroundings. Near by is a kame terrace at 520 feet and another at 580 feet. The upper terrace extends with more or less interruption as far north as McAfee. A third kame terrace, at an elevation of 600 to 620 feet, lies a mile south of McAfee, in the direction of Rudeville. Immediately south of the McAfee depot is a mass of stratified drift heaped up into very characteristic kame forms. Here are kettles 20 to 40 feet deep, many of them nearly circular, with unbroken rims. A good view of them may be obtained from the hill opposite the hotel at McAfee, where the gravel attains an elevation of 560 feet. A little east of the station is a kame 60 to 75 feet high, built against a rock ledge, which it almost buries.

Sand Hills station gets its name from the huge hills of stratified drift in the vicinity. Extending northwestward from Sand Hills to the Sprague schoolhouse, and southward to a point within half a mile of McAfee is still another area of kames and kame terraces, in which the gravel locally attains a thickness of 100 feet or more.

The gravel deposits in the Vernon Valley are composed largely of gneiss and limestone with smaller proportions of material from the Martinsburg, Shawangunk, and High Falls formations. In general, the bowlders occur only on the massive kames near Hamburg.

The gravel deposits on opposite sides of the Vernon Valley do not correspond in elevation, a fact that indicates the presence of the ice in the axis of the valley while the drift was being deposited.

Other areas of stratified drift.—Several areas of stratified drift outside of the valleys occur within this quadrangle, but few of them are of much importance. One northeast of Washingtonville lies along the inner border of the moraine, a situation where stratified drift is in many places abundant; a second occurs just outside the moraine near the same place; and there is another near Beaver Run.

Undifferentiated drift.—At several points in the Kittatinny Valley there are areas where, for one reason or another, it is not possible to determine the character of the drift. In such areas there are few or no exposures, or the exposures are indecisive. It is probable that in all such places there is more or less mixture of stratified and unstratified drift.

DRIFT ON KITTATINNY MOUNTAIN.

The east face of Kittatinny Mountain is practically free from drift, and the crest itself has but little. The relatively gentle western slope, on the other hand, is more generally covered. The drift here is principally of local origin, but in addition to the local materials there are bowlders of gneiss which must have come from the northeast and fragments from formations which lie northwest of the mountain. This mixture of material shows that at one time or another the ice must have reached the west slope of the mountain from both sides. This statement is borne out by the striæ, which show that the ice diverged toward the mountain from the Kittatinny Valley on the one hand and from the Delaware Valley on the other. These two movements may not have been strictly contemporaneous. Except on the steep eastern slope and the immediate crest of the mountain ridge, the depth of the till on the mountain is probably comparable to that in the Kittatinny Valley. A little of the drift on the mountain is stratified.

TILL OF THE HIGHLANDS.

General statement.—The till of the Highlands is composed largely of gneissic and granitic material derived from the underlying formations; but as the movement of the ice was a little less toward the west than the trend of the face of the Highlands, some material was carried up from the Kittatinny Valley. As would be expected under these conditions, such material is most abundant along the slope of the Highlands facing the valley. The ice which reached the Highlands from the north had been passing over gneiss and schist for but a few miles when it entered New Jersey. Farther back in its course, it had traversed broad areas of shale and sandstone, and materials derived from these formations in New York are more abundant in the drift of the Highlands than those carried up from the Kittatinny Valley in New Jersey. The ice had also crossed the ledges of Shawangunk Mountain, to the north, and had brought bowlders from the Shawangunk formation with it to the Highlands. In general, materials of distant origin are more plentiful, or at any rate more readily recognizable, where the drift is thick than where it is thin.

Much of the till of the Highlands is clayey and compact, and some of it is foliated, but neither of these characters is universal. Locally it is loose and much like the unconsolidated products of gneiss decay. It is generally stony, and many of the bowlders are large, exceeding 10 feet in diameter. Not uncommonly they are so abundant at the surface as to render the task of clearing and cultivating the land almost hopeless, particularly where the till is thin and where numerous outcrops of the underlying rock add to the general stony character of the surface.

Nearly everywhere the larger part of the bowlders are of local rock, those of other origin being abundant only near the western edge of the Highlands. Many of the bowlders show little sign of wear; others are distinctly glaciated, though rarely striated. The proportion of bowlders showing signs of wear varies greatly in different localities, and the proportion of bowlders of different varieties of rock showing evidence of glaciation is also variable. Sandstone and shale bowlders are as a rule distinctly glaciated, many of them on all sides. This is partly because of the readiness with which they receive striæ, and partly because they weather less rapidly than some of the others. Few if any of the limestone bowlders on the surface retain the marks of glaciation. Many of them, indeed, are exceedingly rough.

Owing to the forested character and the scanty population of much of this region, exposures of the till are not numerous. The shallow cuts along the roads, many of them old and weathered, afford nearly all the available data, aside from those furnished by the surface, from which to judge of the constitution, physical character, color, amount of oxidation, and thickness of the till.

The color of the till at the surface is uniformly that of the residual clay of gneiss, a yellowish brown. This color commonly changes beneath the surface to grayish brown, but in many places exposures are too few to make this change evident on cursory inspection. In places the brown color extends to a depth of 6 feet, but this is exceptional. The till exposed in shallow cuts (6 feet and less) is rarely calcareous, even where limestone bowlders of good size are present at the surface; but where the till contains limestone as a considerable constituent, it is in places so calcareous as to respond to the acid test within 1 or 2 feet of the surface.

The till is almost uniformly thin on the steep slopes, many of which have barely enough soil to afford a foothold for timber. On the gentler slopes, on the broader summits, and in the cols it is more plentiful. Although outcrops of rock are more or less common over all the Highlands area, there are, in the aggregate, considerable areas where it is well concealed.

Without the evidence of numerous exposures and borings, any estimate of the thickness of the till may be far from the truth. Where its thickness exceeds the depth of the shallow exposures, there is usually no way of determining whether it is 10 or 50 feet deep, though as between these extremes the surroundings may give some clue. The general average for the Highlands is roughly estimated to be between 10 and 20 feet, and probably nearer the former figure than the latter. Thicknesses of 40 feet, however, are known. Striæ are rarely seen on the bed rock.

Till west of Sparta Valley.—In the region west of Sparta Valley the till is generally bowldery, and notably thicker on flat surfaces and in cols than on the steep slopes and narrow summits. This is well illustrated, for example, in the immediate vicinity of Sparta, where the drift is thin on the upper slopes of the two sharp hills just north of the village, though thick against their lower slopes. Bowlders and other materials from the Kittatinny Valley are more abundant here than in most of the area farther east. The exposures are mainly along the roads and railways. A perched bowlder of gneiss, 8 by 10 feet in size, between 2 and 3 miles southwest of Sparta, is especially noteworthy for its delicately balanced position on a gneiss ledge.

Drift on Pochuck Mountain.—The drift on Pochuck Mountain is, on the whole, thin, as everywhere in the Highlands region, though depths of 12 to 20 feet are known at several points. The material of the till is chiefly local, but bowlders from the sedimentary rocks to the north are of common occurrence. Limestone bowlders, however, are rare. Where thick, the till is usually clayey and compact, though as a rule very stony. The steep slopes and sharp summits, such as those of the high hills east of Decker Pond, show numerous exposures of the gneiss, but other areas are generally well covered. Striæ are rare on the exposed rock surfaces here as throughout the Highlands. This is the result of postglacial weathering rather than of original failure to receive striæ.

Till east of Sparta Valley.—The till of the Highlands east of the Sparta and Vernon valleys is essentially the same as that of Pochuck Mountain and the Pimple Hills. Except along the western faces of Wawayanda, Hamburg, and Wallkill mountains, and in certain places where there are local sources of quartzite, sandstone, and shale, the Highlands till is made up almost wholly of gneiss. Where well developed, the till of this type consists of a gritty matrix of finely ground gneiss and schist, in which are embedded fragments and masses of gneiss ranging in size from sand grains to bowlders several feet in diameter. The stony constituents are generally abundant, constituting a considerable part of the mass of the till. Bowlders commonly abound on the surface where it has been left in its natural state, and elsewhere many stone walls are made from them. Till containing much gneiss is rarely gravelly; on the other hand, it is nowhere so clayey as much of the till which overlies shale formations.

Although consisting largely of gneiss, the till of this part of the Highlands, like that of Pochuck Mountain and the Pimple Hills, has an admixture of material derived from other formations. Nine-tenths or more of the stones of the drift of this region, including large and small, came from the underlying rock, but the small remainder contains a goodly variety of material. There are sandstone and slate bowlders from the Martinsburg shale to the north; quartzite and conglomerate from the Shawangunk, High Falls, and perhaps other formations; limestones; black flints; a few masses of Cambrian sandstone; and, locally, bowlders of zinc ore. Bowlders of magnetite should perhaps be mentioned, though they are of local origin.

The source of some of the quartzite bowlders has not been determined, but may be in the Highlands. The same may be said of some of the sandstone masses, which are in places of great size and angular form. Such blocks are common, for example, 2 miles northwest of Stockholm, where one 15 feet in diameter was seen. Some of the limestone bowlders are white and crystalline, and others are blue and compact, corresponding to the two varieties of limestone west of the Highlands.

Except on the western slopes of the Hamburg and Wallkill mountains, till containing abundant material other than schist and gneiss is present in the Highlands only near the southeast corner of the quadrangle where the underlying rock is not schist or gneiss.

LAKES.

The lakes of the quadrangle belong to several classes, though all are due to glaciation. Sand Pond, in the Hamburg Mountains, is believed to lie in a rock basin. If this belief is correct, the basin was doubtless excavated by glacial erosion. Several of the lakes are situated in preglacial valleys that were obstructed by the deposits made by the ice. To this class belong Decker Pond, Roe Pond, and Mud Pond, in the northeastern part of the quadrangle. Lakes of another class occupy depressions in the surface of the drift itself, most of them being in the stratified drift. To this class belong Long Pond, Iliff Pond, Howell Pond, White Lake, and Lanes Pond. Some of the lakes owe their origin partly to the obstruction of river valleys, and partly to the deposition of drift against higher elevations, leaving a depression between. To this class belong Morris and Losee ponds.

The average depth of the lakes is not great. Morris Pond is said to have a depth of 110 feet and Long Pond a maximum depth of about 100 feet. Most of the lakes, however, are much shallower.

CHANGES IN DRAINAGE OCCASIONED BY THE ICE.

All the streams of consequence in this quadrangle now flow in preglacial valleys, and the changes in drainage which the ice effected are limited to possible changes in the direction of the flow of some of the minor streams. The present drainage is somewhat different from that which prevailed while the ice existed. This difference has already been pointed out in connection with the valley extending from North Church to Hewitt Pond. The course of the drainage in this valley in preglacial time is not known. Similar changes may have affected other subvalleys in the great valley. Many of the marshes of the area were the sites of shallow ponds for a time after the ice left. They disappeared when their outlet had been lowered enough to drain them, or when their shallow basins had been filled by sediment.

POSTGLACIAL CHANGES.

Postglacial erosion.—The amount of postglacial erosion in this area is on the whole, slight. The deepest postglacial gorge is probably that of West Branch of Papakating creek, where it cuts through the stratified drift near Woodbourne. Here the postglacial gorge is 80 to 100 feet deep. Few of the valleys of the area, however, have been deepened as much as 20 feet since the ice departed, and many of them have not been deepened at all. Some of them have even been aggraded.

Surface weathering and leaching have extracted the lime carbonate from the surface portion of the drift somewhat generally to a depth of 2 to 4 feet. The till has usually been discolored by oxidation and hydration to a similar depth. As the drift in many places is no thicker than this weathered zone, it appears in such places to be free from lime carbonate. The postglacial weathering of the rock itself has not been important except along the limestone belts, as already pointed out.

Postglacial deposits.—Three classes of postglacial deposits occur within the quadrangle, but none are of great importance. These are (1) the deposits of humus, which occupy considerable areas in the meadows northeast of Newton, southwest of Sparta, southwest of North Church, and in the lower part of the Wallkill Valley. The accumulations of peaty material, mixed with more or less silt, are in many places several feet in depth. Besides these larger areas, there are numerous small marshes and meadows, in which the same sort of accumulation has taken place.

(2) The second class of postglacial accumulations is calcareous marl. This material occurs in some of the ponds and lakes and is also found beneath the humus in some of the marshes. In the latter situations it was accumulated before the lakes which preceded the marshes were drained. It appears to be made up in part of the more or less disintegrated shells of fresh-water mollusks, but the secretions of algæ may be more important than appears on inspection. Shell marl is known to occur in Davis and Drake ponds, near the southwest corner of the quadrangle, in the pond between White Lake and Lanes Pond, and in various swamps south and southwest of Plumbsock. It also occurs in swamps south of North Church, and probably at other points.[a]

(3) The third class of postglacial deposits is the alluvial accumulations in the valleys of the sluggish streams. Nowhere, so far as known, do these deposits have any considerable depth, and probably they do little more than even up the rough surfaces which the ice left.

GEOLOGIC STRUCTURE.

GENERAL STATEMENT.

The rocks of this region have been disturbed from their original positions in different ways and at different times. Some of the movements were accompanied by alterations of substance, others merely by changes in position, and some of the movements have left no record, except such as can be inferred from facts in adjoining areas. Earliest of all were the earth movements which attended the formation of the ancient gneisses and the crystallization of the limestones associated with them. The structural relations between these gneisses and limestones and their generally laminated make-up are believed to have resulted from deep-seated flow of the materials involved under the action of regional compression. There can be no doubt that the granitoid gneisses and the marbles acquired their characteristic features at a time when they were deeply buried, and their appearance at the surface of the earth prior to the deposition of the oldest Paleozoic formations is considered to be due to a long pre-Cambrian period of erosion.

Throughout the region comprising and adjacent to the present Appalachian Mountains, within what may be called the Appalachian province, important earth movements closed the Paleozoic era. Evidence of this great deformation, which is often called the Appalachian revolution, is preserved in the folded formations occurring west of the New York and New Jersey Highlands and in other parts of the general region occupied by the pre-Cambrian rocks, and in the highly metamorphosed representatives of the same formations occurring east of the Highlands in West Chester County, N. Y., and on Manhattan Island. In this eastern district previous folding had occurred at the close of Ordovician time.

From the presence of the well-defined, long and straight folds, in places broken by faults, which are so characteristic of the Appalachian structure both east and west of the Highlands, and to a less extent within that area, it must be inferred that the whole region has suffered a general compression transverse to the northeast-southwest trend of the folds. Part of the faulting may have been produced by earth movements which occurred during late Triassic time, but this suggestion can not be established by observations within the Franklin Furnace quadrangle. Though it is plain that the pre-Cambrian rocks must have been deformed by the forces which disturbed the younger formations, the effects of deformation in the gneisses are so obscure that they have not been detected.

In addition to those movements which have obviously deformed the rocks, there have been numerous other movements of uplift and depression. The majority of these are necessarily unknown. One of long duration preceded the Cambrian and permitted the surface to be worn down until the deep-seated rocks were at the surface. Cambrian deposition was initiated by a widespread movement of depression. Uplift took place in the early Ordovician and again between the Ordovician and Silurian, and was followed in Silurian time by widespread depression. Another uplift terminated the Paleozoic, and extended the land areas until the surface was again lowered in Triassic time and sediments were deposited. Similar uplift and depression preceded the Cretaceous, the Tertiary, and the Pleistocene depositions. With these there is good evidence of tilting of the land toward the southeast.

STRUCTURE OF THE PRE-CAMBRIAN ROCKS.

By A. C. Spencer.

Within the Franklin Furnace quadrangle the pre-Cambrian gneisses and associated limestones are disposed in northeast-southwest bands. The rocks are nearly everywhere distinctly layered and foliated, and these features strike parallel with the trend of the rock bands. Dips are toward the southeast, with few exceptions, so that the general structure of these ancient rocks is monoclinal. In many places the gneisses are affected by minor corrugations with axes pitching in an easterly direction down the plane of strike and dip. Eastward pitch is also exhibited by the troughs of ore in the zinc mines, by the ore shoots in the iron mines, and by pencils of hornblende which commonly occur in certain varieties of the gneisses. A generally present though obscure linear graining in the rocks is revealed by the fact that the summit profiles of many ridges are asymmetrically serrate, with scarplike breaks toward the southwest and gentle slopes toward the northeast.

No estimate can be given of the extent to which the attitude of the ancient rocks was modified by the earth movements which have folded and faulted the Paleozoic formations.

STRUCTURE OF THE PALEOZOIC ROCKS.

By H. B. Kümmel.

Introduction.—The Paleozoic rocks of this quadrangle have the northeast-southwest structure lines characteristic of all parts of the Appalachian province. This feature is due primarily to a system of folds whose axes trend northeast and southwest and to a series of faults which have the same general direction. Although the structure is simple in its major features, in detail it is much more complex. Minor folds, some of them closely compressed and in places overturned occur within the larger folds and complicate the structure. These small folds are more common in the slate and shale of the Martinsburg than in the massive Kittatinny limestone, and occur more abundantly in the lower layers of the slate, where the sediments are finer, than in the upper beds, where thick layers of sandstone are numerous. In other words, the thinner-bedded, less resistant sediments have yielded by crumpling, whereas the more massive layers have accommodated themselves to the pressure by forming folds of much greater radius.

Folds.—The folds are rarely symmetrical; on the contrary one limb is usually much steeper than the other. In most places the beds which dip to the southeast dip at a lesser angle than those which dip to the northwest; 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.

[a] See Ann. Rept. State Geologist New Jersey for 1877; Ann. Rept. New Jersey Board Agr., 1878.

In this respect they follow the common Appalachian type of folds that are not overturned. But there are some exceptions to this rule, where the reverse relationship holds true and the steeper limb of the syncline is on the northwest. In addition to this close folding, the strata are affected by a series of cross folds of great length and low amplitude which manifest themselves in a slight pitch of the axes of the northeast-southwest folds.

Faults.—Most of the larger folds are cut off by faults along their flanks, in places parallel and in places oblique to their axes. Almost without exception the uplift has been on the northwest side, the beds on the southeast having been relatively depressed. The amount of dislocation ranges from a few feet to probably several hundred or even a thousand feet or more, but in the case of the larger faults it is not possible to make accurate determinations of the throw. Nowhere is the plane of dislocation of any of the larger faults of this area shown in section, but the indirect evidence indicates conclusively that they are vertical, or nearly so. So far as they depart from verticality the large faults seem to hade slightly to the southeast or downthrown side. Where this is the case they are distinctly normal faults similar to those that traverse the Newark beds in the region to the southeast and which were probably due to the same crustal movements.

Locally, however, in this and adjoining regions small faults of the overthrust type have been observed. In a small roadside quarry north of Furnace Pond three small faults occur in the Kittatinny limestone. These show curving planes of fracture which are nearly vertical or hade steeply to the northwest, with overthrusting, complicated by crushing, minor faulting, and crumpling of the finer beds. The amount of dislocation is only a few feet in each fault. These relations indicate that the faulting probably accompanied the folding and was a result of the same forces of compression. These overthrust faults are only a few rods distant from the large fault which separates the Kittatinny limestone from the Franklin limestone and perhaps are indicative of conditions attendant on that fracture, although, as noted above, all the large faults seem to be inclined to the southeast, with downthrow on that side, and to be of the normal type.

Cleavage.—Most of the Paleozoic sedimentary beds possess in varying degrees, a definite cleavage. It is best developed in the finest-grained, even-textured members of the Martinsburg shale, but is absent in the massive sandstone beds of the same formation and in the heavy conglomerate layers of the Shawangunk and Green Pond conglomerates. There are at best only faint traces of it in the thick beds of the Kittatinny limestone, but in the more shaly layers it is present, although not to so great a degree as in the Martinsburg slate. 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 sandstones 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, even-textured beds the cleavage is in straight, parallel planes along which the slate splits with great regularity. Although the coarser layers show little or no signs of cleavage, beds of slate an inch or less in thickness between them are sharply cleaved. Between the two extremes occur all degrees of cleavability.

The cleavage is almost invariably inclined to the southeast at angles ranging from 20° up and averaging about 60°. In a few localities, however, it is inclined to the northwest. There is no constant relation between the angle of dip and the angle of cleavage, as may be inferred from the fact that the cleavage is most commonly to the southeast, whereas the beds dip both northwest and southeast at all angles.

Age of folds and faults.—The folding is probably to be referred to the general movement which affected the Appalachian region at the close of the Paleozoic era. There is no positive evidence within this region, nor indeed in closely adjoining regions, to prove that the Martinsburg and underlying rocks participated in the folding at the close of the Ordovician which so greatly affected these beds in New York State and farther northeast. The slight differences in strike and dip of the Martinsburg shale near its contact with the Shawangunk conglomerate are not greater than the variations known to occur within the slate itself within equal distances, nor greater than would be expected where beds of considerable difference in strength are folded together. Furthermore, in accounting for any differences of strike and dip the possibility of a thrust fault along the contact of the Shawangunk conglomerate and the Martinsburg shale, such as seems to be present at Otisville, N. Y., a few miles north of this quadrangle, can not be entirely eliminated. No conclusive argument in favor of an earlier period of folding can, therefore, be based on variations in dip between the slate and the overlying Shawangunk conglomerate. Neither can the greater folding of the Ordovician beds of the Kittatinny Valley as compared to the Silurian beds of Kittatinny Mountain and the adjoining region to the northwest be urged in favor of the earlier date of folding, for it is recognized that the Appalachian folding is everywhere complex to the southeast and that it dies away to the northwest. Although the Shawangunk conglomerate and the overlying beds in Kittatinny Mountain dip for the most part regularly to the northwest, yet they are slightly folded at several places within the State, and farther southwest in Pennsylvania the conglomerate is greatly folded. Furthermore, the Silurian and Devonian rocks of the Green Pond area, lying southeast of Kittatinny Valley, within the Highlands, are even more closely folded than the Ordovician beds of the great valley. The conclusion is fully warranted, therefore, that the folding is due to movements occurring after the deposition of the youngest Paleozoic sediments of the State and presumably at the close of the Paleozoic era, rather than at the close of the Ordovician.

As indicated above, some faulting seems to have taken place during the folding, resulting in overthrusting along nearly vertical fault planes. The great faults, however, by which the region is traversed and broken into long, narrow blocks are not so positively connected with these movements, but on the contrary resemble in many respects the normal faults which occur in the Newark group a few miles to the east, where the movements occurred in post-Newark time. The prevalence of extensive and profound normal faulting in that region, only 8 or 10 miles distant, in post-Newark time makes it extremely probable that this region was also similarly affected, particularly as one or two of the faults in the Newark bed measure several thousand feet. The facts seem, therefore, best explained on the assumption that there have been two periods of faulting, one during the folding at the close of the Paleozoic, which was of small importance in this region but more significant to the southwest, and a second and greater in post-Newark time. The former caused overthrust faults, the latter normal faults.

Local details.—The limestone belt near Sparta shows a closed synclinal fold with dips vertical on the east limb and from 55° to 75° on the west limb, still further depressed by a fault on the west limb which has brought up the underlying gneiss; but the same belt north of Ogdensburg is anticlinal in structure, with dips of 10° to 30° on the east flank and from 55° to 90° on the west flanks, and limited on both flanks by faults. Outcrops are too few to determine the relationship between these diverse structures. The Sand Hills belt of limestone also forms a syncline faulted close to its axis and including minor undulations. The two prongs of Kittatinny limestone northeast of Hamburg are also the eastern limbs of faulted synclines.

The long belt of slate separating the large areas of Kittatinny limestone southwest of Pochuck Mountain is synclinal in structure, its axis rising gently toward the southwest, so that a few miles beyond the limits of the quadrangle it terminates in a prominent ridge around the end of which wrap the underlying limestones with dips ranging from 10° to 30°. To the northeast it disappears as it is gradually cut out by an oblique fault along its northwestern margin. Minor folds undoubtedly complicate the simple structure shown in the cross sections. The limestone belt on the east of this shale area is a part of the same syncline, but near Hamburg its width of outcrop has been much increased by minor folding and faulting. The limestone belt west of the slate ridge is anticlinal in structure, with steeper dips of 50° or 60° on the southeast flank and its axial plane dipping steeply to the northwest, an exception to the common type of Appalachian folds. Near Branchville the northeast end of a faulted anticline of the Kittatinny limestone can be seen, but its continuation can not be traced within the shale.

In the large shale area comprising most of the northwestern portion of the quadrangle there is at least one prominent syncline extending from Sussex (Deckertown) southwestward to Augusta, northwest of which the dips are on the whole toward the northwest at angles ranging up to 50°, so that the Martinsburg shale passes beneath the Shawangunk conglomerate halfway up the slope of Kittatinny Mountain. Minor folds, some of them with sharp turns and vertical limbs, complicate these general features. Such close folds occur in the hills south of Augusta and southeast of Wykertown.

In the isolated area of Paleozoic rocks in the southeast corner of the quadrangle, Bowling Green Mountain is an anticlinal mass of the Green Pond conglomerate wrapped around a core of gneiss, pitching steeply about 35° to 40° to the northeast and cut off on the southeast by a fault, which has brought the conglomerate into juxtaposition with the Pequanac shale. The anticline is succeeded on the northwest by a sharply turned syncline with a dip of 78° to 80°, likewise pitching northeastward and terminated on the northwest by a great fault which has brought up the underlying gneiss and against which higher and higher members of the sedimentary series terminate toward the northeast.

GEOLOGIC HISTORY.

PRE-CAMBRIAN TIME.

By A. C. Spencer.

The oldest geologic records in the Franklin Furnace district are found in the Pochuck gneiss and the Franklin limestone. The rocks that have been described under these names were formed by the metamorphism of materials originally deposited, in large part at least by sedimentary processes. There is practically no doubt as to the sedimentary origin of the deposits now forming the limestone, but rocks of igneous origin may enter into the make-up of the dark Pochuck gneiss. The original relations between these two formations can not be determined or even plausibly surmised; all that can be added concerning them is that they existed as more or less metamorphosed rock masses prior to the invasion of the field by the Losee and Byram igneous rocks, and that during this invasion they suffered intense alteration.

The Losee and Byram gneisses comprise granitoid rocks corresponding in chemical constitution to well-recognized igneous rocks. Their most striking differences from ordinary granites or soda granites are those of texture, inasmuch as they possess foliation due to a parallel arrangement of their mineral grains. There can be little doubt that they were formed mainly by the solidification of silicate magmas of deep-seated origin, but it may well be true that these magmas derived from the deep portion of the lithosphere dissolved and incorporated portions of the previously solid rock into which they were injected. The rocks of the two groups are separable mainly on the basis of chemical composition, the Losee gneiss being high in soda and very low in potash, whereas the Byram gneiss contains the two alkalies in varying but subequal proportions. They can not be separated on determinable age relations, and were perhaps essentially contemporaneous in that they both took part in a great fluxional migration which can not now be analysed. It is possible that the magmas or silicate solutions contained considerable water, and that cooling and decrease of pressure led to the beginning of solidification by the separation of the least soluble constituents through crystallization. Once divided into solid and fluid portions, separation of these phases might ensue, and such separations would amount to differentiation of the original magmas. It is believed that in some such way, and possibly also by the absorption of older rocks, all the varieties of the Losee and Byram gneisses may have originated. This differentiation hypothesis provides also for the production of metamorphism in the Pochuck gneiss and the Franklin limestone and suggests a method by which the notable deposits of iron and zinc ore may have been segregated. Hot mineral-bearing waters expelled from the magmas during the progress of crystallization would have been able to produce the observed metamorphism and the ore deposits.

The foregoing considerations are recognized as, for the most part, highly speculative, and in reality the history of pre-Cambrian time is very obscure. What may be confidently stated is that all the rocks of the ancient complex reached their present state of crystallinity together, during a period in which materials were being transferred from the deep earth toward the surface; that an unmeasurably long period elapsed before the oldest Paleozoic rocks were laid down; that during this interval deep erosion ensued; and that when the Paleozoic seas advanced over the region it had been reduced to an almost featureless plain. It is probable that the interval between the original deposition of the Franklin limestone and the deposition of the Hardyston quartzite was longer than the sum of all the subsequent periods.

PALEOZOIC TIME.

By H. B. Kümmel.

Although certain sedimentary rocks occur in the pre-Cambrian series, as above noted, yet they are in general so highly metamorphosed and so cut by later intrusives that no definite inferences can be drawn regarding the geographic conditions prevailing during their deposition.

It is certain, however, that for a long period previous to the deposition of the Hardyston quartzite, land conditions prevailed within this region, and that the rocks were deeply eroded, for the quartzite everywhere rests upon the beveled surface of the earlier formations and is composed of disintegrated materials derived from them. Its varying lithologic character, as well as its great range in thickness, locally within narrow geographic limits, indicates a wide range of sedimentary conditions, such as would prevail close to a shore presenting marked differences of topography. In early Cambrian time a narrow sea extended southwestward from the St. Lawrence embayment across this region and far to the southwest. Outcrops of the quartzite beyond the limits of this quadrangle and southeast of the Highlands at Trenton, N. J., and in the Harlem quadrangle of New York indicate that at the beginning of Cambrian time sedimentation occurred in this region as the sea encroached upon the land toward the southeast, and that the shore ultimately lay far to the southeast of the Highlands belt. As the quartzite does not attain great thickness and passes somewhat abruptly into the Kittatinny limestone, it is inferred that the land was low and that the migration of the shore line was relatively rapid.

During the very long period of sedimentation indicated by the Kittatinny limestone there was a comparative absence of land-derived material within this area, but inasmuch as wave marks occur at various horizons, comparatively shallow waters must have prevailed and hence it is inferred that the adjoining land continued low, with the shore farther distant than during the Hardyston deposition. The presence of thin shales and scattered seams of sandstone interbedded with the limestones, however, shows an influx of land sediments at recurrent intervals, interrupting the formation of limestone.

The basal conglomerate of the Jacksonburg limestone and the slight unconformity beneath it denote an uplift of the sea bottom, erosion, and the prevalence of shore conditions in the regions where the conglomerate occurs. Outcrops in Orange and Dutchess counties, N. Y., as well as near the Delaware, show that the movements extended far beyond the limits of this quadrangle, although the area affected was probably small as compared to the whole area in which limestone of this age was deposited. In general perhaps the movement gave rise only to a series of low limestone islands and reefs around which the conglomerate was formed, but the profound faunal change at this horizon indicates that the break in the record was long enough for the incursion of a new and abundant fauna of different facies from the preceding one.

In the Green Pond Mountain region this movement seems to have been more pronounced than in the Kittatinny Valley, and the period of erosion much longer. There is here no record of the Jacksonburg, and the Kittatinny limestone has only a fraction of its thickness elsewhere. Moreover, there are in this region only doubtful occurrences of the Martinsburg shale. These facts are interpreted to mean that the erosion interval was so prolonged as to remove most of the Kittatinny limestone and to prevent the deposition of the Jacksonburg limestone entirely and of the Martinsburg shale in great part at least. In the larger area, however, the unconformity is but slight.

The changes which terminated the deposition of the Jacksonburg limestone and brought about that of the Martinsburg shale were gradual and gentle, but were widespread, inasmuch as from Vermont to Alabama the limestones are succeeded conformably by shales. An approach of the shore line from its position far to the southeast, a probable shoaling of the waters, and a greater elevation of the adjoining land brought about the deposition of siliceous silts and sands in place of the calcareous sediments. The change in sedimentation began in this region at a much earlier period than in the typical Trenton area in New York, for here the lower Martinsburg shale contains a Normans Kill fauna, which is characteristic of the middle Trenton of central New York.

With the close of the Ordovician there were extensive crustal movements in Vermont and Canada which affected this region and raised it above sea bottom for a long period, for between the Martinsburg shale and the Shawangunk conglomerate there is a gap that is filled in other regions by the later Ordovician and two lower major subdivisions of the Silurian. During a large portion, if not all, of this period this region was a land area and subject to erosion. The Shawangunk conglomerate, formed in the advancing Salina sea, indicates another period of shore conditions, more prolonged than the Hardyston, and a less rapid transgression of the sea to the southeast.

In the Green Pond region land conditions may have prevailed continuously from the close of the Kittatinny limestone deposition, although there is some evidence that for a short period, at least, shales supposed to be Martinsburg were deposited. As a result of this prolonged erosion, followed by subsidence and consequent deposition, the Green Pond conglomerate now rests upon the basal beds of the Kittatinny limestone or even upon the gneiss in this region. As the shore advanced still farther to the east during Silurian time the red sands and muds of the High Falls and Longwood formations succeeded the gravels of the Shawangunk and Green Pond formations. The Decker limestone, Kanouse sandstone, and Pequanac shale of the Green Pond region indicate a brief period of deeper water and comparative freedom from land sediment, followed by recurrent periods of silts and sands, as the sea grew shallower and the adjoining land was raised again. This change culminated in the accumulation of the heavy beds of sandstone and coarse conglomerate which overlie the Pequanac shale in Bearfort Mountain, just east of this quadrangle, and which are the youngest Paleozoic sediments of the State.

In the upper Delaware Valley, northwest of this quadrangle, there is a somewhat similar although more complicated series of limestones and shales followed by grits and conglomerates indicative of the same general succession of physical conditions. Although at present none of these higher Silurian and Devonian beds are found in the area between Kittatinny Mountain and the Green Pond Mountain belt, they, together with still higher beds, may once have covered that region and have been eroded in post-Paleozoic time.

MESOZOIC AND LATER TIME.

By A. C. Spencer.

Of the time since the Paleozoic sediments were deposited, there is little record in this region. No information is obtainable from sedimentary deposits and the student is limited to the forms of the surface.

The topography of the Franklin Furnace quadrangle is the result of long-continued erosion of the rocky foundation of the district. The various local features may be interpreted in the light of general studies of topographic development extending throughout the Appalachian province. The slightly undulating crest of Kittatinny Mountain and the Highlands plateau are remnants of an old surface of low relief (peneplain) produced by subaërial erosion during late Mesozoic time. If the intervening valleys were filled in, and if this were done with due adjustment to the configuration of the existing remnants, the old lowland surface would be restored, as a gently warped plain somewhat diversified by broad, low knolls. The warping and a slight tilting toward the southeast were incident to continental movements which followed the planation of the surface and which produced a general uplift of the region.

With uplift the streams were quickened into renewed activity and they began again the effort to reduce the land to a condition of low relief. Had sufficient time elapsed since the uplift the existing uplands would have disappeared, and the fact that they still persist affords a rude though striking measure of the relative duration of the early and late periods of erosion in the district. The work of the rejuvenated streams was more effective on the weaker rocks of the central zone than on the stronger rocks of the present uplands, so that the Kittatinny depression has been excavated to a depth of about 600 feet.

The later erosion of the district has progressed by stages, a fact which is deducible from the existence of several broad benches within the Kittatinny Valley. Three of these benches have been recognized in the extension of the valley in New Jersey and Pennsylvania, and each is interpreted as representing an interim between recurrent uplifts whose combined effects have produced the existing elevations of the region.

The oldest lowland surface, that of the Kittatinny and Highlands summits, has been called the Cretaceous peneplain in reference to the period of its development, and the Kittatinny peneplain from the long mountain of that name. It has also been called the Schooley peneplain, from Schooley Mountain, in western Morris County, N. J. The successively younger surfaces have been called the Harrisburg, Somerville, and Millstone peneplains.

Within the Highlands the stages of uplift are not decipherable. Here the main transverse rivers have much steeper grades than the longitudinal rivers of the valley, showing that the resistance of the pre-Cambrian rocks to the downcutting of the streams has been very great. The lower and middle courses of the Highlands streams exhibit deep and rather narrow valleys without noteworthy benches, but the headwater valleys are open meadows merging by gentle acclivities with the ridges that rise to the general plateau level. Having been worked upon by the same agents, the rocks of the valley and of the Highlands afford a very striking illustration of the control of topographic development exercised by rocks of different physical characteristics.

The main features of topography were developed before the region was invaded by the ice of the last glacial epoch, and the movement of the general ice sheet was very largely influenced by those features. The direct effects of the ice mass on the topography were very slight, and the indirect effects, due to the deposition of débris on the melting of the ice, though striking, are in the nature of the case very superficial. These effects are more fully described in the section on glaciation.

ECONOMIC GEOLOGY.

INTRODUCTION.

In the Franklin Furnace quadrangle mining is at present confined to the zinc ores occurring in the property of the New Jersey Zinc Company at Franklin Furnace, and in the pre-Cambrian rocks quarrying is limited to the limestone which is being worked at several points for the manufacture of quick lime and hydrated lime and for blast-furnace flux. It is known that pyrite deposits were worked for the manufacture of copperas during the war of 1812. Iron ores were worked at intervals from the Revolutionary period down to very recent years, and several early forges were operated at Hamburg and Franklin Furnace and along Pequanac River near Stockholm. During the prosperous years of the iron trade between 1890 and 1893 a furnace owned by the Franklin Iron Company was in blast at Franklin Furnace; but this industry was never entirely supported by the products of local mines.

No metals other than zinc, iron, and manganese have ever been mined on a commercial scale, though somewhat extensive explorations were made at one time in the attempt to develop certain occurrences of silver-bearing galena near the Andover iron mines and at a locality 3 miles east of Newton. Graphite occurs locally in the dark gneisses, at a few places in the masses of pegmatite, and very generally throughout the Franklin limestone, but no serious attempt at mining this mineral is known to have been made. Building stone suitable for local uses in the construction of foundations and the like is available everywhere in the areas of gneiss, and any of these feldspathic rocks would be suitable for crushed stone to be used as road metal or ballast. A much better material for the latter purposes, however, is found in the "trap" dikes which occur here and there in the area of crystalline rocks.

IRON-ORE DEPOSITS.

By A. C. Spencer.

No iron mines are now operated within the Franklin Furnace quadrangle, but the mining of iron ore has been an important industry, and it is possible that the future may see a moderate renewal of activity in this direction, inasmuch as there is every reason to suppose that other deposits exist below those which have been worked. The ores are of three sorts—those of magnetite, or magnetic iron oxide; of hematite, or red oxide; and of limonite, or brown hydrous oxide. The following is a list of the mines formerly operated within the quadrangle:

Iron-ore mines formerly worked in Franklin Furnace quadrangle.

MAGNETITE ORES.

Andover group, 4 miles south of Newton.
Ford group, near the High Bridge branch of the Central Railroad of New Jersey, 3½ miles southeast of Sparta.
Ogden group, at Edison, the terminus of the High Bridge branch.
Sherman group, 1 mile southeast of Sparta.
Sickles mine, 3 miles south of Sparta.
Franklin Furnace or Pikes Peak group, extending southwest from the zinc mines at Franklin Furnace.

HEMATITE ORES.

Simpson mine, three-fourths mile southwest of McAfee.
Cedar Hill mine, west of McAfee.

LIMONITE ORES.

Pochuck mine, 1 mile west of McAfee.
Edsall mine, 2 miles east of Hamburg.

The present account of the details of these mines is based largely on existing descriptions in the reports of the New Jersey Geological Survey and the Tenth Census, as none of the mines have been in operation for several years. The distribution of the ore ranges south of Franklin Furnace is shown on the sketch map forming fig. 8.

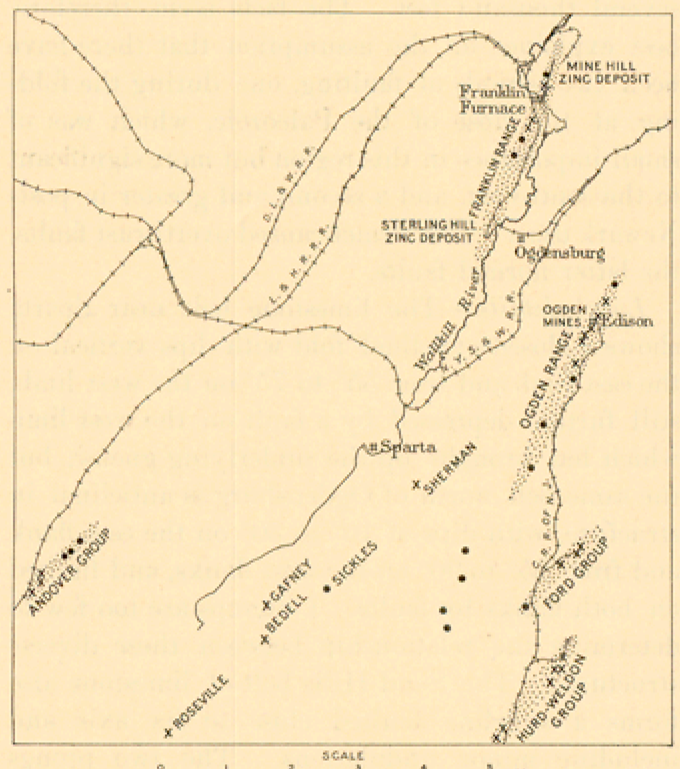


Fig. 8.—Sketch map showing distribution of ore ranges south of Franklin Furnace.
Crosses are mines; dots are prospects.

MAGNETITE ORES.

ANDOVER GROUP.

General outline.—The mines included in the Andover group, known as the Andover, Sulphur Hill, Tar Hill, and Longcore, are located about 4 miles south of Newton and somewhat more than a mile northeast of Andover. The Andover and Sulphur Hill mines have each been large producers; the Tar Hill and Longcore are credited with a small tonnage only. The ground in the vicinity of the openings was carefully explored by the former operators of these mines, and though this prospecting showed a very general distribution of magnetic ore, the outlying deposits were found to be either lean or, if fairly high in iron, too small to permit profitable mining.

The deposits of the Andover group lie in an ore zone perhaps 600 feet in maximum width and nearly 2 miles in length, extending from southwest to northeast along the ridge of gneiss near the extreme northwestern edge of the crystalline rocks in Sussex County. (See fig. 8.) The country gneiss in which they occur has been mapped with the Pochuck type, but in this vicinity the black or nearly black Pochuck rock is accompanied by more than the usual amount of finely granular gneiss (Losee gneiss). The two sorts of gneiss are disposed in parallel tabular masses of varying thickness, and alternation of the dark and light rocks produces a prominent and somewhat regular banding. The ore zone, the separate deposits of ore, and the grain of the gneiss itself all follow the northeast-southwest trend of this banding in the gneiss, and the structures dip toward the southeast at varying but usually steep angles. The gneisses are invaded by pegmatite masses the outcrops of which show a general tendency to follow the banding. Several outcrops of this rock are to be seen near the mines, and it occurs adjacent to the ore in the Sulphur Hill mine. A few narrow plates of white crystalline limestone are known from outcrops in the ore zone, but these probably have no great continuity. Larger masses of lime rock occur in the Andover flux quarry, located a short distance toward the southwest, and similar limestone has been found in some of the mine workings associated with the ore, as may be seen from material in the waste dumps on Tar Hill and at the Sulphur Hill mine. Most of the mine openings show gneiss as the wall rock of the ore bodies, but in the pits of the Andover mine several other varieties of rock occur as the actual matrix of the ore, though these are of relatively small bulk and are inclosed by the ordinary gneiss.

Plans and sections of the Andover and Sulphur Hill mines are given in the 1868 report of the New Jersey Geological Survey.

Andover mine.—The workings of the old Andover mine are situated at the southwest end of the Andover and Tar Hill ore range. The deposit has been worked out along the veins for a distance of approximately 1000 feet and to a maximum depth of about 70 feet. The old excavations show that the principal deposit of ore was of somewhat irregular shape and of variable constitution. The deposit, though similar in a general way to the usual deposits of magnetite in the Highlands, is different in several respects. Not only was the character of the ore distinct from that of the ordinary magnetite, but the mine rock has a very different nature. Layers of siliceous breccia and indurated carbonaceous shale occur in the form of strata having an aggregate maximum thickness of perhaps 100 feet. These rocks contain irregular masses of iron ore, both hematite and magnetite, and mining operations have revealed them in a continuous northeast-southwest band about 1300 feet long. In the southwestern pits the strata stand nearly vertical, but in the northern workings they dip toward the southeast, in some places at an angle as low as 25°. As a whole these apparently sedimentary rocks form a tabular mass conformable with the foliation of the gneisses which inclose them. The presence of coarsely crystalline white limestone in the vicinity suggests that the siliceous beds found at the mine are part of a series of sedimentary rocks belonging with the white limestone of the Franklin region.

The Andover mine was among the first to be worked in the Highlands belt of New Jersey, and previous to the Revolutionary War was noted for the quality of the iron which it produced. The original Andover furnace was built in 1763, and its product was made into refined bars, which were shipped to Philadelphia by way of the Delaware Railway. In 1776 the Andover mines, furnace, and forges were taken possession of and operated by the Continental Congress.[a]

After the close of the Revolutionary War the mines seem to have been abandoned until 1847. In that year they were purchased by Peter Cooper for the Trenton Iron Company, which worked them for a period of about eleven years. The

[a] Lesley, J. P., Iron Mfrs. Guide, New York, 1859, p. 427, footnote.

unusual character of the ore was recognized from its behavior in the blast furnace. Its peculiarity consists in the presence of a considerable amount of manganese, which gave the pig iron a composition favorable for use in the manufacture of steel. Analyses made by P. W. Shimer of old specimens of pig iron from the Andover charcoal furnace and from the anthracite furnace at Phillipsburg are given below.[a]

Analyses of spiegeleisen made from Andover ore.

	Andover.	Phillipsburg.
Graphite	0.101	0.005
Combined carbon	4.529	4.212
Silicon	.037	.294
Manganese	5.75	3.75
Sulphur	.003	.031
Phosphorus	.06	.072
Iron	89.44	91.57
	99.92	99.934

Analyses of slag from the old Andover furnace show from 4.43 to 7.2 per cent of manganese oxide.

The following description of the mine is quoted from the account by Henry Wurtz, chemist in 1854–1856 for the Geological Survey of New Jersey:

The ore bed is embedded in the same kind of rock as the ordinary magnetic iron-ore seams of this region, and bears a general resemblance to them also in configuration and structure, the longer axis of the mass of ore lying in a direction from northeast to southwest, or parallel to the strata of the gneiss rocks of this country, and the walls of the ore bed wherever they are well defined being vertical, or nearly so; but the ore itself is for the most part quite different in its nature, approaching generally more nearly to the constitution of hematite or red oxide of iron. * * * These ores generally contain a much greater proportion of manganese and zinc than the magnetic ores, and usually quantities of these metals which must exert an important influence upon the quality of the iron made from it. There are also associated with this ore bed in various places quantities, more or less great, of minerals containing lead, copper, zinc, and manganese, which are not found at the other mines.

The following description is credited to Richard George, at one time superintendent of the Andover mine:

The open excavation which has been made along the course of the ore deposit * * * is 750 feet in length and from 30 to 60 feet or more in width and variable in depth. At the southwest end the depth of the deposit appears usually to have been small, although in places it increases to perhaps 30 or 40 feet, forming what may be called basins or bowls, formerly filled with ore. There are two or three of these basins in the southwestern portion of the mine, the ore of which has been entirely worked out. Proceeding toward the northwest [northeast] we find another basin of very great size, several hundred feet in length and 85 feet in depth, where the deposit expands to an average width of 65 feet, its maximum width being as much as 75 feet. In this part of the mine also the ore has been mostly worked out, leaving a vast pit, the side walls of which are generally vertical and the bottom very uneven and irregular.

In the bottom of this excavation there are two principal bowl-shaped cavities with a ridge of rock rising between them, the longitudinal direction of which is the same as that of the whole mine. The cavity on the southeast side of this ridge is much the deepest, and the southeast wall of the ore bed, or the hanging wall, as it is called, * * * presents the appearance of a perpendicular precipice 85 feet high at the highest place and 200 or 300 feet in length. Upon the wall is perceived an appearance similar to that described as occurring upon the foot wall at the entrance to the Mount Hope open workings, namely, a marking or furrowing of the face of the rock, the furrows being, however, in this case, unlike those at Mount Hope, very irregular and ill defined. These furrows * * * dip toward the northeast at an angle * * * of about 15° from the horizontal. * * * Some of the furrows visible on the hanging wall are filled with a pulverulent hydrated sesquioxide of manganese.

The immense mass of ore which has been taken out of the great basin above described had a peculiar structure. There are two principal varieties of ores found, known to the miners by the names of "blue ore" and "red ore." * * * The mass of the ore bed presents the general structure of a kernel of the blue ore surrounded by a thick shell of the red ore. Thus on the top the ore is found to be of the red variety, and the same next to the two walls and the bottom of the deposit, while the center is usually of the blue variety.

Passing on to the northeast from the great basin we come to the middle stopes, where the * * * railroad upon which ore is taken to the Morris canal at Waterloo, 7 miles distant, enters the mine. * * * The workings at the middle stopes have reached to some 25 or 30 feet below the level of the railroad, and at this point the ore bed is much narrower than usual. Passing onward to the northeast the workings are no longer open to the sky, but are entered by means of drifts and shafts. They extend about 200 feet beyond the middle stopes, making the whole distance throughout which this ore deposit has been opened nearly 1000 feet. In the extreme northeast workings the width of the ore averages about 30 feet, and the lowest point or deepest part of the whole mine is 50 feet below the railroad. The ore in the northeast stopes approaches more to the condition of magnetite, being in some places identical in appearance with some of the ores of the ordinary magnetic iron seams in Morris County.

In 1858 the deposit was described by J. P. Lesley[a] as being more shaly than previously. The mass above water level is said to have been all oxide of iron, 50 or 60 feet deep. In this ore zinc was scarcely noticed, and the iron made from the ore was particularly pure; but in reaching the plane of underground drainage the heavy sulphurets come in, as in the Polk County mines of Tennessee and elsewhere.

Several analyses of the Andover ore are recorded in Cook's Geology of New Jersey (1868). Of these the following three have been selected for presentation here:

Analyses of Andover iron ore.

	1.	2.	3.
Iron	56.85	46.80	64.65
MnO	.45	19.85	.40
P_2O_5	Tr.	Tr.	.19
Sulphur	Tr.	--------	Tr.
Insoluble	5.80	6.90	2.75

1. Hematite ore, southwest opening.
2. Polaric magnetite from central part of deposit in large mine (blue ore).
3. Magnetite from extreme northeast end of large mine.

Sulphur Hill mine.—The northeast extension of the old Andover mine is generally known as the Sulphur Hill opening. Work was in progress at this place in 1879, when two parallel veins or ore deposits striking northeast and southwest had been opened. The line of strike prolonged to the southwest passes north of the old Andover mine. In 1879 the main excavation on Sulphur Hill was 65 to 75 feet deep, about 30 feet wide, and 100 feet long. Access was had to this pit by means of a tunnel 175 feet long. The ore bodies had a pitch of about 30° NE., the hanging wall being smooth and dipping at a high angle toward the southeast. The second opening, known as the northwest pit, had developed the so-called back vein to a depth of 20 feet. Among the rocks associated with the ore in this mine are mixtures of garnet, calcite, and hornblende apparently derived from the metamorphism of limestone. Material of this sort is inclosed by ordinary gray gneiss, and dikes of pegmatite are present near the ore. In the hanging wall garnet predominates and gives the rock a brownish color. In the plate of rock lying between the two veins galena, pyrite, and chalcopyrite are found, but these minerals are irregularly distributed through the rock and do not form as definite a vein as the iron ore itself. The ore from the Sulphur Hill mine is not only rather lean, but it also contains bunches and seams of iron pyrites and must therefore be roasted before going to the smelter. The mine was finally abandoned about 1880.

Tar Hill mine.—The Tar Hill mine seems to have been worked mainly prior to 1855, though an attempt to develop it was made subsequent to 1873. It is stated that in 1855 there were two large openings, one about 60 feet long and 70 feet wide, and the other about 100 feet long and 10 feet wide.

Longcore mine.—In 1855 there were two small openings on the summit of the ridge about half a mile northeast of the Tar Hill mine. The ore at this place contains a large amount of pyrite. The mine has apparently never been a producer.

OGDEN GROUP.

The Ogden group of mines is situated about 2 miles southeast of Ogdensburg, at Edison, the northern terminus of the High Bridge branch of the Central Railroad of New Jersey. The ore zone in which the mines are located has a maximum width of about 1000 feet, and strong magnetic attraction may be observed almost continuously along the zone for a distance of 2½ miles. Prospecting has been carried on through the whole of this band, but productive mines have been developed only in the portion near the original Ogden mine. The country rock outside of the ore zone is a rather massive gneiss of the microcline and microperthite variety (Byram gneiss). Within the ore zone the same rock occurs, but here it is interleaved with layers of hornblende and mica gneiss, sheets of magnetite ore, both large and small, and stringers or plates of quartz and feldspar forming a pegmatite-like aggregate. Alternation of the layers of different mineral composition and different colors produces a strongly banded effect in the gneiss of the ore zone, which contrasts with the greater homogeneity of the general country rock. At the same time, in view of the poorness of the rock exposures on either side of the orey belt, no sharp line can be drawn between the eminently banded and the less strongly banded gneisses.

The manner in which the magnetite occurs is well exhibited in the abandoned workings, where extensive exposures have been made by the complete stripping off of surface materials during the operations of the New Jersey and Pennsylvania Concentrating Company. The magnetite occurs in both large and small sheets. The larger masses of ore which were worked underground for many years were found to be similar in shape and of comparable size to the ore bodies of many other mines in the crystalline belt, showing the same elongated podlike form, pinching and swelling, southeasterly dips combined with northeasterly pitch, and conformity in attitude to the structure of the inclosing rocks. The three larger mines of the group are said to have worked the same ore shoot, which ranges in thickness from 10 to 30 feet. The ore was mined to a height of 85 to 110 feet, and if actually continuous through the various mines was worked for a length of nearly 1500 feet. In addition to this large ore mass, several smaller bodies were discovered, though none of them have developed into important mines. In general the ore in the smaller shoots seems to have contained considerable feldspar and quartz, and some of it carried noteworthy amounts of pyrite.

In addition to the ore shoots that are of such size as to permit independent mining, minor sheets and bunches of magnetite associated with stringers of pegmatite penetrate the gneiss through practically the whole of the ore zone. So considerable is the amount of this distributed orey material that large masses of the rock are reported to contain 20 per cent of metallic iron. This estimate is, however, perhaps too high, for the same authority states that the rock contains from 10 to 12 per cent of magnetite. The existence of this large amount of iron-bearing material led to the experiments of the New Jersey and Pennsylvania Concentrating Company, extending from 1889 to 1901, during which period many thousand tons of rock were excavated, crushed, and separated.

The ores are moderately low in phosphorus, and some ore of Bessemer grade has been mined. Among the minerals associated with the magnetite are molybdenite and cyanite. Pyrite is irregularly distributed and chalcopyrite occurs, with other copper minerals derived from it by oxidization. Rock thrown thrown out from the northeasternmost prospecting shaft on the ore zone, half a mile or so beyond the Ogden mine, contains magnetite accompanied by apatite in good-sized crystals, garnet in crystalline aggregates or poorly formed crystals, cyanite in long bladelike prisms, and chalcopyrite in irregular blotches. The chalcopyrite shows partial alteration to bornite. These minerals are mixed irregularly through the gneiss, which is composed of feldspar, quartz, and dark-colored mica.

The Ogden mine bears the name of Abram Ogden, who is said to have opened it in 1772. In 1854 mining was in progress and the mine had been opened to a depth of 40 feet. The vein was found to range from 10 to 30 feet in thickness. In the same year workings one-half mile to the southwest, known as the Vulcan mine, had revealed two veins 9 and 10 feet thick. By 1868 the mine had been worked to a depth of nearly 100 feet. The ore shoot was 24 feet thick, and the ore reported as of high grade. Adjoining the Ogden on the northeast the same vein was being worked by the Glendon Iron Company, the ore being similar and from 7 to 10 feet thick. Another mine just southwest of the Ogden was also yielding excellent ore in large amounts.

In 1880 the Ogden mines comprised the Davenport, Old Ogden, Roberts, and Pardee, named in order of position from southwest to northeast. (See fig. 8.) At the Davenport mine the nearly vertical vein had been worked to a depth of 165 feet. The vein was 6 to 8 feet thick at the stope. Previous to being reopened in the winter of 1880 the mine had been idle since 1873. The Old Ogden mine was reopened during the same year, and the Roberts mine had been put in operation in June, 1879. At the latter there were two shafts about 130 feet apart, the northeastern, 270 feet deep, being in use. Stoping was progressing on both sides of the shaft and at a depth of 250 feet, the ore body measuring 15 feet. The Pardee mine had been opened on the same vein as the Roberts to a depth of 300 feet, and the ore body measured 20 feet. The upper part of the Pardee shaft was in rock, as the ore shoot does not outcrop on this property.

In 1883 only the so-called Pardee-Ogden mine was in operation. Stoping had progressed 300 feet northeast of the shaft, and for this distance the ore shoot averaged 14 to 15 feet in width. It was mined to a height of 85 feet. "The ore thins out in the roof or cap rock. The actual limit in that direction is unknown, but in the bottom the ore is removed and there does not seem to be any more at greater depth." The walls of the shoot are nearly vertical, and the bottom of the ore descends slightly toward the northeast.

In 1884 the workings were 375 feet deep and the shoot was carried 110 feet high, no cap rock having been discovered.

The Ogden mines seem to have produced no ore from underground workings since 1884, but in 1889 a tract of land covering a large part of the north end of the Ogden ore zone was obtained by the New Jersey and Pennsylvania Concentrating Company. An extensive plant was erected, including crushing machinery, magnetic ore separators, and briquetting works. The most accessible portion of the ore zone was stripped of overlying soil, along a belt averaging 100 to 200 feet in width and nearly a mile in length. Tracks were laid to several points of attack, and the rock was blasted down and loaded by steam shovels onto cars. Experimental work for perfecting the plant continued until 1901, but the undertaking was never brought to the point of profitable operation. During a test run extending over a period of two months in 1898 a daily production of 200 tons of merchantable magnetite bricks was attained. This product was reported to contain 68 per cent of metallic iron, but an output of 10,000 tons produced during the year 1900 is stated to have shown 62.83 per cent of metallic iron.

FORD GROUP.

The Schofield, Ford, and Dodge mines are located near Ford station, on the High Bridge branch of the Central Railroad of New Jersey. The Schofield shaft on the northeast and the Dodge shaft on the southwest are about one-half mile apart; the Ford workings are adjacent to those of the Schofield mine. Two nearly parallel ore shoots have been worked in each of the mines, and in the Ford and Schofield the ore bodies were in all probability identical, though connection was never made between the workings. The Dodge is on the strike of the other mines, but it is too far away to permit accurate correlation of the veins, though a strong magnetic attraction is said to be present through the whole interval. Along the same line southwestward as far as Lake Hopatcong several prospects have been opened, and near Woodport, at the head of the lake, about 3 miles from the Schofield shaft, a small mine was formerly worked.

The ore zone upon which these mines are located lies midway between the southwestward projection of the Ogden range and the northeastward extension of the Weldon range, the relative positions being shown in fig. 8.

The country rock is not well exposed near the mines, but the rock of the surrounding region is the ordinary Byram gneiss, containing microperthite and microcline as the principal feldspar, with minor amounts of oligoclase. Masses of pegmatite abound, as in the continuation of the same general

[a] Trans. Am. Inst. Min. Eng., vol. 37, 1906, p. 198.

[a] Iron Mfrs. Guide, 1854, p. 427.

Franklin Furnace.

belt of rocks northeastward in the direction of Stockholm. The gneisses are not so strongly banded as those occurring in the vicinity of the Ogden mines, though their foliation can be recognized. The general run of the rock from the mines has a gray, bronzy color and contains more quartz and somewhat more oligoclase than the usual country rock, but in other respects is essentially like it. With the gray rock there are darker phases rather rich in hornblende and locally containing mica, which occur in sheets or tabular masses, as is usual throughout the gneisses of the Highlands region. At the Dodge mine this dark gneiss seems to be more abundant in association with the ore than the light-colored phase. All varieties of the rock have a distinct grain parallel with the banding, and the gneissic structure or foliation is followed by the invading masses of pegmatite. One of these pegmatites showing in the northeasternmost surface workings of the Schofield mine lies near the ore body, and itself contains considerable magnetite in bunches intergrown with coarse crystals of feldspar and aggregates of quartz.

As shipped, after careful sorting, the ore is reported to have carried from 50 to 62 per cent of metallic iron and from 0.01 to 1 per cent of sulphur, with phosphorus above the Bessemer limit. The iron content of each ore shoot is said to have been fairly constant, but the average of different shoots varied as much as 8 or 10 per cent.

The ore bodies conform to the foliation of the inclosing gneiss. From the development of the mines it is apparent that the shoots are thickened portions of practically continuous layers of orey rock. Two shoots worked in the Ford mine were separated by a 22-foot horse of rock in the upper workings of the southwestern part of the mine. Both ore bodies pitched toward the northeast, and with increasing depth in this direction they were found to approach, until at a depth of 250 feet in the northeastern shaft of the Ford mine they came almost together. Farther to the northeast, with greater depth, they were again separated by a plate of rock, and were stoped separately to the bottom of the mine. The drawings of the mine workings (fig. 9) show clearly that the line along which these

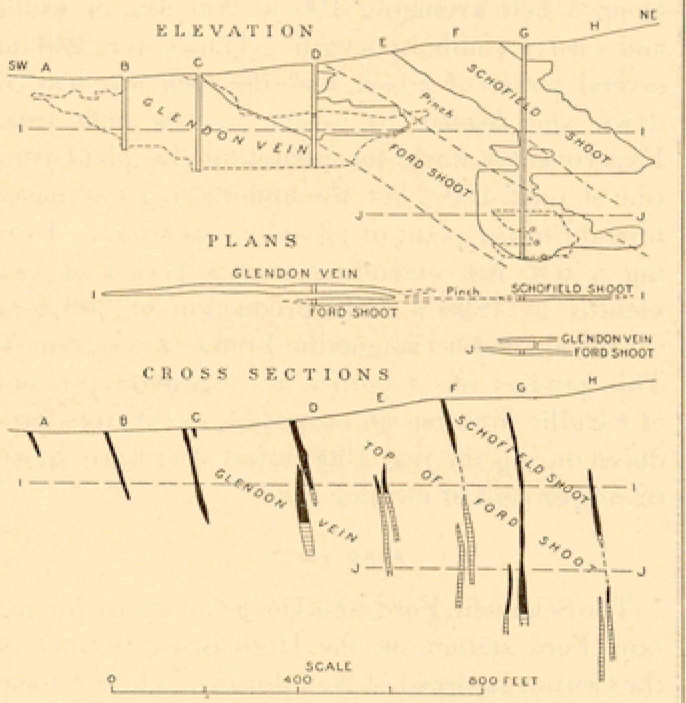


FIG. 9.—Elevation, plans, and cross sections of the ore bodies and workings of the Ford and Schofield mines. In the sections stoped ore is shown in solid black; inferred veins are cross lined.

two veins lie near each other has approximately the same average pitch to the east as the ore shoots themselves and that above and below this line they are farther apart. The shoots were not capped or bottomed by entirely barren rock, as in certain other mines in the State, but the thickness of the ore decreased in the roof and floor, and the veins were not followed where they were thinner than 2 feet. Both the top and bottom edges of the shoots as thus limited were found to descend toward the east, the height of workable ore remaining nearly constant, though showing local variations. The average pitch of the shoots amounts to about 38°. The dip of the foliation in the gneiss parallel to the dip of the ore veins ranges from vertical to about 80°, the steeper inclination being in the lower levels.

The northwest or foot-wall ore layer, known as the Glendon vein, averaged between 9 and 12 feet of workable ore, and the hanging-wall layer, or Ford vein, was somewhat wider.

The Schofield mine was located on an ore shoot apparently on the same vein or ore layer as the Glendon shoot. This shoot was worked from the surface to a depth of 278 feet, and had the usual southeast dip and northeast pitch. It was mined out for a length along the pitch of 400 feet. In the shaft the bottom of the workable ore in the Schofield shoot was encountered at a depth of 86 feet, but 90 feet lower another shoot was struck which proved to be 110 feet high, as measured on the dip. There is every reason to believe that this second shoot is a continuation of the Glendon shoot of the Ford mine. A certain amount of magnetite was doubtless present throughout the interval of 90 feet mentioned above, for, although no statement to this effect is to be found in existing descriptions of the mine, the drawings of the mine workings show small stopes on both sides of the shaft between the two large ore bodies.

In the hanging wall, from 10 to 15 feet distant from the lower shoot, a third body of ore was discovered. A considerable amount of ore was mined from it, but so far as known its top and bottom were never located. This shoot corresponds in position with the Ford shoot and is probably identical with it. It is said that in 1896, when the mine was closed down because of the low price of ore, a large amount of mineral had been developed.

The Dodge mine was worked previous to 1868, when it had been developed to a depth of 130 feet and for 100 feet along the only vein which had then been discovered. The ore body seems to have lain between masses of hornblende gneiss, as this material is more abundant on the waste dumps than at the Ford and Schofield mines. Some of the lean ore is very coarse grained and resembles the ordinary pegmatites of the district, but whether this material is derived from actual dikes of pegmatite or is merely a coarse phase of the magnetite-bearing gneiss is not apparent.

After having been abandoned for several years the mine was reopened in 1880, and two parallel veins separated by 10 to 12 feet of rock were then being developed. These veins are reported to dip to the northwest at a steep angle, but the shoots of ore pitch, as usual, to the east. Although the Dodge workings are nearly half a mile distant from the Ford mine, strong magnetic attraction is reported throughout the interval, and it is likely that the Dodge ore bodies are thickened portions of the same two layers in the gneiss that carry the several shoots developed in the Ford and Schofield mines.

From the above descriptions it it apparent that the mines of the Ford group are by no means exhausted, and it seems entirely possible that they may in the future produce at least as much ore as has already been extracted from them. The strongly defined character of the ore shoots and the apparent persistence of the ore layers in which they occur make it seem very probable that they can be followed profitably to a much greater depth than was reached in the now abandoned mines. Just how far they may be expected to continue can not of course be determined out of hand, but it would seem that the facts warrant further exploration on an extended scale.

If the two parallel shoots in the lower part of the Schofield mine correspond with the two shoots of the Ford mine, as there is every reason to believe that they do, one of them is developed for 1000 feet and the other for 1200 feet along the pitch. For more than two-thirds of these distances they were mined to a width (measured in the plane of dip at right angles to the pitch) of 100 to nearly 200 feet, and found to be perhaps 6 or 8 feet thick on the average. There is ore on both shoots in the bottom of the Schofield mine, and so far as known nothing was found to suggest that either the width or the thickness of minable ore is decreasing. On the contrary, the top of the Ford shoot on the hanging-wall vein shows a distinct flattening in the northeast stope, and this stope has been carried nearly to the probable position of the lower edge of the upper shoot, if this edge continues with its average pitch beneath the floor of the upper stope. It seems, therefore, that this lower shoot should continue for some distance below the present workings. The Schofield shoot has been mined out for a length of 400 feet without narrowing, and it too with very little doubt will hold its own for several hundred feet at least. If it actually continues, it may still contain as much ore above the bottom of the Schofield mine as has been removed from it.

A much longer step into the realm of inference is the suggestion that the Dodge shoots may extend far enough on the pitch to reach beneath the Ford and Schofield workings. The only basis warranting such a suggestion is a comparison with more fully developed localities in the State, where the pinch and swell feature of the veins and the pitch of the ore shoots are always found. The facts determined at the Hurd mine, 2 miles south of Ford, are distinctly favorable to the idea of the persistence of individual shoots. In this mine a shoot was followed and worked out for a length of about 6000 feet on the pitch, and in this distance only minor variations in width were found. Among other striking examples the body of zinc ore at Franklin Furnace may be mentioned as having been developed for a length of more than 3000 feet, and the mines of the Hibernia group, in Morris County, have revealed a continuous vein of ore which extends for $1\frac{1}{2}$ miles and whose limits are still undetermined. In these two localities pinches and swells in the veins, though present, are less prominently developed than in the veins of the Ford group. There can be little doubt, however, that the more nearly continuous veins and those in which the workable ore is gathered into distinct shoots have originated in the same way and are equally likely to extend for long distances. In fact, there is every reason to expect that certain veins containing marked shoots of the ordinary moderate size near the surface may acquire practical continuity in depth, and vice versa, that veins which in shallow workings show no strong tendency to pinch and swell may have this feature as depth is gained.

If the Dodge shoots extend beneath the Ford workings, they lie at a considerable depth, say about 800 or 900 feet, below the bottom of the Ford and Glendon shoots, if we assume the same average pitch as has been determined for these shoots, which is approximately the same as that recorded for the shoots in the Dodge mine. Between the Dodge shaft and the southwestern shaft of the Ford the position of the shoots would lie proportionately nearer the surface, and it is evident that prospecting for the northeasterly continuation of the Dodge shoot should first be undertaken in this part of the belt. The troublesome feature which would attend prospecting with the diamond drill along this ore zone is the nearly vertical average dip of the veins and the fact that the dips vary both ways from a vertical plane. Under these conditions it is evident that ore bodies might readily be missed by vertical holes. Inclined drilling would seem advisable.

SHERMAN GROUP.

The Sherman and Bunker magnetite mines are located about 1 mile southeast of Sparta. There are several openings, though none of any great depth, and the mines have produced but a small amount of ore. They are situated nearly $1\frac{1}{2}$ miles from and 200 feet above the most accessible point on the New York, Susquehanna and Western Railroad. They could also be reached by a spur from the Central Railroad of New Jersey not over $2\frac{1}{2}$ miles in length and with a practicable grade.

The principal workings are on the northeast slope of a prominent hill, but fragments of ore may be found on top of the hill toward the southwest in places where the soil is thin. Examination of the several pits shows that there is no continuous vein or ore, though there is a narrow and somewhat irregular range of lean ore bodies following the foliation of the gneisses. This foliation, though rather obscure, is still determinable, and strikes from northeast to southwest and dips 35° to 50° NW., which is contrary to the general rule of the gneissic structure. The country rock is of the rather dark hornblendic phase of the Byram gneiss, though a band of white Losee gneiss passes just east of the mines.

A large amount of ore is evidently present in this vicinity, but so far as development shows the material is mostly lean, through admixture of the same silicate minerals as are in the inclosing gneiss. Moreover, the bodies of ore seem to be not persistent but very irregular in shape and variable in size. In places the ore grades almost imperceptibly into the wall rock.

The rocks show more than an ordinary amount of jointing, and it is apparent that the original irregularities of the ore layers have been increased by a system of faults across the ore range. Just how troublesome this faulting may prove to be can not be estimated, because the exposures are poor and the developments slight.

Prospecting was in progress during 1904 and 1905, for the purpose of determining the average value of the ore and the size of the ore bodies, with a view to the possibility of concentrating the lean rock.

SICKLES MINE.

The Sickles mine, located 3 miles south of Sparta, was first opened in 1870. In 1873 there were two shafts 150 yards apart. The southwest shaft, 30 feet deep, had developed a body of ore 12 feet thick at the surface but narrowing to 5 feet at the bottom of the mine. In the northeast shaft a 2- to 3-foot vein of rich ore had been opened. "The wall rock near the northeast shaft contains layers or sheets of ore separated by rock."

The mine (probably the northeast shaft) was reopened in 1879 and worked during the following year, and is reported to have produced 2000 tons of ore of Bessemer grade. The width of the vein is said to average 4 feet.

The line of magnetic attraction passing through the Sickles shafts is known to extend northward for some distance, but there has been no extensive exploration in this direction. The rock occurring with the ore is a dark gneiss, presumably a layer inclosed between masses of more siliceous Byram rock. If this is the case, this deposit illustrates a feature of the magnetite veins which, though common in other parts of the State, has not been established for the deposits in the Franklin Furnace quadrangle. This feature is the existence of a so-called "vein rock" accompanying the ore, more or less distinct in appearance from the mass of the country rock.

Much of the ore is coarse grained, and in some of it the magnetite is intergrown with feldspar, forming a sort of pegmatite. This material may be merely a coarsely crystallized phase of the lean ore belonging to the vein, or it may come from invading bodies of pegmatite, several of which outcrop along the strike of the ore veins on a bare knoll a few hundred feet northeast of the old workings.

FRANKLIN FURNACE GROUP.

The magnetite mines belonging to the Franklin Furnace or Pikes Peak group extend in a line southwestward from a point near the Trotter shaft on Mine Hill for a distance of half a mile. Still farther south several prospects have been opened along the same line. Small shoots of magnetite occur beneath the west leg of the zinc vein on Mine Hill, and also beneath the deep workings of the zinc mines, and from the northeast to the southwest the length of the iron range is at least $1\frac{1}{4}$ miles.

There are two distinct and nearly parallel veins of ore, or, more accurately, two layers along which the bodies of ore are distributed, the different shoots in each layer being more or less discontinuous. One of these veins lies close to the contact between the Franklin limestone and the gneiss lying beneath it, the ore occurring, however, for the most part within the gneiss. The second vein lies east of the first, and well within the limestone. The strike of both veins is northeast and southwest, and their dip 50° or so to the southeast, corresponding with the lay of the west leg of the zinc deposit.

The gneiss lying below the white limestone and carrying the lower ore layer has a different appearance from the gneisses usually associated with the iron ore. It is less homogeneous than the ordinary gneisses and there are two distinct elements in its make-up. First, there is a ground or base of dark gneiss, in itself more or less banded, and, second, a filling of light-colored granitic material, usually pegmatitic or coarse grained. This filling has the appearance of having been injected into the older gneiss along a multitude of openings following approximately the foliation of the rock. Though the pegmatite tends to follow the foliation of the older gneiss, it is not only interleaved with plates of the latter but is also crosscutting to a certain extent. On the geologic map the rocks lying immediately west of the white limestone have been represented as belonging to the Pochuck gneiss. Pegmatite is more or less prominent throughout the band, which is nearly one-half mile in width, but the intermixture of the two sorts of rock is most intimate near the boundary with the white limestone. It can not be determined whether or not the folia of pegmatite injected into the gneiss correspond with the larger masses of coarse granite that occur in the white limestone, but it seems natural to regard the two as essentially of the same age.

South of the Wallkill the western vein in the gneiss was worked prior to 1883 for a length of about 1800 feet, one of the shafts being reported in 1879 as 190 feet deep. Mining developed the fact that the ore shoots were separated by pinches, as is common in the magnetite mines of the Highlands, and the pitch of the ore bodies was without exception toward the northeast. The ore from the western vein seems to have been low in iron content, and the magnetite is said to have been mixed to a large extent with hornblende. The materials to be seen on the dumps of the various openings comprise dark gneiss, pegmatite, and white limestone. It is apparent from these rocks and from a few exposures that the vein was situated very near the contact of the gneiss with the limestone. A large variety of garnets of different colors are to be found in the limestone next to the ore, and apparently the magnetite and garnet originated together. The pegmatite is noteworthy because it contains a considerable amount of magnetite and also the mineral allanite in rather large and perfect crystals.

The vein in the limestone was worked by a shaft near the old charcoal furnace in the valley (Furnace mine) and by a slope near the base of Mine Hill, on the opposite or northeast side of the Wallkill (Pikes Peak mine). In 1879 the principal slope in the Pikes Peak mine, standing at an angle of 60°, was 300 feet long. Three northeastward pitching shoots separated by pinches had been developed by horizontal drifts and partly stoped. "The ore bodies show no clean, well-defined walls, but ore and limestone are mixed, and the mining stops where the lattter predominates." In 1880 the ore body in the Pikes Peak mines was being worked in the upper levels 100 feet below the surface. "The ore is concentrated in two bands, the centers of which are about 5 feet apart. On either side of the center of each band the mass gradually grades off from a magnetite with calcite to a crystalline limestone with magnetite, the grains of magnetite always being arranged in lines parallel with the walls of the mine. The width of the stope is from 6 to 8 feet, and perhaps on an average 4 feet of this goes to the furnaces." It is reported that exploration by drifts and with the diamond drill failed to show workable shoots of ore below those developed in the Furnace mine, and in 1881 this mine was abandoned. Southwest of the Furnace mines, near the old Furnace flux quarry, iron ore was discovered in the limestone about 100 feet east of the vein in the gneiss. Here, however, the body of ore was not large enough to pay for mining.

A feature of interest concerning the iron veins is their attitude in reference to the zinc deposit in Mine Hill. The outcrop of the zinc ore forms a bow or hook convex toward the southwest, the two legs of the vein or ore stratum dipping together to form a keel, which pitches to the northeast. The outcrop of the iron vein is parallel to that of the west leg of the zinc vein of Mine Hill, but from the turn of the latter the two diverge and the iron vein keeps a nearly straight course to the southwest, with the same trend as the boundary between the white limestone and the gneiss. The pitch of the iron ore shoots is in the same direction as the pitch of the keel forming the bottom of the zinc-ore deposit. The following analysis is quoted from the report of the Tenth Census:

Analysis of iron ore from Pikes Peak mine.

FeO	14.43
Fe_2O_3	30.69
Al_2O_3	.28
MnO	2.90
CaO	17.63
MgO	7.53
FeS_2	.78
$FeAs_2$	.47
Sb_2S_3	.05
CuS	.03
P_2O_5	.077
CO_2	22.25
SiO_2	1.67
Graphite	.98
H_2O below 100°	.06
H_2O above 100°	.18
	100.007

Franklin Furnace.

The same report contains the partial analyses given below.

Analyses of iron ore from Franklin Furnace group.

	1.	2.
Metallic iron	27.88	33.15
Phosphorus	.045	.033
Sulphur	.267	.439

1. Western vein in the gneiss. 2. Pikes Peak mine.

HEMATITE ORES.

SIMPSON MINE.

The undeveloped property known as the Simpson mine is located about 1 mile southwest of McAfee station. It is located not over 230 yards from the railroad and 100 feet or so above the right of way. From two excavations, about 20 feet deep and about 40 feet apart, several tons of hematite ore were mined many years ago and smelted in the old Hamburg furnace. The ore has a brownish-red color, a metallic luster, and a fine-grained steely texture. Apparently a large proportion of the ore is almost free from foreign materials. It occurs in the form of a bed or irregular deposit from 6 to 10 feet wide, interbedded with layers of sandstone and shaly material, both of which are more or less charged with iron oxide. In the pits the beds are seen to dip to the southeast and to be overlain by white limestone. The bottom of the set of beds which carry the ore is not exposed, but there can be little doubt that there is white limestone beneath them. About 100 yards to the southwest of the openings several masses of ore have been encountered, and it seems that the ore-bearing strata have a considerable extent along the strike. The hill on which the pits are situated is mantled by loose drift, except in a few places, but the overlap of the westward-dipping Hardyston quartzite and Kittatinny limestone probably lies only a few yards west of the hematite deposit.

CEDAR HILL MINE.

About one-third mile east of the Pochuck mine, on the brow of the steep limestone ridge above McAfee station, are two old pits formerly known as the Cedar Hill or Ten Eyck mine. The best exposures are at the northeastern of two excavations about 500 feet apart. Here a stratum of hard green rock about 50 feet thick stands in a nearly vertical position between walls of white limestone. This rock is of a nondescript character and for want of a better name may be termed quartzite. It contains abundant pebble-like but more or less angular fragments of quartz up to about one-fourth inch in diameter set in a matrix of chlorite, and throughout the mass, as seen near the surface, there is considerable red hematite in an amorphous or noncrystalline condition. The pit was opened in such a way as to expose the rock to a depth of about 25 feet, and from a few feet below the surface pyrite is found rather evenly disseminated through the rock. With the pyrite there is considerable siderite, occurring as yellowish crystalline grains of a pearly luster. The hematite, which causes the red color at the surface, has evidently been formed by the alteration of the two iron minerals named.

The sample from this place is reported to contain 31 per cent of iron, but as it is very doubtful if ore of this low grade could be mined the deposit has probably no value.

LIMONITE ORES.

Deposits of limonite, the hydrated oxide of iron, or brown iron ore, were formerly mined on a considerable scale at two localities in the limestone valley northeast of Hamburg.

POCHUCK MINE.

The Pochuck limonite mine, though at one time a large producer, has not been operated for more than thirty years. The old workings are situated about three-fourths of a mile west of McAfee station, on the western slope of a prominent ridge of Franklin limestone lying between the valley occupied by the Lehigh and Hudson River Railway and Pochuck Mountain. The mine is about 200 feet above the railroad, with which it was formerly connected by a tramway. It was worked prior to 1835 and was not finally abandoned until 1876. The locality is mentioned in the first report of the first New Jersey Survey as at that time (1835) giving promise of becoming a rich mine. The following description is condensed from the final report of the first Survey:

This large accumulation of ore occupies the summit and slopes of a narrow ridge * * * extending parallel with Pochuck Mountain. * * * Very little rock is visible in the immediate vicinity of the ore, which exists in the concretionary state embedded in a highly ferruginous clayey loam which displays the utmost variety of color, texture, and composition, being mottled and streaked with clays of all shades, white, yellow, red, and brown. The ore distributed irregularly throughout this mass presents no less diversity of aspect, though it all belongs to one species, denominated brown iron ore. It occurs massive and cellular, and sometimes fibrous, also in a mammillary and botryoidal form, and is often so hard and compact as to require blasting. The workings are generally dry. The earth in some portions of the mine gives evidence of resulting from a decayed feldspar and the other constituents of the adjacent gneiss rock, and contains besides much plumbago in a disintegrated and pulverulent state, clearly indicating that the dissolution of the crystalline limestone has been in part at least the cause of this large accumulation of ore.

The mineral is of excellent quality, yielding a much superior iron to that procured from the magnetic ores of the adjacent primary districts. The facility with which it may be smelted in blast furnaces, compared with the magnetic ore, is another great recommendation. * * *

Though but five or six years in use, this ore has already become rather extensively worked, being not only smelted at a large furnace recently erected near Hamburg, but hauled over the Wallkill Mountain a distance of 12 miles to Clinton Furnace, and a still greater distance to Ryerson's Furnace, near Pompton.

In 1854 the mine had been idle for several years, but the results of the previous operations were reported to have been an excavation 200 yards in breadth and from 60 to 80 feet in depth.

In 1873 the mine was equipped with a hoisting plant, and a gravity tramway was built, giving an outlet to the railroad. Operations continued from that time until 1876. The ore was bounded on the northwest and southeast sides by decomposed gneissic rocks, which appeared to be true walls. These soft rocks continued for over 100 feet in depth and 500 to 600 feet in length.

The Pochuck deposit was classed by H. D. Rogers, whose description is quoted above, with the residual brown ores commonly associated with the blue limestones in many localities in Pennsylvania and New Jersey. These ores he rightly regarded as shallow deposits formed during the gradual and long-continued wasting away of limestone by the accumulation of iron originally disseminated through the limestone itself. The white crystalline limestone was believed by Rogers to be merely blue (Kittatinny) limestone which had been metamorphosed under the influence of igneous intrusions. Near the Pochuck mine both blue and white limestone are found, so that the suggestion of this mode of origin seemed not in itself unlikely for the Pochuck deposit. It is now proved that the white and blue limestones are distinct in age, and detailed study of the areal geology and structural relations of the various formations has placed the Pochuck deposit in a new light. The broader relations of the formations are shown on the areal geology map, and somewhat greater detail is given on the sketch map forming fig. 10.

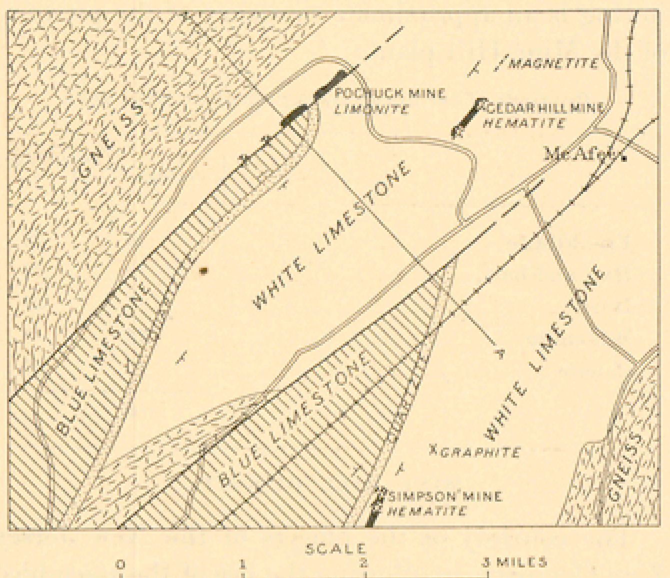


Fig. 10.—Geologic sketch map of vicinity of Pochuck mine and section along line A–A.

The old mines are situated along and near a profound northeast-southwest fault, with the downthrown block on the southeast. On the downthrown side of the displacement a tongue of blue limestone coming in from the southwest extends past some of the old pits, but decreases in width and terminates a short distance south of the main workings. This well-bedded and unmetamorphosed limestone contains strata of limy shale, and is underlain by a thin irregular bed of quartzite. The latter rests upon the coarsely crystalline white limestone which forms the main country rock of the ridge between the mines and the valley at McAfee. The dip of the blue limestone strata is toward the northwest, or in the direction of the fault. At the mines and to the north no rock outcrops appear west of the fault until the slopes of Pochuck Mountain are reached. To the south, however, white limestone outcrops at various points on the westward slope of the hill, and the position of the fault is clearly shown by several prospecting pits extending in a nearly straight line for about 1200 feet southwest of the principal mine opening. Still farther south the fault can be accurately located by outcrops of white and blue limestone no more than 3 feet apart. At the place where the position of the fault is so closely determined no iron ore exists.

The mine openings show that the main body of ore occurred beyond the north end of the blue limestone tongue inclosed in the older crystalline rocks. These rocks comprise white limestone as the principal rock; dikes of pegmatite, evidently intrusive; and layers of light-colored granitoid gneiss, which are perhaps also intrusive into the limestone. The western edge of the white limestone belt is not exposed, but is located somewhere in the northeast-southwest valley at the base of Pochuck Mountain. The layers of gneiss included in the white limestone strike northeast and southwest and stand approximately vertical or are steeply inclined to the southeast. One of them, which has been exposed by the caving of the mine, is perhaps 10 feet in width, and others outcropping a fourth of a mile to the northeast are somewhat wider. The description of the mine by Rogers leads to the belief that the decomposition of similar rock gave rise to the soft earthy material which inclosed the ore.

The more southerly pits have exposed a bed of reddish-brown shale, which lies east of the fault and evidently forms the east wall of the ore. This shale presumably corresponds with the shale strata mentioned above as being interbedded with the blue limestone. Its appearance, however, is quite different from that of the shale exposed on the east side of the fault farther south, for near the mines it shows little evidence of stratification and is impregnated with iron oxide and in places contains minute but abundant scales of graphite. In the same pits are found large masses of sintery quartz rock showing honeycomb or cellular structure. This rock contains flakes of mica and of graphite, and through it here and there are irregular masses of limonite. Limonite also occurs in minute crystals which have the form of pyrite and are evidently derived from the decomposition of that mineral. The presence of this sintery quartz-carrying limonite that can be so definitely proved to be derived from pyrite suggests that the iron ore as a whole may have been originally a deposit of pyrite formed by mineral-bearing waters from a deep-seated source rising along the fault which has been shown to exist. If this suggestion is correct, the Pochuck deposit should be regarded as the decomposed capping of a large body of iron sulphide or pyrite. Alteration of this sort is very commonly observed in the surficial portions of sulphide deposits, and in many instances which might be cited exhaustion of comparatively shallow masses of limonite has been followed by the mining of pyrite, which in some places has been accompanied by chalcopyrite.

Whether or not a body of sulphide minerals actually exists below the workings of the old iron mine can be determined only by actual testing, but the probability seems strongly in favor of the view that the limonite will lead to a deposit of iron pyrite, if followed to sufficient depth. Ferruginous cappings lying above sulphide deposits ordinarily extend downward only to the level of permanent ground water, and at the Pochuck mine this level can hardly lie far below the bottom of the old workings, which, as stated above, were more than 100 feet in depth.

EDSALL MINE.

The Edsall limonite or brown-ore pit is located about 1¾ miles east of Hamburg. In 1840 the excavation was reported to be 140 feet long, 40 feet wide, and 40 feet deep. The ore is said to have occurred in ferruginous gneiss. The locality is near the eastern edge of the white-limestone belt where this rock comes against the gneiss, and it may in fact be situated along this contact, the position of which can not be accurately determined because of the glacial drift which covers bed rock in the vicinity. For this reason no suggestion can be made concerning the nature of the deposit. It may be an accumulation of iron oxide derived from the decay of the adjacent rocks, in which case it would be rather shallow; or, as has been inferred for the deposit at the Pochuck mine, it may be the decomposed capping of a pyrite deposit.

ZINC MINES.

By A. C. Spencer.

HISTORY OF DEVELOPMENT.

Two large bodies of zinc-bearing ore, different in character from any other known ore deposit, occur at Mine Hill, near Franklin Furnace, and at Sterling Hill, near Ogdensburg. Some evidence exists that these deposits had been discovered and prospected prior to 1650, but the earliest authentic record concerning them shows that about 1774 several tons of "red ore" (zincite) were sent to England by a landed proprietor of that period, Lord Stirling.

About 1817 the lands on which the present mines are situated came into the possession of Dr. Samuel Fowler, and in 1822 the first descriptions of the deposit were published by Nuttall and by Vanuxem and Keating. Previously the minerals zincite and franklinite had been analyzed and described by Bruce in 1810 and Berthier in 1819.

About 1838, at the United States Arsenal in Washington, the first metallic zinc made in the United States was reduced from zincite ore furnished by Dr. Fowler to Dr. Hasler, then Superintendent of the Coast and Geodetic Survey. This metal was used in preparing brass for the first set of standard weights and measures ordered by Congress. The ore from which this metal was made came from a pit on Mine Hill which was afterward known as the Weights and Measures opening. The process of reduction employed was too expensive to permit its adoption on a commercial scale, and it was not until about 1860 that the production of spelter from New Jersey ores was placed on a practicable basis.

Experiments made for Dr. Fowler had resulted in the production of a bluish oxide of zinc, which about 1830 he had used as a substitute for white lead in painting his house. Between 1848 and 1860 there was considerable activity in the zinc mines, the ore being then used mainly for the manufacture of white oxide of zinc for use as a paint. During the same period several serious though commercially unsuccessful attempts were made to manufacture a special grade of iron from the franklinite.

At Sterling Hill two superficial basin-like deposits of calamine and smithsonite were mined out about 1875, and underground mining of zincite and franklinite continued until 1900. At Mine Hill extensive operations have been in progress since about 1850.

The treatment of New Jersey zinc ores has presented many difficult problems, the practical solution of which has given the mines their present value. Metallurgical methods now in use were developed mainly before 1860, but in ore dressing the greatest advance came in 1896, with the perfection of the Wetherell system of magnetic concentration.

DESCRIPTION OF THE ORES.

The complex ores of Mine Hill and Sterling Hill are composed of varying proportions of the valuable minerals franklinite, willemite, and zincite, usually mixed with calcite and in places further contaminated by a variety of silicate minerals including garnet, tephroite, and rhodonite (variety fowlerite). In parts of the vein franklinite is the only metallic mineral; elsewhere it is accompanied by both willemite and zincite, or by one of these alone; and in still other places there are layers composed mainly of rounded grains or bunches of zincite set in a matrix of coarsely crystalline calcite. In the great bulk of the ores as mined the minerals occur in the form of dull rounded grains which appear to be corroded crystals. Perfect crystals of willemite and franklinite are found, however, protruding into or inclosed by masses of calcite. Crystal faces of zincite are only rarely to be observed.

The texture of the ore is highly granular, and in much of it foliation is strongly marked. The size of grain varies greatly, but in a given mass the grains of the different components are ordinarily all about the same size.

At Mine Hill the ore (run of mine) has been estimated to contain from 19 to 22½ per cent of iron, 6 to 12 per cent of manganese, and 23 to 29 per cent of zinc. The average of four estimates by different persons is iron 21 per cent, manganese 10 per cent, zinc 27 per cent. Figures giving the metallic content of the Sterling Hill ore have not been published, but it is known to average considerably lower in zinc than the ore from Mine Hill.

The proportions of the various minerals in the Mine Hill ore have been given as follows:

Mineral composition of zinc ore from Mine Hill.

	1. (Ulke.)	2. (Ricketts.)	3. (Ricketts.)
Franklinite	51.92	48.20	51.50
Willemite	31.58	28.10	20.23
Zincite	.52	2.70	6.40
Carbonates	12.67	11.32	10.00
Silicates	3.31	9.50	11.13
	100.00	99.82	99.26

The franklinite, $(Fe,Mn,Zn)O(FeMn)_2O_3$, has been found to contain from 39 to 47 per cent of iron, 10 to 19 per cent of manganese, and 6 to 18 per cent of zinc. Pure willemite $(2ZnO.SiO_2)$ carries about 58 per cent of zinc, but in the ore the mineral has been found to contain iron and manganese to the extent of 1½ to 3 per cent each. The zincite (ZnO) contains about 77 per cent of zinc and, as impurities, about 5 per cent of manganese and iron, principally the former.

As now operated, the Wetherell magnetic concentrators yield from crushed ore three products, known as franklinite, half-and-half, and willemite. The first product, composed mainly of franklinite, is used for the preparation of zinc white, the residuum from this process going to the blast furnace to make spiegeleisen. The half-and-half contains franklinite, rhodonite, garnet, and other silicates, with attached particles of the richer zinc minerals. This product carries somewhat more zinc than the franklinite. It is used for zinc white, but its residuum is too high in silica for the spiegel furnaces. The willemite product consists of willemite and zincite, with calcite and silicate minerals as impurities. The calcite is removed by means of jigs and concentrating tables, leaving material suitable for the production of high-grade spelter free from lead and cadmium. A large part of the waste from the jigs finds use in concrete construction. The dust from the crushing and concentrating plant is collected and used with the other materials for the manufacture of zinc oxide. The following is an approximate summary of the products of the Mine Hill plant:

Products of the ore-dressing plant at Mine Hill.

	Percentage.	Percentage of zinc.
Franklinite	49	22
Half-and-half	12	24
Dust	4	27
Willemite	25	48
Calcite	10	5
	100	

MINE HILL DEPOSIT.

The courtesy of the officers of the New Jersey Zinc Company in allowing the use of the assembled plans of the extensive underground workings has made possible the construction of diagrams which exhibit in clear manner the essential form of the great ore body which lies beneath Mine Hill. (See figs. 11, 12.)

The ore mass is a layer varying in thickness from about 12 feet up to 100 feet or more, bent upon itself to form a long trough with sides of unequal height. The trough lies with its keel pitching in a northerly direction at an average rate of 36 feet per 100 for a horizontal distance of about 2800 feet from the elbow of the hook-shaped outcrop at the south end of Mine Hill. Still farther toward the north it rises at the rate of 16 feet per 100 for 600 feet, to the north edge of the deposit. The west flank rises from the keel at an average angle of about 55° and comes to the surface along the northwest brow of the hill. Its outcrop is about 2600 feet in length, but toward the north its full extent is not seen because the top of the vein is capped by Paleozoic formations. The greatest dip length of the west vein, measured from the surface to the bottom of the trough, about 1350 feet, is on a section near the most northerly outcrop. On either side of this the height of the vein is less. Near the north edge of the deposit its full height, though not yet determined, is probably not more than 1000 feet. Toward the south the height decreases through the gradual rising of the keel. flanks becomes narrower and narrower toward the north until below the 650-foot mine level it is a very thin wedge.

The principal underground workings are those of the Parker mine. The vertical shaft situated east of the deposit extends to the 950-foot mine level, the workings of which are reached by a tunnel about 300 feet long. In this mine the deposit has been almost completely outlined by foot-wall and hanging-wall drifts on levels 50 feet apart from 700 down to 1100 feet. The lowest point in the mine, at the bottom of the ore body, is 1126 feet below the top of the Parker shaft, which is taken for a datum for measures in depth.

The southern part of the 700-foot mine level was worked through the Taylor mine, which is reached from the open-pit workings on the south by a long slope nearly parallel with the pitch of the east vein. On the 650-foot level of this mine the bottom of the keel has been outlined and the west vein developed for several hundred feet. In 1905 connection had not been made with the Parker workings on this level, but a raise on the west vein connected with one of the old Trotter mine slopes at a depth of about 380 feet below the outcrop.

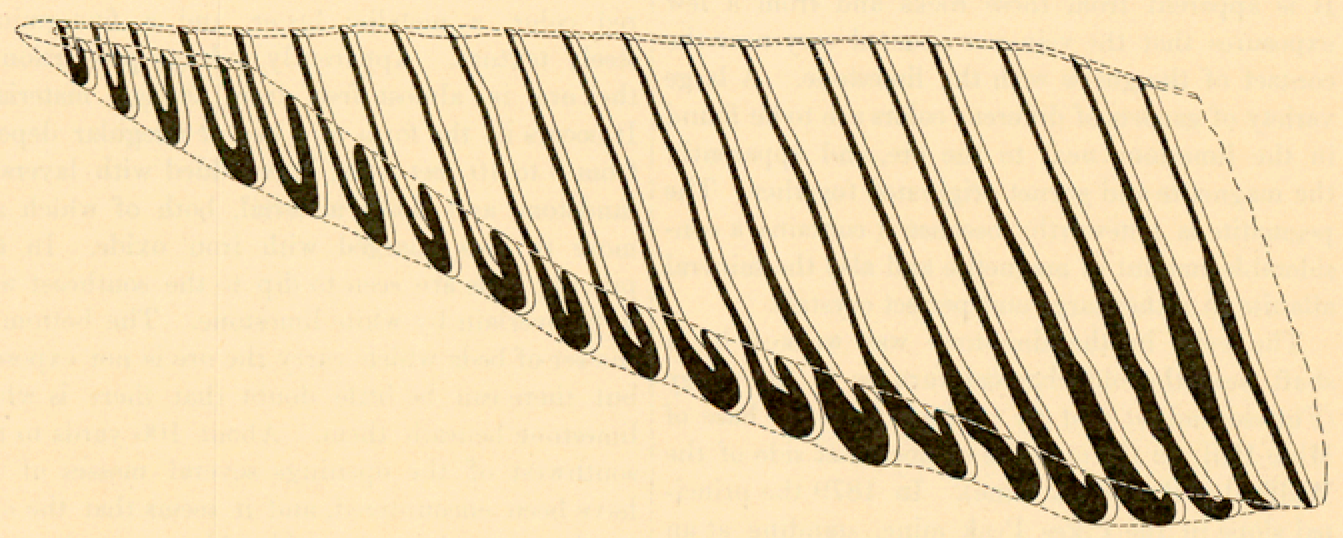


Fig. 11.—Stereogram of Mine Hill ore body.

The east flank has not been fully developed in the underground workings, but enough is known to show that its attitude is somewhat variable. In the lower part of the mine it apparently stands nearly vertical. Farther south it dips strongly to the east and locally lies nearly parallel with the west leg; and still farther south, as its outcrop is approached, it either stands nearly vertical or dips steeply toward the east. This side of the trough appears at the surface for a distance of about 600 feet northward from the elbow where it is joined by the outcrop of the west leg. Its maximum height, about 300 feet, is beyond the north end of the outcrop. Between the elbow and this place its upper part has been eroded away. To the north it is sealed over by an arching cap of the white limestone, and the crest thus formed pitches in nearly the same azimuth as the keel of the trough, though somewhat more steeply, namely, about 60 feet per 100. As a result of this steeper pitch the height of the ore gradually decreases toward the north. On the lowest level of the Parker mine the keel and crest appear to meet, and in the extreme northern part of the 1050-foot level only the west vein exists. Vertical sections across the ore body show that the outer walls come together in a sweeping curve to form the keel of the deposit. Where exposed in the open pit near the elbow, the inner walls meet along a narrower but still an open curve, but underground the rock between the two

In the Parker mine, from the 850-foot down to the 1050-foot mine level, the deposit has been found to pinch out along the strike between 500 and 600 feet north of the crosscut to the shaft, but on the higher levels the edge of the vein had not been reached in 1905. A prominent feature of the deposit is the thickening of the west vein in the vicinity of the keel. Along the bottom of the trough the greatest mass of ore in the deposit is found, and for the most part this ore is of high grade because it contains much willemite and very little calcite. Test holes from the lower levels prove that the ore body is entirely surrounded by barren rock. A vertical hole in the bottom of the mine gave the following section:

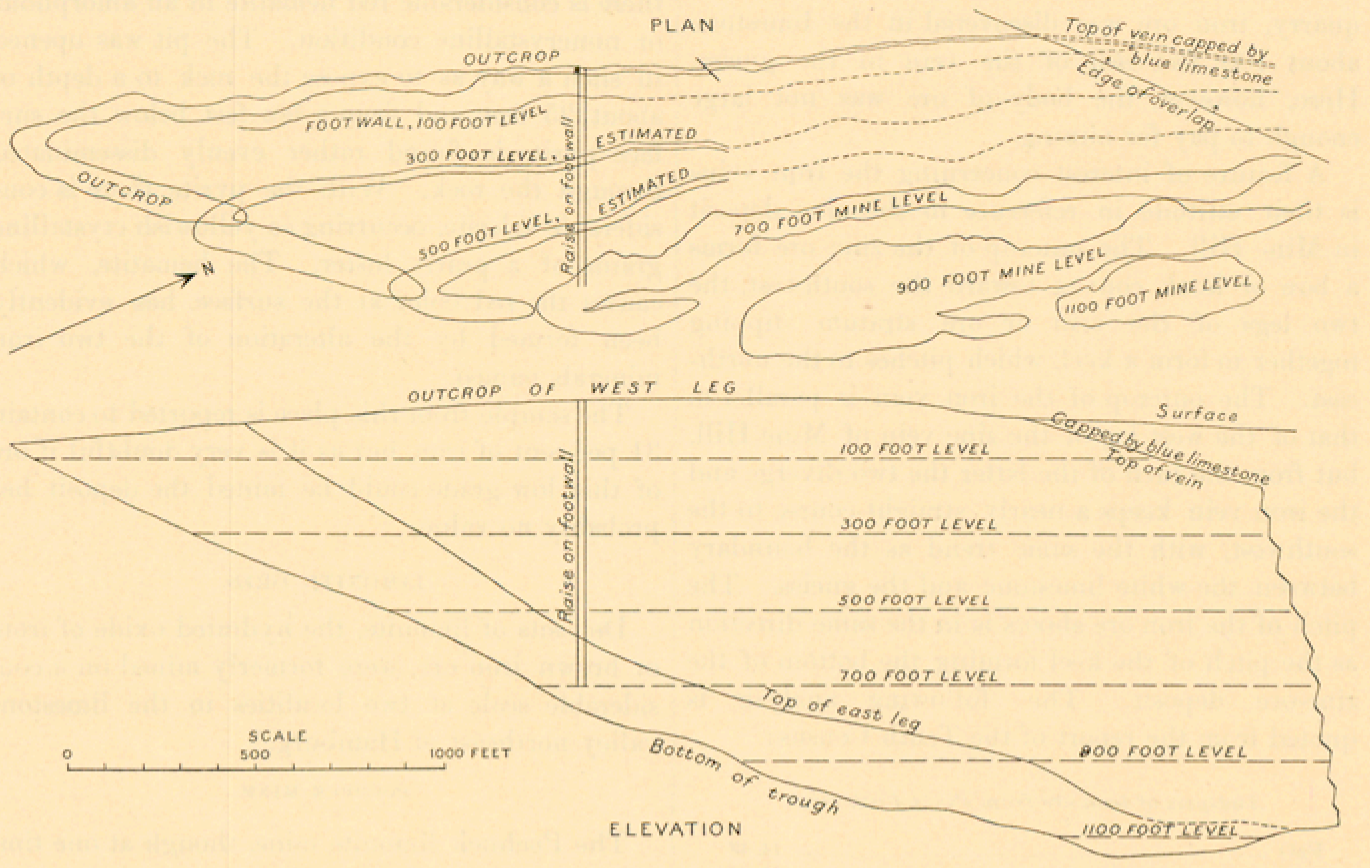


Fig. 12.—Plan of outcrop and levels, and elevation of the Mine Hill ore body.

Section of test hole in bottom of Parker mine.

	Feet.
Limestone	37
Magnetite ore	5
Limestone	24
Garnet and gray rock (gneiss)	5
	71

Wherever the foot wall has been penetrated by the drill, the underlying gneiss has been encountered in about the same relative position as at the surface, but in no one of the several horizontal holes driven from the wall of the east vein into the hanging wall has this rock been found. In this direction there are no other rocks than limestone and injected dikes of pegmatite, from which it is apparent that the parting between the limestone which lies under the ore and the gneiss beneath does not rise parallel with the east leg of the vein, as was at one time supposed.

Interruptions of the ore are produced by some minor faults, by a few irregular injections of pegmatite, and by a diabase dike which crosses both sides of the trough about 600 feet north of the elbow in the outcrop. This dike stands nearly vertical, and is from 15 to 20 feet thick.

Cross sections A–A to D–D, accompanying the economic geology map, illustrate the present conception of the general structural relations of the Mine Hill ore body. Its shape is illustrated by a stereogram in fig. 11. The plan in fig. 12 represents the outcrop and horizontal plans of the ore bodies at 100, 300, and 500 feet below the top of the Parker shaft and on the 700-, 900-, and 1100-foot mine levels. The boundaries of the ore have been fairly well determined on all the mine levels, but above the 700-foot level the outlines have been intercalated except in the neighborhood of the Trotter mine. A longitudinal projection on a vertical plane (also shown in fig. 12) exhibits the pitch of the keel and of the crest of the east vein and the vertical relations of these features to the outcrop of the west vein. The height of the east vein may vary more than has been indicated, as the data on this point are rather meager.

STERLING HILL DEPOSIT.

The Sterling Hill deposit, like that of Mine Hill, is a layer in the form of a trough. (See fig. 13.)

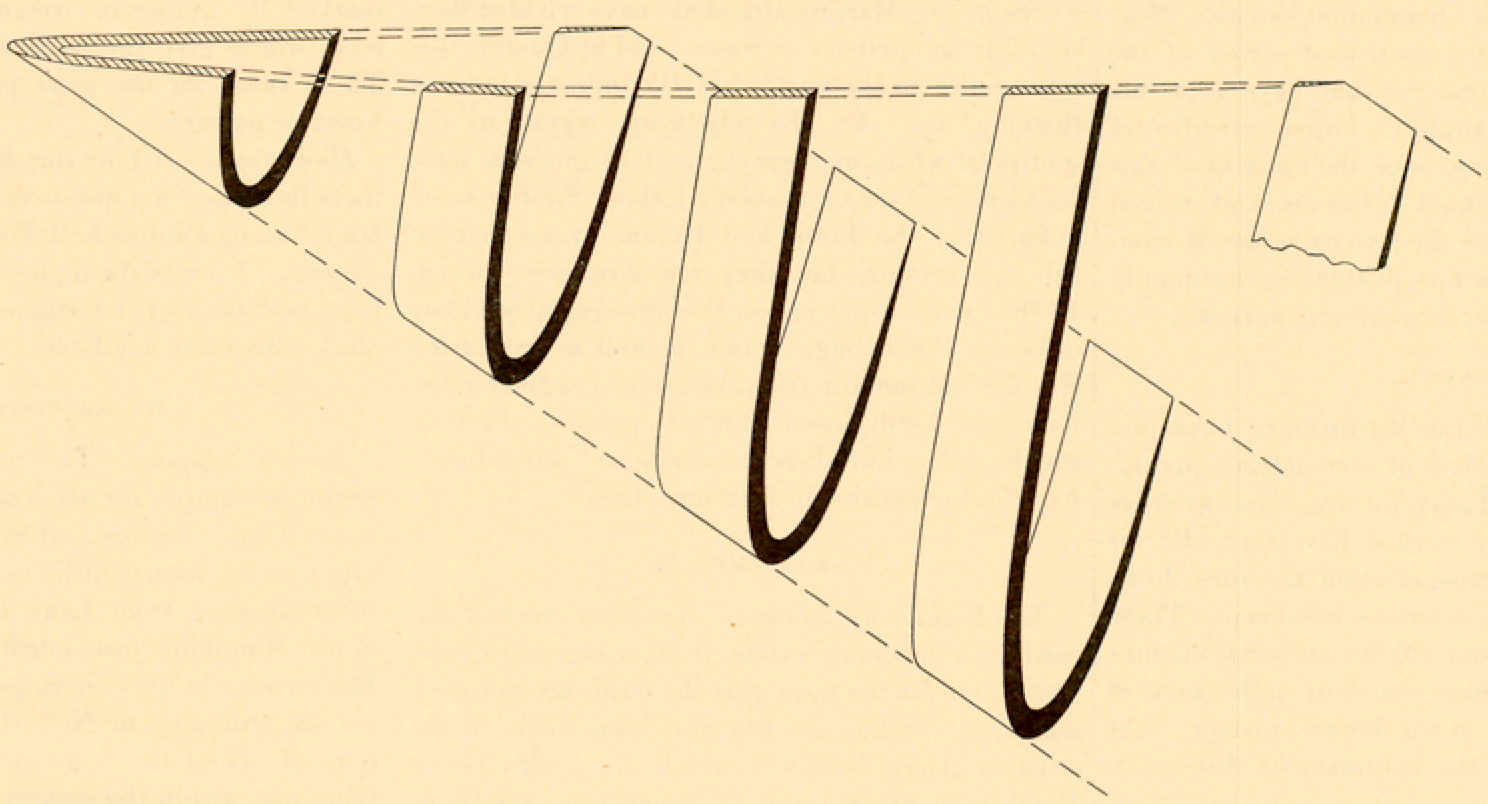


FIG. 13.—Stereogram of Sterling Hill ore body.

The layer ranges in thickness from 10 to 30 feet, and in places it is composed of two parts, one rich in zincite and the other composed largely of franklinite. The sides of the trough, which are of unequal height, both strike in a northeasterly direction, the lower west flank outcropping for about 600 feet, and the higher east flank for about 1500 feet from the sharp elbow at the southwest where they meet. Both veins dip toward the southeast, and the keel of the trough plunges in an easterly direction. Near the surface the west vein dips about 45°. Underground, in different parts of the mine, the east vein, which is the one principally developed, shows dips averaging from 45° to 60°, and from the mine maps it is seen that on each level the inclination of the ore layer becomes gradually steeper as the keel is approached.

In the open pit of the Noble mine, situated within the elbow of the outcrop, the curving surface of the limestone from which the ore has been stripped slopes toward the northeast at an angle of about 50° from the horizontal. This, however, is not the direction of the pitch, the azimuth of which lies more to the east, as may be judged from the general dip of the east vein and from the position of the nearest drifts in the lower part of the Passaic mine. However, because the position of the keel has not been located in any of the underground workings, neither the true direction nor the angle of pitch can be determined.

Each limb of the layer exhibits a feather edge at the northeast end of its outcrop, and it is supposed that these edges plunge into the ground along lines trending more to the east than the strike of the layers. If this supposition is correct, and if the pitch of the edges is about the same as that of the keel, the limbs of the trough may continue to have about the same length on successively lower layers as at the surface. On the accompanying plan (fig. 14) the outcrop and workings are shown, also the estimated position of a horizontal section about 400 feet below the lowest part of the outcrop, on the assumption that the pitch is 45° N. 85° E.

The two cross sections through Sterling Hill (E–E and F–F) which accompany the economic geology map and the three cross sections given in fig. 15, though drawn from incomplete data, illustrate the structural relations of the ore bodies in so far as they are understood. The presence of a great fault running northeast and southwest about 700 feet southeast of the nearest outcrop of the vein indicates that the veins must be cut off on their downward extension if they continue far enough in the direction of dip. The depths at which they meet the fault can not be determine until all the variations in the dip of the veins are known, but an average inclination of 55° for the east vein would give a depth of about 1000 feet at the fault, or a dip length of about 1300 feet, if the plane of the fault stands nearly vertical. This estimate will be increased or diminished if the dip of the fault proves to be toward the southeast or toward the northwest.

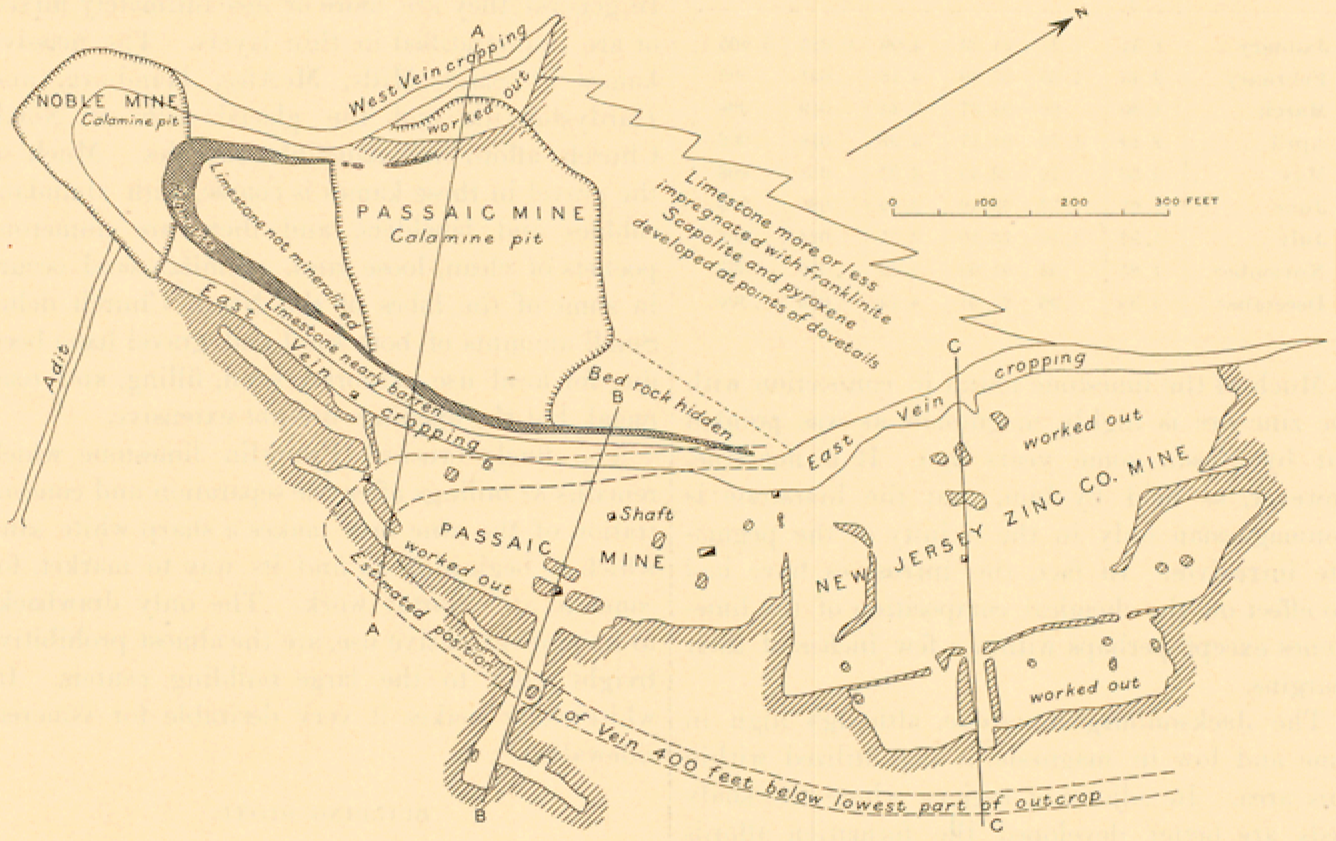


FIG. 14.—Plan of outcrop and workings of the Sterling Hill ore body.

From existing descriptions of the Sterling Hill mines it is known that locally the ore body is divided into layers, one of which, being rich in zincite, has been called the zinc vein, the other, which contains little or none of this rich mineral, being called the franklinite vein. A zinc vein forms the upper part of the east leg of the trough, and another is present on the lower side of the west leg. The zinc vein on the east leg is said to have been from 2 to 10 feet thick. It is not present along the portion of the outcrop near the elbow, and is said to be missing in the lowest levels of the underground workings. Rich masses of zincite, in

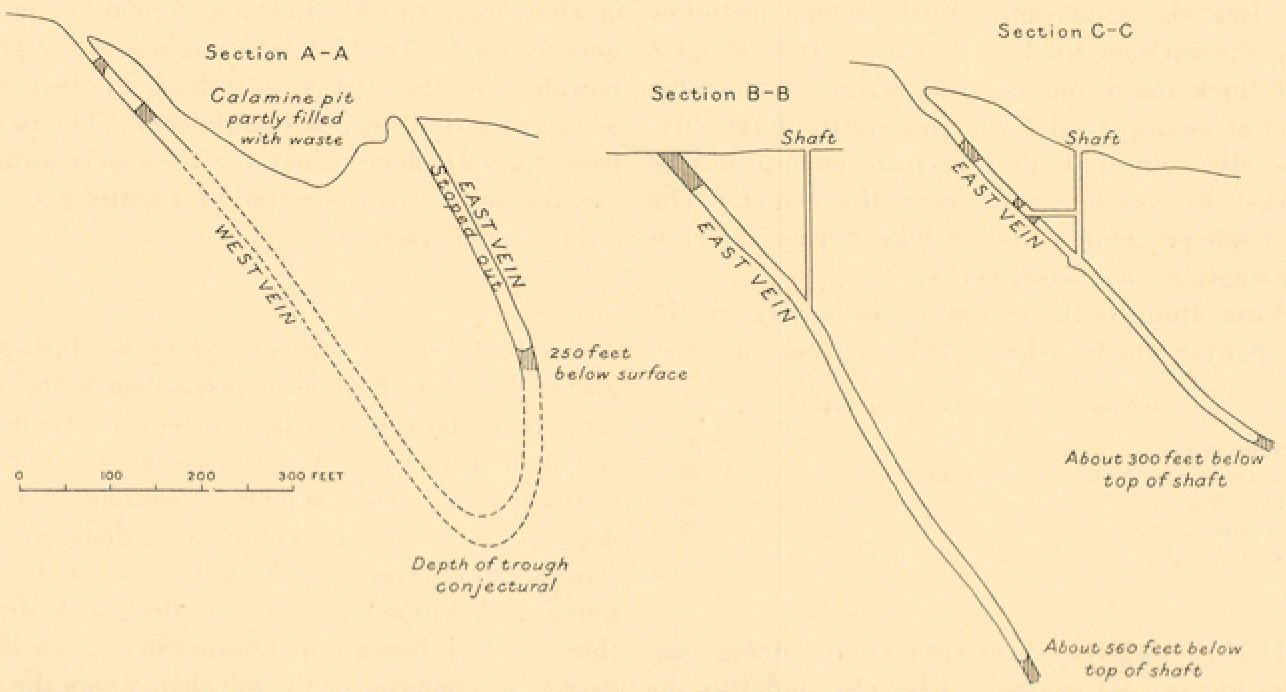


FIG. 15.—Cross sections of Sterling Hill ore body and workings. Location of section lines shown in fig. 14.

the positions stated, may still be seen in pillars near the outcrop of both veins.

In addition to the ore occurring in a distinct layer at Sterling Hill a large amount of franklinite, with more or less intermixed willemite, is distributed through a portion of the rock that lies between the sides of the trough. Within the elbow these minerals are absent, but where the rocks have been exposed on the north side of the open workings of the Passaic mine, and also on the surface above, it may be seen that impregnation of the limestone with zinc-bearing minerals extends from a point near the end of the west vein all the way across to the east vein, giving a mass of lean ore about 250 feet wide though more or less interrupted by streaks of barren limestone. Toward the northeast the mineralization makes out into the country rock in a series of dovetails (see fig. 14) which extend successively farther along the strike as the east vein is approached. From the constitution of the bulk of lean ore, it is thought that the minerals which it contains must have been formed out of materials introduced by solutions of distant origin circulating through the limestone after the trough now followed by the distinct layer of ore had been shaped. Although there is no direct evidence to show whether the ore layer was first deposited and then bent into its present shape, or whether it was formed along a previously folded stratum or fissure, the latter is regarded as the more likely.

NONMETALLIFEROUS RESOURCES.

By H. B. KÜMMEL.

GRAPHITE.[a]

In the New Jersey Highlands graphite, or plumbago, is widely distributed in the white limestone, rather commonly as a constituent mineral in the pegmatite and not rarely in the feldspathic gneisses. The mineral is present in varying amounts in the white limestone, both in the main belt and in the outlying patches within the Franklin Furnace quadrangle, very few outcrops of the rock being entirely free from it. The graphite occurs in brilliant scales or flakes embedded in the calcite of the limestone, and, as is also true of other minerals regarded as impurities, it is much more abundant in some layers than in others. Two of the limestone analyses given on page 3 show the presence of one-fourth and three-fourths of 1 per cent of graphite in samples of the white limestone. In many places the rock contains perhaps as much as 1 to 2 per cent of the mineral, but even such material has offered no inducement for commercial operations, and no attempts to mine and separate it have been recorded. It may be noted, however, that the well-crystallized limestone is easily crushed, and could therefore be treated more cheaply than the highly feldspathic or quartzose rock, in which most of the graphite now mined occurs. For this reason it is clear that with a limestone matrix lower-grade material could be used than is at present worked in other localities.

Graphite has been noted in the pegmatite in rather small amounts near Canistear reservoir, northeast of Stockholm, where the gneisses also contain it. Many bodies of pegmatite inclosed in the white limestone show small amounts of the mineral, and in one locality several of these intrusions in the limestone contain a very good showing of it. These dikes outcrop about a mile south of McAfee, east of the Simpson hematite mine. One opening shows a plastic clay, which has doubtless been derived from the decomposition of a body of pegmatite. Through this clay the graphite is distributed in scales ranging from mere specks up to the size of the thumb nail. The pit has caved so that the solid rock under the clay can not be seen. It seems however that the decomposition can hardly extend to a depth of more than a few feet. Just at the spring, 20 feet or so away, there is an outcrop of pegmatite, but here the rock contains only a small amount of graphite.

A second opening about 100 feet farther northeast is a pit 6 or 8 feet deep, and some of the rock from it has been left on the ground. This material is composed mainly of microcline feldspar and graphite, the former in crystals up to an inch or more across, with the latter lying principally between but also penetrating them. Quartz is the only other mineral noted, and is present in very small amounts. Minute cavities in the feldspar suggest the former presence of a fourth mineral, which has been dissolved away, but the irregular shape of these cavities gives no clue to what this mineral may have been. The graphite rock is strikingly similar to some of the material produced by the well-known mines at Hague, near Lake George, N. Y., and much of it is estimated to con-

[a] The section on graphite is by A. C. Spencer.

tain not less than 5 per cent of graphite and some of it as much as 10 per cent. The work that has been done toward exploring the graphite-bearing dikes at this place has not been sufficient to show how large the deposit may be, and without further development no estimation of their value is possible.

LIMESTONE.

The Franklin limestone is economically the most important of the limestone formations found in this quadrangle. It is extensively quarried near Sparta Junction, Ogdensburg, Franklin Furnace, Hardystonville, Rudeville, and McAfee. Ten or eleven quarries were in active operation during 1907, and their combined output for all purposes was 552,565 tons. From 70 to 75 per cent of the output is used for flux, chiefly in the blast furnaces at South Bethlehem, Pa., and Wharton, Stanhope, Pequest, and Phillipsburg, N. J. About 10 per cent of the output is used in the manufacture of a high-grade white lime.

A manufacturer's analysis of the rock burned for lime is as follows:

Analysis of Franklin limestone burned for lime.

Moisture	0.29
Lime carbonate ($CaCO_3$)	97.08
Magnesia (MgO)	.31
Carbonic acid (CO_2)	.47
Alumina and oxide of iron ($Al_2O_3+Fe_2O_3$)	.56
Insoluble siliceous matter	.81
Loss and undetermined	.48
	100.00

A comparatively small amount is sold to Portland cement manufacturers for use in raising the lime content of their raw mixture. Owing to the variation in the composition of this limestone it has been found difficult to maintain a product uniformly low in magnesia such as is required in the Portland cement industry. This difficulty is rendered greater because it is impossible to differentiate by the eye the rock which contains an excess of magnesia from that which is well within the requirements. In many quarries the variation in composition is so great that a low-magnesia product (under 3 per cent) can not be mined for the prices paid. The requirements for a fluxing stone are much less rigid than those demanded by the cement manufacturers and can be readily met by a larger number of quarries.

Most of the active quarries are situated on steep hillsides where high working faces can be developed and gravity utilized in quarrying and loading. One or two quarries, however, have been sunk to considerable depths below the surface level and hoisting is necessary. The occurrence or nonoccurrence of intrusive rocks (pegmatites, basic dikes, etc.) is a matter of considerable economic importance in the development of quarries, as large masses may seriously interfere with the development of the quarry, and the labor of sorting the rock, where the intrusives are small, may greatly increase the expense. The possibility of the occurrence of such rocks, not only on the surface but anywhere within the formation below the surface, must be recognized, and thorough examination of a property both by surface exploration and by diamond drills should be undertaken before large sums are invested.

There are wide variations in the chemical composition of the Franklin limestone, as shown by the following analyses, which fairly represent the extremes:

Analyses of Franklin limestone.

	1.	2.
Silica (SiO_2)	0.37	0.09
Oxides of iron and alumina (Fe_2O_3 + Al_2O_3)	.30	.85
Calcium carbonate ($CaCO_3$)	98.18	55.28
Magnesium carbonate ($MgCO_3$)	1.20	44.51

1. A single sample 4 feet from a large pegmatite dike 700 yards east of the north end of Franklin Pond.
2. Sample from the Parker shaft of the New Jersey Zinc Company, 450 feet from the surface.

Between these extremes there are all gradations. Many analyses show less than 3 per cent of magnesium carbonate, indicating that much of the rock is low in magnesia, but there are considerable variations in samples from adjacent layers. The following analyses represent the monthly averages of the limestone shipped in 1905 from the Bethlehem Steel Company's quarries at McAfee, amounting to 6000 to 9000 tons per month. They therefore show well the composition of the limestone from that locality when considered in large amounts.

Monthly averages of analyses of Franklin limestone from Bethlehem Steel Company's quarries, McAfee.

	SiO_2.	$Fe_2O_3+Al_2O_3$.	$CaCO_3$.	$MgCO_3$.	S.	P.
January	1.54	1.24	94.23	4.09	0.025	0.005
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

Much of the limestone found in connection with the zinc ore is highly magnesian, as was pointed out by Nason some years ago. It is not true, however, as held by him, that the limestone is nonmagnesian only in the vicinity of the pegmatite intrusives. In fact, the intrusives have had no effect on the chemical composition of the limestones except perhaps within a few inches of their margins.

The Jacksonburg limestone, although high in lime and low in magnesia, is not utilized within this area. In adjoining regions where the shaly beds are better developed the formation affords rock suitable for the manufacture of Portland cement. Here the shaly beds are thin, the formation is steeply inclined, and the outcrop is narrow. The limestone is not, therefore, commercially available.

The Kittatinny limestone, which is almost universally dolomitic, is not at present extensively quarried. Locally, as at Newton, it is used in a small way for rough foundation stone. Near Andover, in the extreme southwest corner of the quadrangle, extensive quarries that have been idle for many years once supplied large quantities of stone for flux. Scattered over the outcrop of this formation are many small openings and ruined lime kilns where, before the extensive use of commercial fertilizers, a few tons of stone were annually quarried and burned for agricultural purposes.

SLATE.

The lower portion of the Martinsburg formation affords black roofing slate of commercial quality. Two miles north of Lafayette are slate quarries which though formerly worked have been idle for many years. Poor transportation facilities, however, have always been a serious handicap. There is a smaller opening from which a moderate amount of slate was taken about one-half mile west of Long Pond and a much larger quarry near Newton, just beyond the boundary of this quadrangle.

CLAY.

The only clay deposits of the quadrangle are those found along the streams or low-lying meadows, and represent either alluvial deposits of the streams or glacial accumulations in local lakes formed during or at the close of the glacial period. A black clay containing much organic matter is dug for common brick at Newton. It is about 8 feet thick and is found at the margin of the large tract of swamp land lying just north of the city. The clay may underlie the entire swamp and be buried by swamp muck near the center. The tract was probably a shallow lake during the closing stages of the glacial period.

Near Branchville occurs a sandy clay of the composition shown below. It has not been utilized.

Analysis of clay from Branchville.

Silica (SiO_2)	80.03
Alumina (Al_2O_3) and ferric oxide (Fe_2O_3)	12.94
Lime (CaO)	.48
Magnesia (MgO)	.36
Water (H_2O)	2.67
	96.48

Highly calcareous clays are present near Ogdensburg but are not worked. Clay also underlies the drowned lands along Wallkill River, but is not commercially available. Near Fuller's mill on Clove River, near Sussex, clay was formerly dug for common brick. There are probably other localities where clays suitable for common brick may be found, but the absence of any extensive local demand and the lack of adequate shipping facilities render these low-grade clays practically valueless at present.

SAND AND GRAVEL.

There are abundant deposits of sand and gravel, particularly along the valleys, within this area. In general they are more or less intimately mixed or are interstratified in thin layers. The massive kames at Sand Hills, McAfee, Hamburg, and Hardystonville and the glacial delta at North Church afford inexhaustible supplies. Much of the gravel in these kames is coarse, with abundant cobbles and bowlders, and there are numerous pockets of clean, loose sand. Similar sand occurs in some of the lobes of the North Church delta. Small amounts of both sand and gravel have been dug for local use as mortar sand, filling, and road metal, but the openings are not extensive.

The finely crushed Franklin limestone which remains as tailings after the separation and concentration of the zinc ores makes a sharp white sand which is beginning to find its way to market, for concrete and mortar work. The only drawbacks to its more extensive use, are the almost prohibitive freight rates to the large building centers. Its white color makes it very desirable for concrete sidewalks.

BUILDING STONE.

No building stone of any importance is produced within this region, owing to the absence of exceptionally valuable grades of stone, the lack of a strong local demand, and the distance of the most available grades from markets and railroads. The Kittatinny limestone, together with the bowlders of the glacial drift, supplies the local demand for rough foundation work. The thin-bedded sandstones in the Martinsburg shale have yielded flagstones from quarries at Sussex and at Quarryville, a few miles to the north, but the industry is not a thriving one. In the adjoining region to the southwest white and gray granitoid gneisses have been quarried near Cranberry Lake. Similar stone is found in the Losee and Byram gneiss belts of this quadrangle, but they are nowhere worked. In the Green Pond region the variegated bowlders of Green Pond conglomerate, as well as those from Bearfort Mountain (Skunnemunk conglomerate), have been locally used with very pleasing effects in rough walls, but these bowlders are exceedingly hard and expensive to split and dress.

ROAD METAL.

The Kittatinny limestone has been crushed and used to a moderate extent in this region as road metal, but for the most part the roads are not macadamized. Some use has also been made of the crushed glacial bowlders, which are chiefly Green Pond and Shawangunk conglomerate, sandstone from the Martinsburg, and in the Highlands the gneisses. At many places within the areas of the Martinsburg shale the broken and partly weathered shale is spread upon the roads. When ground up and compacted this gives fair results, if the bed rock is near enough to furnish a good foundation. Glacial gravel, particularly that composed largely of slate from the Martinsburg formation, is frequently used. In the Highlands region the gneiss bowlders on the surface, as well as the bed rock, when crushed, furnish fair road metal. The narrow basic dikes which occur more or less widely scattered can also supply road material of a better grade but only in small amounts.

SOILS.

The entire region was covered by ice during the glacial period, and glacial deposits mantle the older formations and to a very large extent determine the character of the soil. Nevertheless, as the character of the glacial deposits is more or less closely dependent on that of the underlying rock, there are some significant differences in the soil found on the different rock formations. Where the glacial drift is thin, the rock beneath determines to a much larger degree the character of the soil than where the drift is thick. Except in the wet meadows and swampy areas, all the soils are stony and many of them are very bowldery.

Glacial soils.—The soils on the areas of till are greatly different from those on the areas of stratified or modified drift. The till, where thick, usually gives rise to a stony, clayey soil, more or less bowlder-strewn. The subsoils are in many places calcareous and effervesce freely, particularly along the southeastern side of Kittatinny Valley. On Kittatinny Mountain and the adjacent upper slopes of the Kittatinny Valley huge bowlders of the Shawangunk conglomerate are exceedingly abundant. The slopes of Bowling Green and Green Pond mountains and the adjacent lowlands are likewise encumbered with bowlders of the Green Pond conglomerate. Throughout the Highlands bare ledges are common and the soil is more than ordinarily stony with huge bowlders of gneiss. This region, as well as the mountain ridges previously mentioned, is chiefly forest covered.

The areas of stratified drift have a variety of soils. Locally the surface is loose and extremely sandy. More commonly it is a gravelly loam, there being enough clayey matter mixed with the sand and gravel to make a strong, fertile soil. In many places the sand and gravel is covered by 1 to 3 feet of rich, clayey loam. Practically all the areas of stratified drift are cleared and under cultivation.

Shale and slate soils.—The drift is exceedingly thin or wanting on the crests or slopes of many hills of the Martinsburg shale. In these places the soil is apparently nothing more than the broken disintegrated slate or shale. In reality even in these spots there is considerable fine material mixed with the slate, as is indicated by the vegetation. The area of the Martinsburg formation is largely under cultivation, the forested area being limited to the farm woodlots.

Limestone soils.— Limestone soils in the true sense of the term—that is, soils resulting from the disintegration of the rock—are almost entirely lacking, but in many localities the drift on the limestone hills is exceedingly thin and the surface is marked by numerous irregular, knotty ledges of rock, which give the surface a warty appearance. These areas, for the most part, have been left in forest or pasture.

Humus soils.—Under this designation are included the soils of the "wet meadows, swamps, and drowned lands" along Paulins Kill, Wallkill River, and other streams. Locally the higher portions of these areas have been ditched and drained and their deep, rich, black soils made available.

WATER RESOURCES.

Surface supplies.—The water resources of the region are ample for all demands and the quality is excellent. Newton and Sussex both have public supplies, the former utilizing Morris Pond and the latter drawing from Lake Rutherford, on Kittatinny Mountain just north of this quadrangle. The streams in the eastern portion of the quadrangle are tributary to Newark's water supply, portions of one of the large reservoirs of that supply lying just within the eastern margin. The surface waters of Kittatinny and Wallkill valleys are less valuable as sources of potable water than the mountain lakes and streams, owing to their greater liability to pollution. This danger, however, has not yet become serious.

During a year of average rainfall, amounting to 44.09 inches, the flow of the streams of this region is equivalent to 24.41 inches on the drainage area. This run-off drops to 16.82 inches in an exceedingly dry year, when the rainfall is as low as 31.63 inches. During extreme drought the minimum daily flow per square mile of drainage area, when it is not held back in ponds, may fall as low as 81,000 gallons for streams with ordinary basins and 110,000 gallons for streams with low, flat, drift-covered basins which furnish large ground flow. With adequate storage reservoirs, the streams will yield 669,000 gallons daily per square mile of tributary area.

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 per square mile of drainage area for each foot of fall. 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 twelve hours, the above-stated amount of 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 per year.

At Branchville the outflow from Culvers Pond and Long Pond (Lake Owassa) can be utilized and the former drawn down 7 feet if need be. The minimum available flow at Branchville is said to be 1800 cubic feet per minute, ten hours daily throughout the year, even in severe droughts.

The water powers enumerated in the subjoined table are now or have recently been in use. In addition to these there are numerous other sites either once utilized but now abandoned or where good power can be developed. At Woodbourne and Wykertown there are falls of 40 feet, at Branchville of 13 feet, and at Lafayette of 11 and 12 feet, all of which were formerly in use.

Ground waters.—Springs are abundant throughout the region and ground water of good quality is usually found in shallow wells in the glacial drift. Owing to the abundance and quality of these supplies and the relatively sparse population, very little search has been made for deep-seated waters. Conditions are not favorable for obtaining large supplies of water in the hard-rock formations and so far as they have been penetrated the supply has been very moderate. Bored wells have been sunk at the points shown in the accompanying table.

May, 1908.

Water powers in Franklin Furnace quadrangle.

Stream.	Locality.	Feet of fall.	Gross horse-power developed.
Paulins Kill	Lower Lafayette	$20\frac{5}{6}$	66
Do	do	8	20
Do	Lafayette	27	50
Unnamed tributary of Paulins Kill	Branchville	22	57
Do	do	24	58
Do	do	18	33
Do	do	40	250
Wallkill River	Hamburg	$21\frac{1}{2}$	107
Do	do	$21\frac{1}{2}$	
Do	do	24	78
Do	do	24	
Do	Sparta	18	31
Do	do	11	10
Do	do	21	51
Branch at Decker Pond	Vernon Township	40	30
Do	do	15	24
Papakating Creek	Franklin Township	12	20
Clove River	Sussex	16	40
Do	North Sussex	12	41
Do	do	22	33
Do	Wantage Township	24	40
Do	do	35	48
West Branch of Papakating Creek	Plumbsock	20	60
Do	do	18	52
Beaver Run	Wantage Township	16	24
Do	do	24	60
Branch	Hardystonville	20	60
Do	Ogdensburg	18	25
Do	Lake Grinnell	8	37
Do	do	12	35

Bored wells in Franklin Furnace quadrangle.

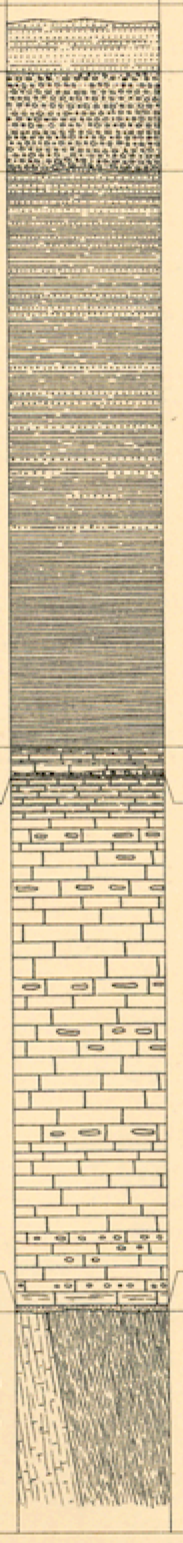
Locality.	Owner.	Material.	Depth (feet).	Yield (gallons per minute).	Remarks.
		Feet.			
Augusta	George Roe	Glacial drift 63; Slate 187	250	15	
Franklin	James May	Limestone	35	(?)	
Hamburg	Reeves Harden	Clay 70; Sand 65	135	20	Water rises within 14 feet of surface.
Do	W. E. Rogers & Co.	Drift 95; Limestone 65	160	20	Water at 95 feet.
Lafayette	Gilbert Ingersoll	Limestone	36	10	
Monroe	J. M. Demerest	Drift 16; Limestone 72	88	6	Water stands within 13 feet of surface.
Mulford	C. C. Cox	Drift 9; Limestone 50	59	15	Water stands 14 feet from surface.
Newton	Jos. Hunt	Drift 7; Slate 49	56	15	
Do	Wm. McCain	Drift 3; Slate 136	139	25	
Do	Wm. Latamore	Drift 12; Slate 65	77	5	
Pinkneyville	C. C. Cox	Sand and gravel	73	12	Water stands 32 feet from surface.
Sparta	do	Sand 15; Limestone 79	94	8	
Do	M. Demerest	Sand and gravel	58	20	
Sussex	Condensed Milk Co.	Drift 22; Slate 12	34	(?)	
Do	John Moore	Drift 6; Slate 59	65	(?)	

Franklin Furnace.

COLUMNAR SECTIONS

GENERALIZED SECTION FOR THE FRANKLIN FURNACE QUADRANGLE.

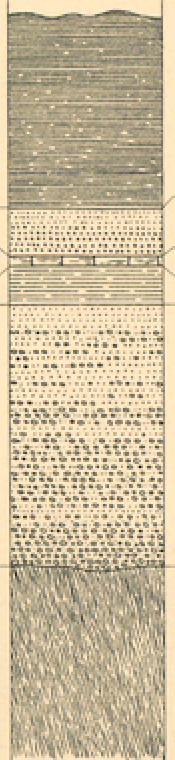
SCALE: 1 INCH = 1000 FEET.



System.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.
SILURIAN	High Falls formation.	Shf		400+	Hard red quartzitic sandstone and softer gray sandstone and red shales.
SILURIAN	Shawangunk conglomerate.	Ss		1500–1600	Coarse quartzite and conglomerate of small white quartz pebbles, reddish in color toward the top.
	UNCONFORMITY				
ORDOVICIAN	Martinsburg shale.	Om		3000±	Fine black shale, slates, and sandstone. The sandstones are dark to bluish gray, in part calcareous, and most numerous in the upper portion of the formation.
ORDOVICIAN	Jacksonburg limestone.	Oj		135–150	Dark fossiliferous limestones and shales; limestone conglomerate at the base.
ORDOVICIAN / CAMBRIAN	Kittatinny limestone.	ЄOk		2500–3000±	Massive-bedded bluish-gray magnesian limestone containing layers of black chert and oolite. Shales and interbedded thin limestones at the top and at the base.
CAMBRIAN	Hardyston quartzite.	Єh		5–30	Arkosic quartzite, in places conglomeratic.
	UNCONFORMITY				
PRE-CAMBRIAN	Byram, Losee, and Pochuck gneisses and Franklin limestone.	bgn lgn pgn fl			Gneisses of both sedimentary and igneous origin, composing the basement upon which the Paleozoic sediments were deposited.

GENERALIZED SECTION FOR THE SOUTHEAST CORNER OF THE FRANKLIN FURNACE QUADRANGLE.

SCALE: 1 INCH = 1000 FEET.



System.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.
DEVONIAN	Pequanac shale.	Dpq		1000±	Dark thick-bedded shale, somewhat sandy toward the top.
DEVONIAN	Kanouse sandstone.	Dk		215	Fine-grained white quartz conglomerate, with greenish sandstone above.
SILURIAN	Decker limestone.	Sd		50	Dark-gray impure siliceous and shaly limestone.
SILURIAN	Longwood shale.	Sl		200±	Soft red shale.
SILURIAN	Green Pond conglomerate.	Sgp		1500±	Coarse siliceous conglomerate, interbedded with and grading upward into quartzite and sandstone.
	UNCONFORMITY				
PRE-CAMBRIAN	Byram and Losee gneisses.	bgn lgn			Gneisses of both sedimentary and igneous origin, composing the basement upon which the Paleozoic sediments were deposited.

TOPOGRAPHY

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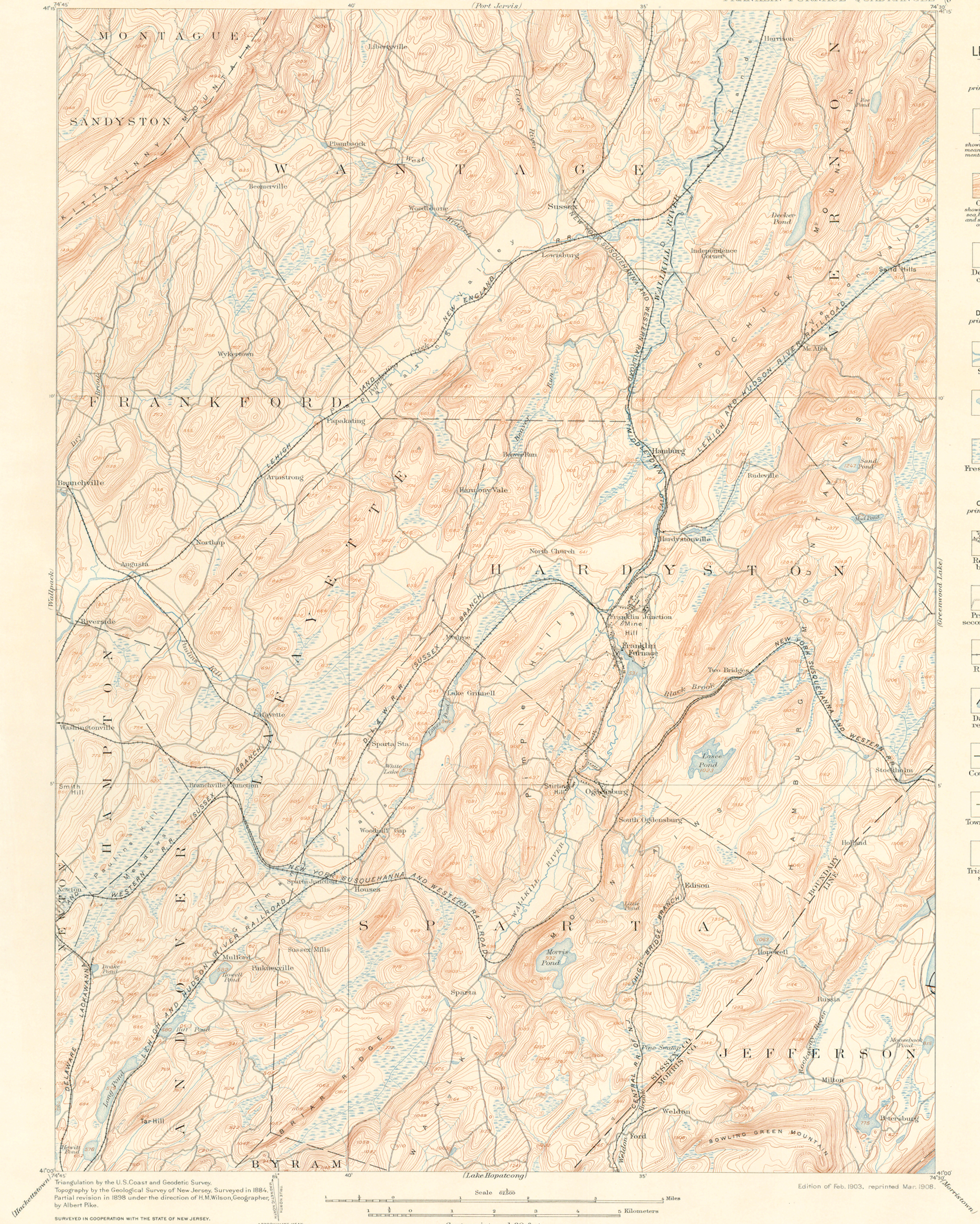
STATE OF NEW JERSEY
HENRY B. KÜMMEL
STATE GEOLOGIST

NEW JERSEY
FRANKLIN FURNACE QUADRANGLE



LEGEND

RELIEF
printed in brown

Figures
showing heights above mean sea level instrumentally determined

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

Depression contours

DRAINAGE
printed in blue

Streams

Ponds

Fresh marshes

CULTURE
printed in black

Roads and buildings

Private and secondary roads

Railroads

Dams and reservoirs

County lines

Township lines

Triangulation stations

Triangulation by the U.S.Coast and Geodetic Survey.
Topography by the Geological Survey of New Jersey. Surveyed in 1884.
Partial revision in 1898 under the direction of H.M.Wilson, Geographer, by Albert Pike.

SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{62500}$

1 0 1 2 3 4 Miles

1 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Feb. 1903, reprinted Mar. 1908.

SURFICIAL GEOLOGY

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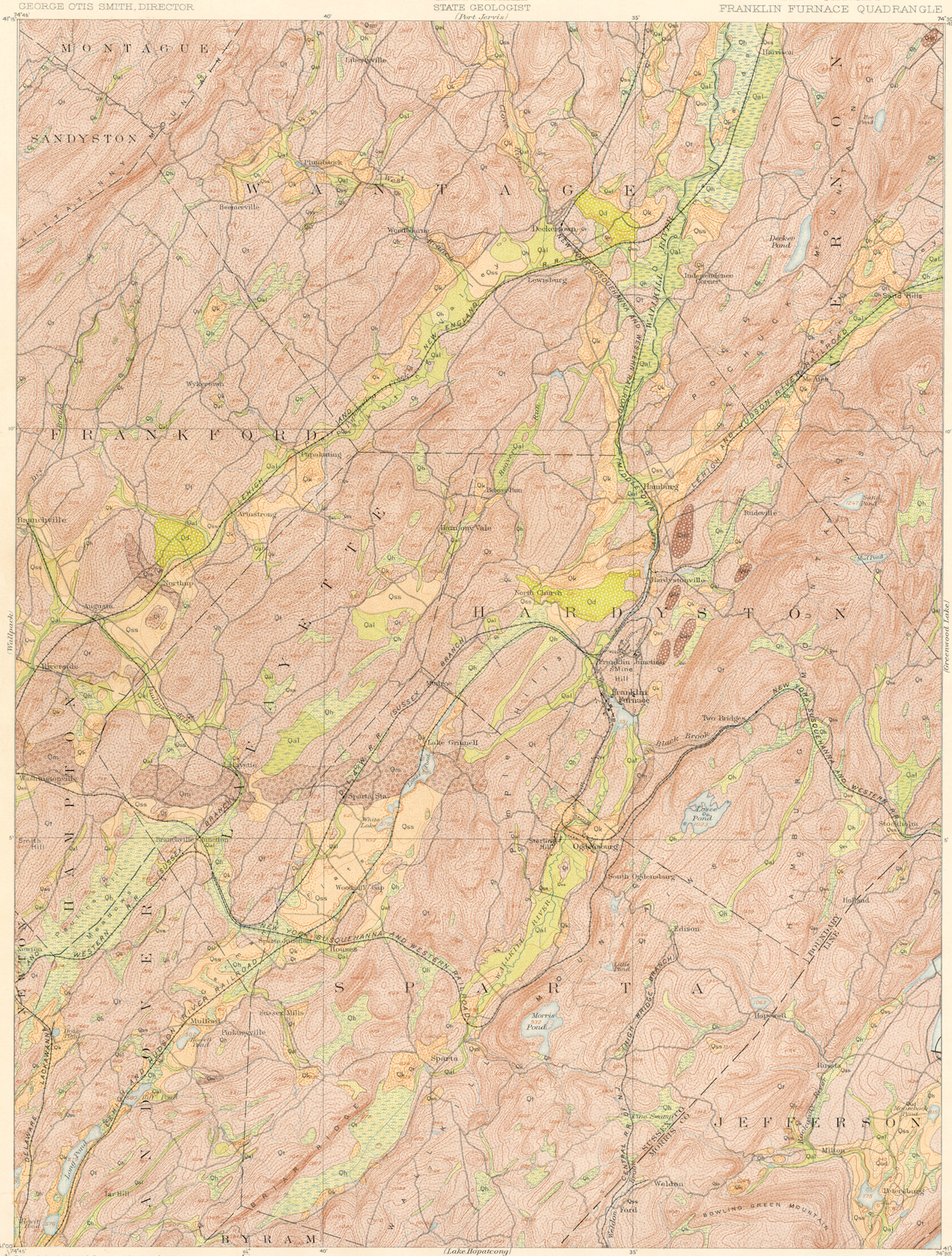
NEW JERSEY
FRANKLIN FURNACE QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of subaerial deposits are shown by patterns of dots and circles)

QUATERNARY

Recent

- Qh — Humus *(peat, more or less mixed with silt, accumulated in marshes)*
- Qal — Alluvium *(in the valleys of sluggish streams)*

Wisconsin Stage of Pleistocene epoch

- Qd — Deltas or subaqueous outwash *(chiefly sand)*
- Qss — Stratified sand and gravel
- Qk — Kames and kame terraces *(includes stratified drift with topography indicating the presence of ice during deposition)*
- Qm — Recessional moraine *(includes patches of kame moraine)*
- Qud — Unclassified drift
- Qdr — Drumlins *(possibly rock ridges veneered with till)*
- Qt — Till *(includes areas where there is little drift)*

Triangulation by the U.S. Coast and Geodetic Survey.
Topography by the Geological Survey of New Jersey.
Surveyed in 1884.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.
Edition of Mar. 1908.

Geology by Rollin D. Salisbury, assisted by Henry B. Kümmel and Charles E. Peet.
Surveyed in 1894–95.

SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY.

AREAL GEOLOGY

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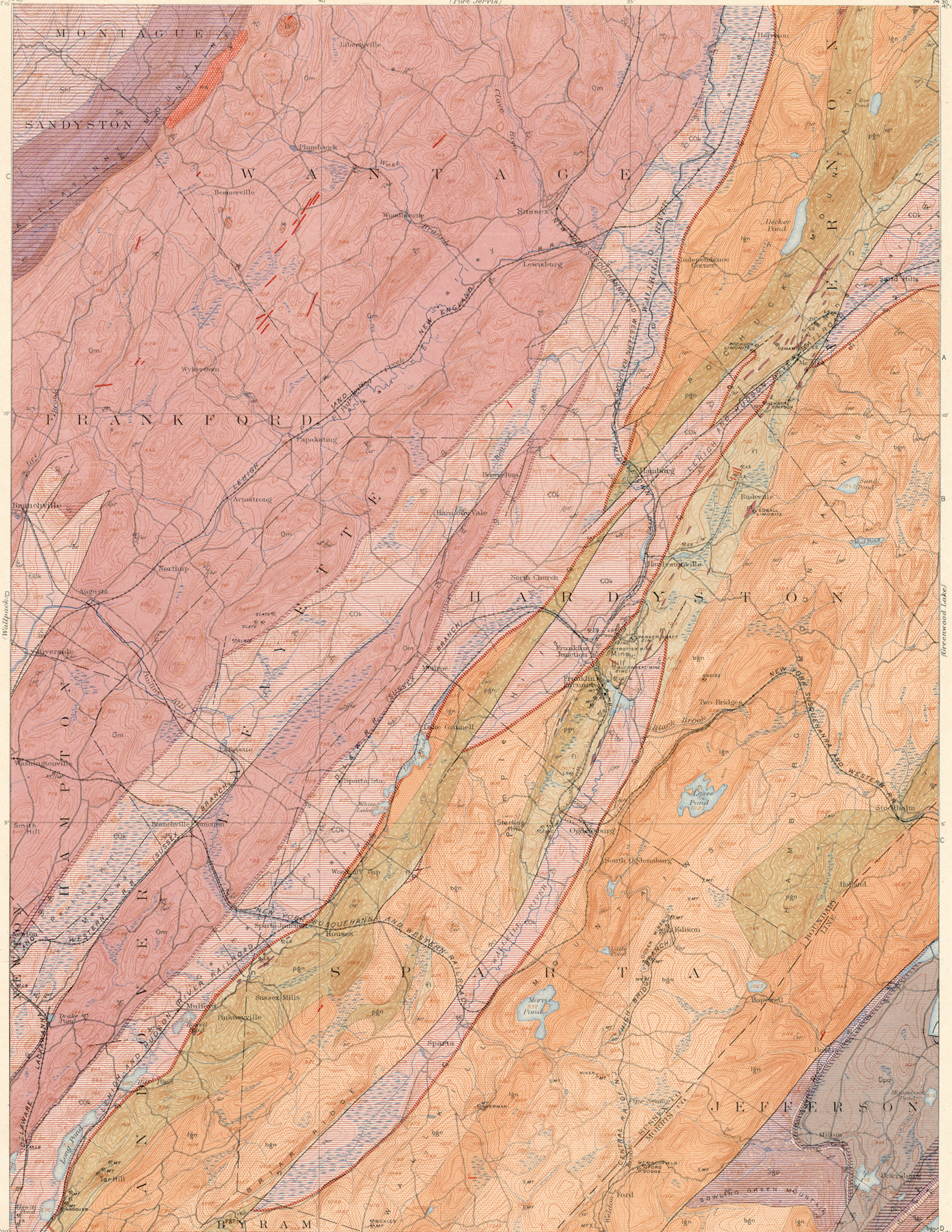
NEW JERSEY
FRANKLIN FURNACE QUADRANGLE

(Port Jervis)

(Goshen)



(Hackettstown)

74°45' 41°00' 40' (Lake Hopatcong) 35' 74°30' 41°00'

(Passaic)

Triangulation by the U.S. Coast and Geodetic Survey.
Topography by the Geological Survey of New Jersey.
Surveyed in 1884.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.
Edition of May 1908

Geology by Henry B. Kümmel,
Arthur C. Spencer, and Stuart Weller.
Surveyed in 1892-1901 and 1905.

SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY

LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines)

DEVONIAN

Dpq — Pequanac shale *(black fissile shale or slate)*

Dk — Kanouse sandstone *(light-colored sandstone or quartzite)*

SILURIAN

Sd — Decker limestone *(dark-gray impure limestone)*

Shf — High Falls formation *(red sandstone and shale)*

Sl — Longwood shale *(red shale)*

Ss — Shawangunk conglomerate *(white quartzitic conglomerate)*

Sgp — Green Pond conglomerate *(conglomerate and quartzite)*

UNCONFORMITY

ORDOVICIAN

Om — Martinsburg shale *("Hudson shale," shale, slate, and sandstone)*

Oj — Jacksonburg limestone *("Trenton limestone," dark-blue or black, massive and shaly limestone, "cement rock," with limestone conglomerate at base)*

CAMBRIAN

€Ok — Kittatinny limestone *(blue limestone, often magnesian, with occasional cherty layers)*

€h — Hardyston quartzite *(vitreous, ferruginous, calcareous, and in part feldspathic)*

UNCONFORMITY

PRE-CAMBRIAN

Metamorphic

fl — Franklin limestone *(coarsely crystalline, roughly foliated, white limestone (marble) containing graphite, chondrodite, pyroxene, and other accessory minerals)*

IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs)

POST-ORDOVICIAN

Dikes *(mostly basic, including nephelite tinguaite, leucite tinguaite, and camptonite)*

bb — Basic breccia *(ouachitite, inclosing numerous fragments of slate, limestone, and gneiss, filling old volcanic necks)*

ns — Nephelite syenite *(intrusive mass of gray coarse to fine-grained rock)*

PRE-CAMBRIAN

pt — Pegmatite *(coarse, obscurely foliated granite, mainly quartz and feldspar)*

gr — Granite *(coarse-grained, rudely foliated, hornblende granite, rich in zircon, titanite, and allanite)*

bgn — Byram gneiss *(gray granitoid gneiss, composed of microcline, microperthite, quartz, hornblende or pyroxene, and sometimes mica)*

lgn — Losee gneiss *(white granitoid gneiss, composed of oligoclase, quartz, and occasionally orthoclase, pyroxene, hornblende, and biotite)*

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

(Areas of metamorphic rocks of unknown origin are shown by patterns of short dashes)

PRE-CAMBRIAN

pgn — Pochuck gneiss *(dark granular gneiss, composed of hornblende, pyroxene, oligoclase, and magnetite)*

Faults

Strike and dip of sedimentary rocks
Strike of vertical beds
Horizontal stratified rocks
Strike and dip of foliation or cleavage
Strike of vertical foliation or cleavage
Quarries and mines
Prospects
MT *Magnetite*
LS *Limestone*

STRUCTURE SECTIONS

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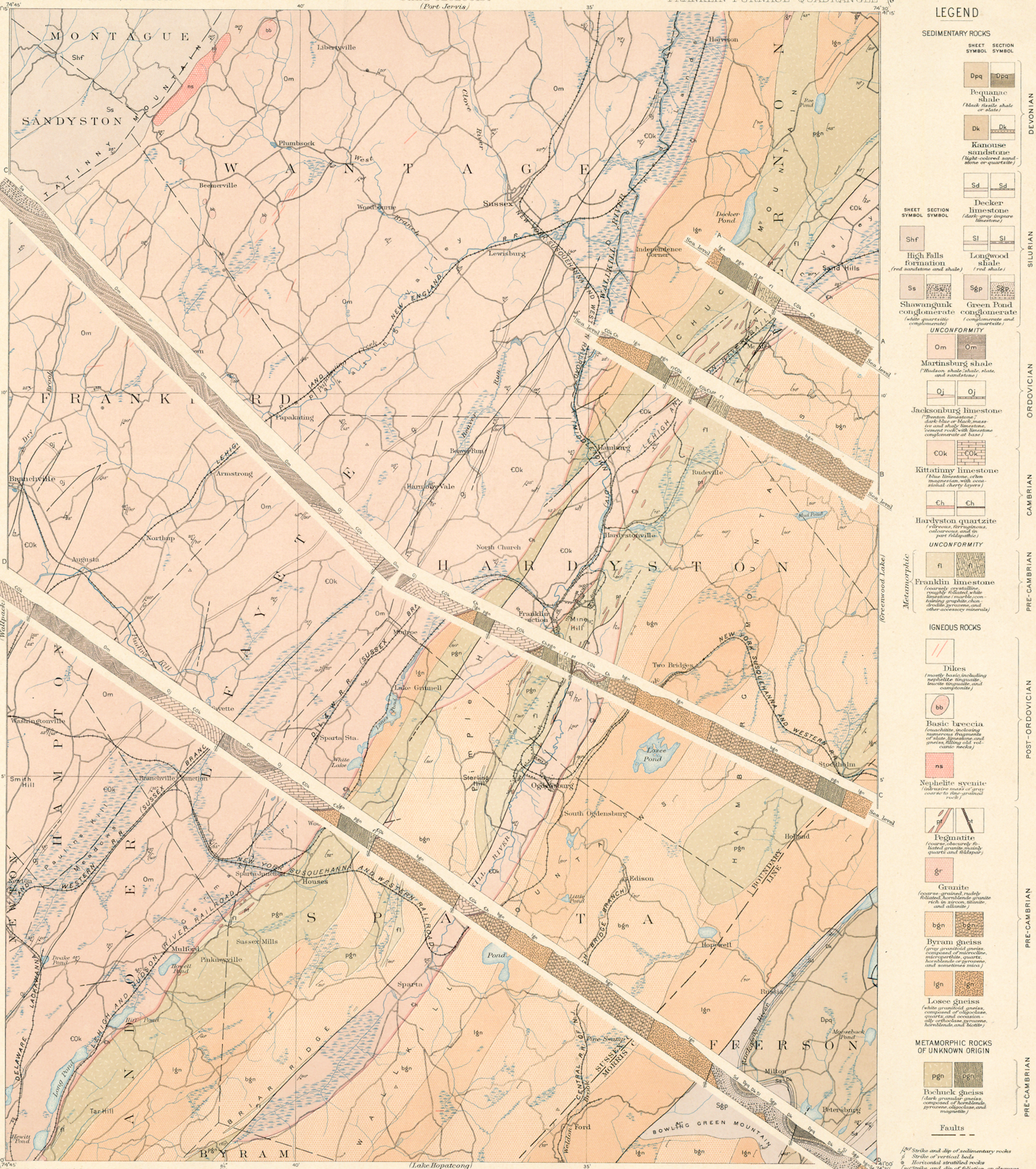
STATE GEOLOGIST

NEW JERSEY
FRANKLIN FURNACE QUADRANGLE



Triangulation by the U.S. Coast and Geodetic Survey.
Topography by the Geological Survey of New Jersey.
Surveyed in 1884.

Scale 1/62500

Edition of May 1908.

Geology by Henry B. Kümmel, Arthur C. Spencer, and Stuart Weller.
Surveyed in 1892-1901 and 1905.

SURVEYED IN COOPERATION WITH THE STATE OF NEW JERSEY

U.S. GEOLOGICAL SURVEY
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TOPOGRAPHY

NEW JERSEY
(SUSSEX COUNTY)
FRANKLIN FURNACE SPECIAL MAP

H.M. Wilson, Geographer in charge.
Topography by Albert Pike.
Surveyed in 1898.

APPROXIMATE MEAN DECLINATION 1907.

Scale $\frac{1}{14400}$ or 1 in. = 1200 ft.

Contour interval 10 feet.
Datum is mean sea level.

Edition of Mar. 1908.

ECONOMIC GEOLOGY

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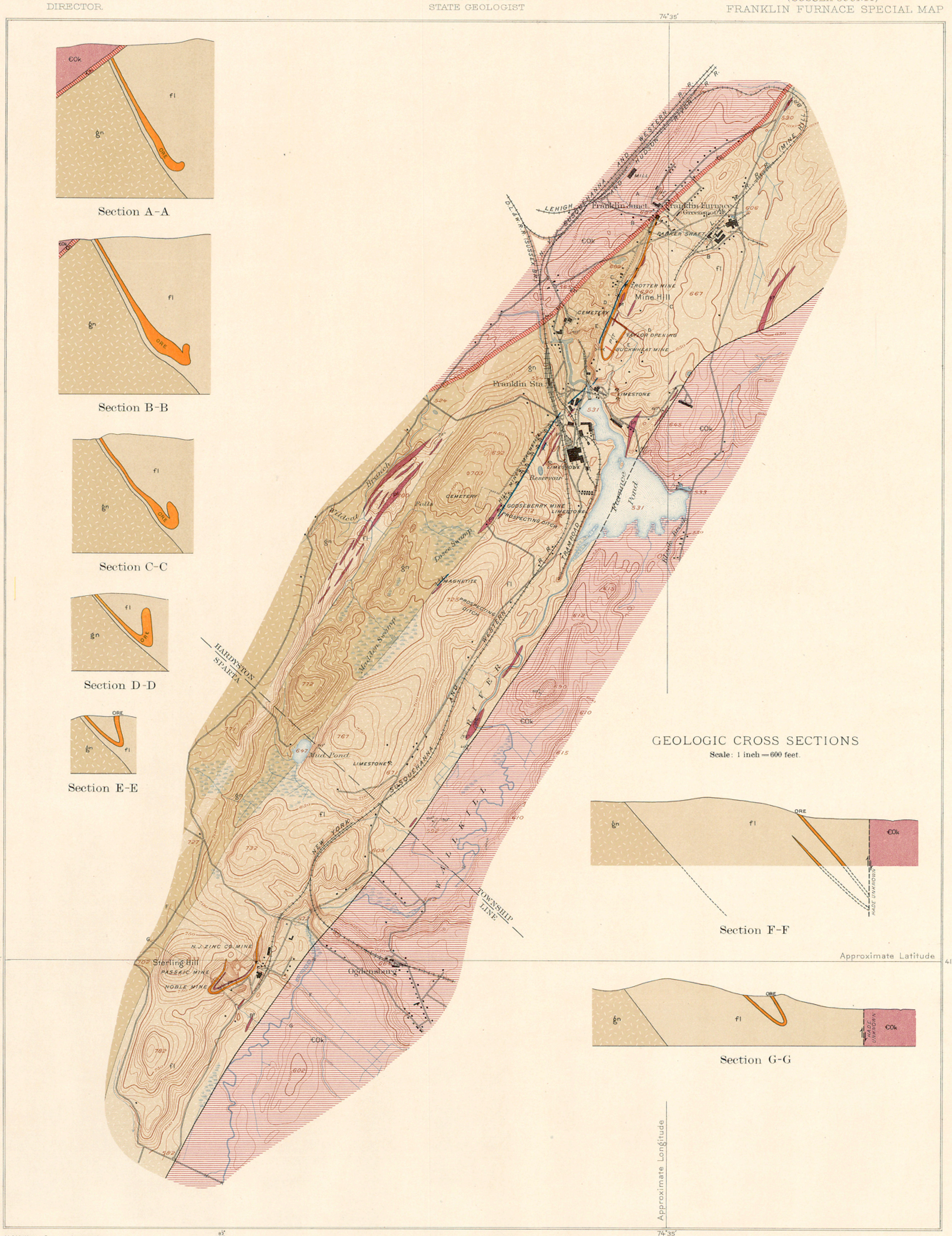
STATE GEOLOGIST

NEW JERSEY
(SUSSEX COUNTY)
FRANKLIN FURNACE SPECIAL MAP



LEGEND

PALEOZOIC ROCKS

POST-ORDOVICIAN

Basic dikes
(camptonite)

CAMBRIAN

€Ok — Kittatinny limestone
(blue limestone, often magnesian, with occasional cherty layers)

€h — Hardyston quartzite
(vitreous, ferruginous, calcareous, and in part feldspathic)

PRE-CAMBRIAN ROCKS

PRE-CAMBRIAN

pt — Pegmatite
(coarse, obscurely foliated granite, mainly quartz and feldspar)

Metamorphic

fl — Franklin limestone
(coarsely crystalline, roughly foliated, white limestone (marble) containing graphite, chondrodite, pyroxene, and other accessory minerals)

gn — Gneiss
(composed of dark and light layers, the latter mainly invading)

Known mineral deposits

Outcrop of zinc ore bodies

Magnetite outcrop

Faults

Strike and dip of sedimentary rocks
Strike and dip of foliation or cleavage
Shafts
Mines and quarries
Prospects
Tunnels

H.M.Wilson, Geographer in charge.
Topography by Albert Pike.
Surveyed in 1898.

TRUE NORTH
MAGNETIC NORTH
8½°
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{14400}$ or 1 in. = 1200 ft.
1 Mile
1200 600 300 0 1000 2000 3000 4000 Feet
1 Kilometer

Contour interval 10 feet.
Datum is mean sea level.
Edition of April 1908.

Geology by Arthur C. Spencer.
Surveyed in 1905.

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

Stratified rocks often contain the remains or imprints of plants and animals which, at the time the strata were deposited, lived in the sea or were washed from the land into lakes or seas, 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. When 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 found 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 often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes 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 is sometimes 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 of their metamorphism.

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.

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.......	....	Ћ	Peacock-blue.
Paleozoic	Carboniferous.	Permian....... Pennsylvanian Mississippian..	C	Blue.
	Devonian.....	....	D	Blue-gray.
	Silurian.......	....	S	Blue-purple.
	Ordovician....	....	O	Red-purple.
	Cambrian.....	Saratogan..... Acadian....... Georgian......	€	Brick-red.
	Algonkian	....	A	Brownish-red.
	Archean	....	Æ	Gray-brown.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. 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 by which formations are labeled 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 recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

SURFACE FORMS.

Hills and 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 thru them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; sea cliffs are made by the eroding action of waves, and sand spits are built up by waves. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are produced in the making of deposits and are inseparably connected with them. The hooked spit, shown in fig. 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, and these are, in origin, independent of the associated material. 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 afterwards 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. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the even surface thus produced is called a *peneplain*. If the tract is afterwards uplifted the peneplain at the top is a record of the former relation of the tract to sea level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—This map shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any colored 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 given formation, its name should be sought in the legend and its color and pattern noted, when the areas on the map corresponding in color and pattern may be traced out.

The legend is also a partial statement of the geologic history. In it the 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.—This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to show these additional economic features.

Structure-section sheet.—This sheet exhibits the relations of the formations beneath the surface. In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which exhibits those relations is called a *section*, and the same 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 the 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 of the earth to a considerable depth. Such a section exhibits what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

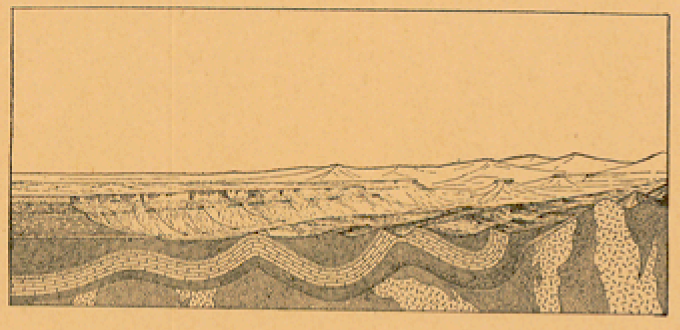


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

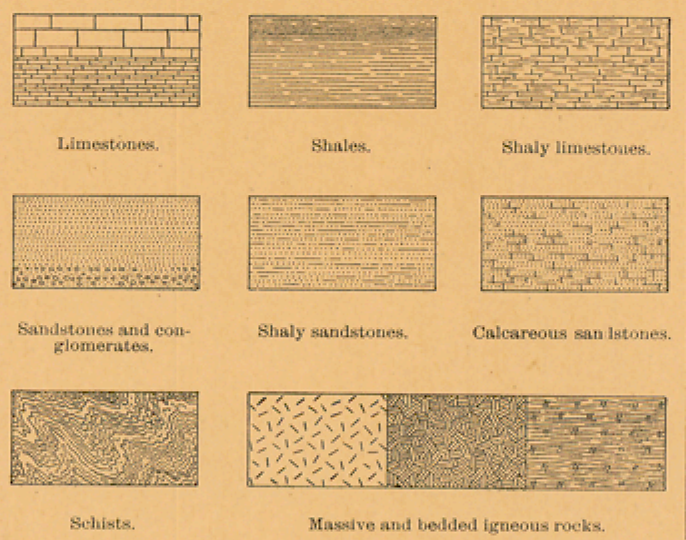


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section. The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to 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 that the intersection of a bed with a horizontal plane will take is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

Strata are frequently curved in troughs and arches, such as are seen in fig. 2. The arches are called *anticlines* and the troughs *synclines*. But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets; that they are now bent and folded is 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 fig. 4.

On the right of the sketch, fig. 2, the section is composed of schists which are traversed by masses of igneous rock. The schists are much contorted and their arrangement underground can not be

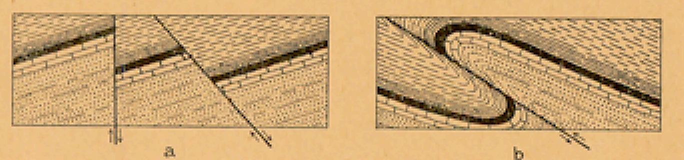


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

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

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

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger rocks thus rest upon an eroded surface of older rocks the relation between the two is an *unconformable* one, and their surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were plicated by pressure and traversed by eruptions of molten rock. But 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 suffered metamorphism; they were the scene of 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 fig. 2 are ideal, but they illustrate relations which actually occur. 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 which appears in the section may be measured by using the scale of the map.

Columnar section sheet.—This sheet contains a concise description of the sedimentary formations which 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 which state the least and greatest measurements, and the average thickness of each is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest formation at the bottom, the youngest at the top.

The intervals of time which 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, 1908.

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