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WASHINGTON, D. C., *November*, 1890.

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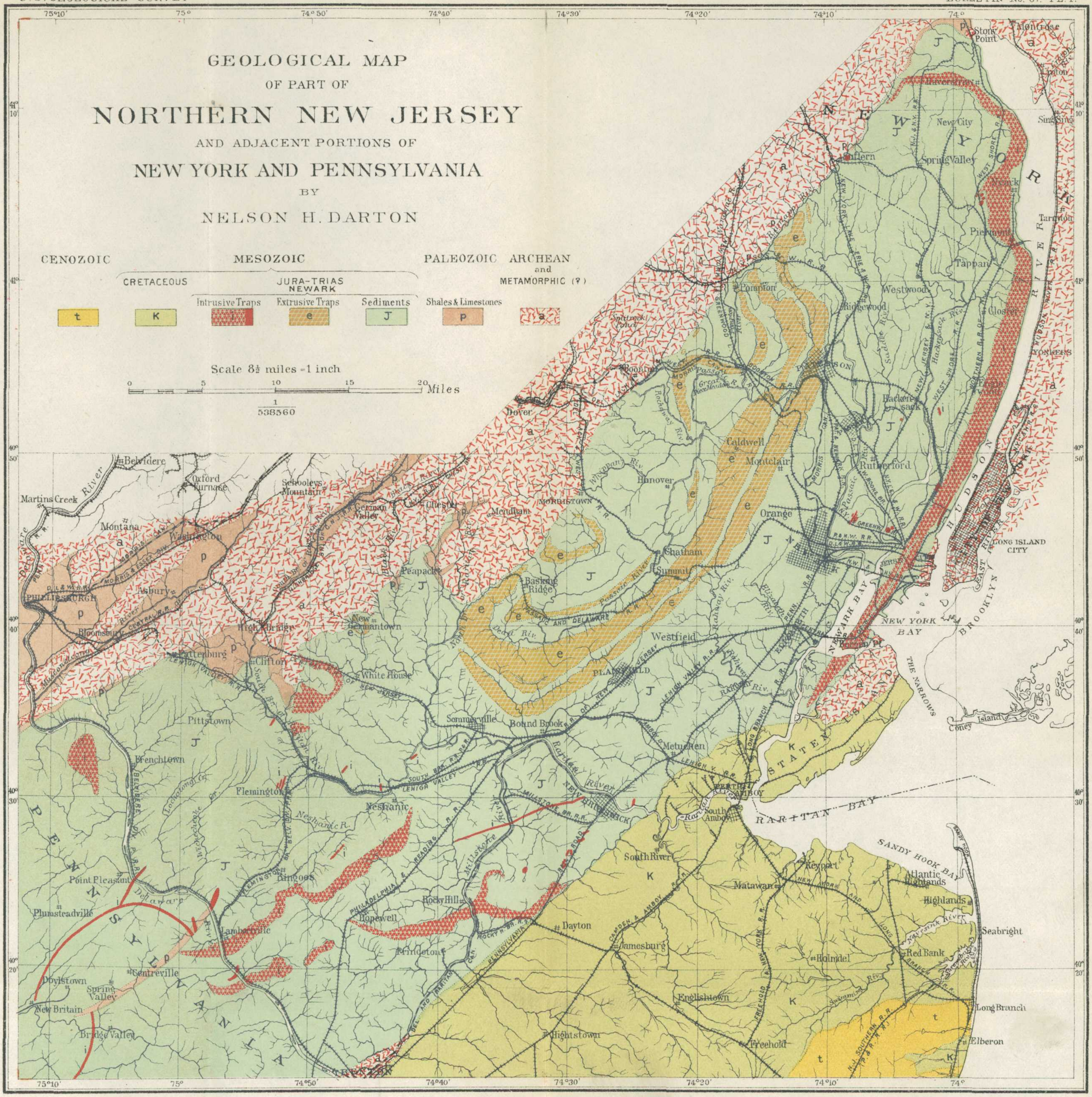

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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

THE RELATIONS

OF THE

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BY

NELSON HORATIO DARTON

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GOVERNMENT PRINTING OFFICE
1890

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LETTER OF TRANSMITTAL.

UNITED STATES GEOLOGICAL SURVEY,
APPALACHIAN DIVISION OF GEOLOGY,
Washington, D. C., April 17, 1889.

SIR: I have the honor to transmit herewith a paper by Mr. Nelson H. Darton, assistant geologist, on the relations of the traps of the Newark system in the New Jersey region to the sedimentary rocks. The field work on which the paper is based was chiefly executed as a personal enterprise previous to Mr. Darton's connection with the Geological Survey, but a few weeks were also spent in revisionary work under the auspices of the Survey.

Very respectfully, your obedient servant,

G. K. GILBERT,
Geologist in charge.

HON. J. W. POWELL,
Director.

THE RELATIONS OF THE TRAPS OF THE NEWARK SYSTEM IN THE NEW JERSEY REGION.

By Nelson Horatio Darton.

INTRODUCTION.

This contribution is a summary of the more complete results of a systematic study of the relations of the Newark system in New Jersey and New York.

In commencing field work in 1882 it was my intention to elaborate a monographic investigation of the Newark system of the eastern United States and the scope ultimately adopted involved a study of all details that might throw light on the genesis and structural relations of the formations, but owing to a variety of circumstances more or less unavoidable, the work was abandoned after several seasons of intermittent fieldwork extending over the entire New Jersey and New York areas.

In reviewing the results of this incomplete investigation it was found that comparatively little new light was thrown on the stratigraphy, structure, or genetic relations which would admit of generalization and only a multitude of heterogeneous details could be presented in this connection. The descriptions by Rogers, Cook, Russell, and others give an adequate general idea of the character and distribution of the sedimentary rocks, to which I could add little of special interest, but the trap masses had not as yet been described in detail, excepting in isolated localities, and it seemed probable that an account of their structural relations would prove an acceptable contribution.

In studying the structure of the formation much important information was gained, but as this was mainly in regard to the region of the trap areas, it was found possible to present it in greater part without extending the memoir beyond a description of the relations of the igneous rocks.

The traps of the New Jersey Newark region are the most prominent features in its topography, the larger masses constituting high ridges rising abruptly from the surrounding plains, and generally presenting escarpments or steep slopes eastward and gentler slopes in the opposite direction towards the dip of the inclosing strata. The more conspicuous outcrops have long attracted attention, and their igneous nature was recognized by the first observers. The first scientific description was by Pierce in 1819, but he did not express an opinion in regard to their origin, and simply termed them "greenstones." Akerly, in 1820, discussed the nature of the Palisade and Newark Mountain rocks, and although his discussion and conclusions were vague, he evidently held the opinion that they represented old lava-flows. Cooper, in 1822, described the occurrence of columnar and amygdaloidal "basalt" at the falls of the Passaic, and considered the rock of Newark Mountains, and by analogy the other trap masses of the State, to have been poured out over the sandstones; but, as suggested by Davis, he does not appear to have had in mind the possibility of intrusion. In 1836, and again in 1840, Rogers described the relations of the traps, and the actual or supposed alteration in the associated strata, and considered them intrusive and dike-like throughout.

In 1843 Mather described some of the relations of the palisade trap in New York, and called attention to the irregularities in contact and to the altered strata at its base, but considered the Palisades, and by analogy the other ridges in New Jersey, due to ancient lavas "that have flowed through rocky fissures in dikes while this portion of the continent was still beneath the waters of the ocean."

In 1846 Emmons described the relations at the base of the palisade trap at the State line, and stated that the rock was intruded in sheets in the sandstone, being the first to definitely recognize its true relations.

In the "Geology of New Jersey," 1868, Cook described the traps at considerable length, and although the structural relations are not discussed in detail, the prevailing sheet structure is recognized, and the rocks were all considered intrusive. In succeeding reports up to 1886, Cook remained unchanged in this opinion of their intrusive nature, and for the Watchung traps advanced as evidence, the occurrence of indurated shales and limestones on the back of the mountain, northwest of Plainfield (Feltville ?), and their analogy in general relations to the palisade and other unquestionably intrusive traps.

Russell, in 1878, described in some detail the occurrence of what were then supposed to be intensely altered shales and limestone at Feltville and added great weight to the prevailing view that the Watchung and all the other trap masses were intrusive. In 1882 Davis visited several typical localities in the New Jersey area for the purpose of determining the nature of the traps, and while he agreed with previous observers, Emmons, Cook, Credner, and Russell, in regard to the intrusive nature of the palisade trap, he stated his conviction that the Watchung traps were extrusive and similar in relations to some of the extrusive sheets which he had studied in the Connecticut valley. He found the base of the second Watchung trap resting on apparent tuff deposits at Little Falls; the conformable base and the amygdular and ropy-surfaced rock of the first Watchung trap exposed near Paterson. At the Feltville locality he found no traces of the alteration described by Rogers, Cook, and Russell, but, on the contrary, it was seen that the vesicular, slag-like rock was overlain by unaltered shales with an intervening trap breccia at some points. This breccia alone was considered satisfactory proof of the extrusive nature of the sheet and he stated his opinion that it could only have been formed on the surface of a preexistent sheet of lava.

Studies extending over the entire Watchung area confirm Davis's suggestions, and in this memoir it will be shown that all the trap outcrops inclosed by the Watchung Mountains, and the outlying mass near New Germantown are lavas, contemporaneous with the inclosing sediments, while all the other traps described are intruded sheets and dikes.

The igneous rocks of the New Jersey region are remarkably uniform petrographically, as they are all basalts varying mainly in structure and development. The eruptives are fine grained and generally somewhat glassy, and the intrusives are coarser grained, generally being doleritic, in some cases including considerable biotite and often near gabbro in structure.

Excepting in some few special instances in this memoir, but limited reference is made to previous descriptions of general features of topography, structure, etc., as they are indicated in full in the appended bibliography, but endeavor is made to give due credit for all observations of important details or discussion of relations by giving the author's name, and if necessary the date, so that the remaining information may be readily found in the bibliography.

The accompanying colored map is not very different in a general way from the maps issued with Cook's reports for 1881 and 1882, but the base is from a tracing of the very accurate, large-scale topographic maps of the New Jersey survey, on which the field work was based and the boundaries were carefully plotted. Beside this, the map is extended into New York, the dikes and smaller masses are shown and modifications are made in the trap and border boundaries to accord with facts determined by the writer's field work. The most noticeable change in the position of the formation boundary is between Clinton and Perryville to exclude the slates which crop out prominently in the Lehigh Valley Railroad cuts and underlie the Newark rocks unconformably.

In conclusion, I have to acknowledge my obligations to those who have aided in the prosecution of the investigation. To Prof. George H. Cook, State geologist of New Jersey, I am greatly indebted for advice and aid, for without his kind help the attainment of the present results would not have been possible.

Mr. Frank Marshall Smith has served as field assistant throughout the work and his efficiency merits my warmest praise.

To Mr. J. S. Diller and to Mr. Whitman Cross I am indebted for information in regard to the petrography of the igneous rocks of the region.

WATCHUNG TRAP SHEETS.

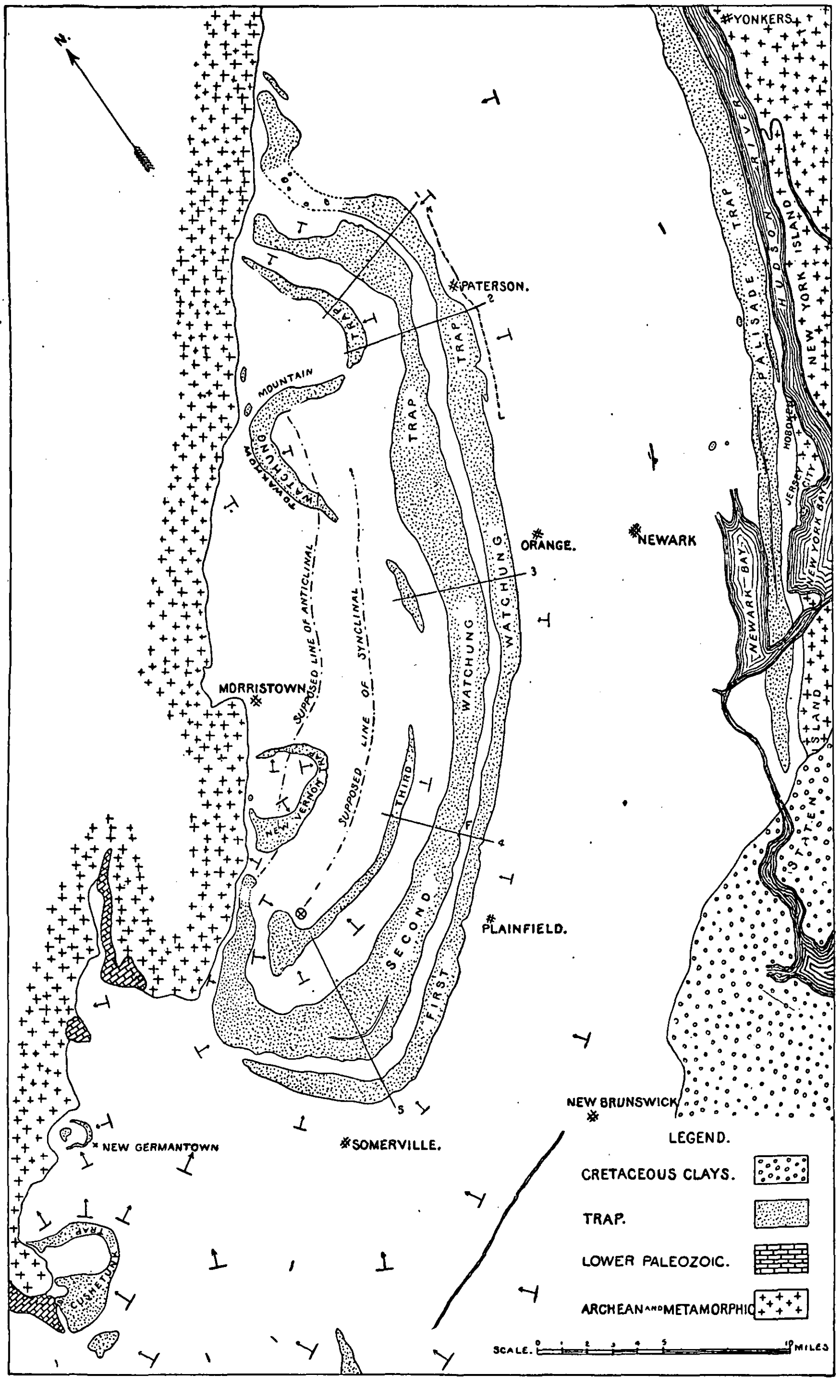
In the western half of the Newark area, in northern New Jersey, is a series of trap outcrops, of which the Watchung or Orange Mountains are the largest and most prominent. These outcrops are the edges of long, thick sheets of lava, which were successively outpoured during the deposition of the Triassic clays and muds, deeply buried in subsequent deposits and uplifted and flexed in the post-Newark deformation. Profound erosion has since removed a great thickness of these sedimentary rocks, and the outer edges of the lava sheets are now exposed, forming prominent elevations above the plains of the inclosing, softer materials. Although deeply decomposed, eroded, and glaciated, these trap sheets present all the usual evidences of contemporaneous extrusions. Their more or less vesicular bases lie conformably on unaltered or but slightly altered strata; their upper surfaces are deeply vesicular; they present evidence of successive flows in part on tuff deposits, and they are overlain by unaltered strata; in one instance with a trap breccia intervening.

STRUCTURAL RELATIONS IN THE WATCHUNG REGION.

As shown in Pl. II, the region is characterized structurally by a long, shallow, irregular trough or synclinal, prominently defined near its broad ends by the curved and recurved terminations of the Watchung Mountains.

With the exception of some narrow, marginal crumples, this is the only well marked flexure in the New Jersey area, and it materially decreases the width of the general northwest monocline of the formation nearly to the latitude of New Brunswick.

In greater part the relations of this "Watchung flexure," as it may be conveniently designated, are well defined and indicated by abundant observations. The region north of the northern termination of the First Watchung Mountain is heavily drift covered, but southward, and thence along the flanks of both Watchung ridges to their ends, sandstone outcrops are frequent, and the changes in strike easily traced. The surface west of the north and south portion of the Second Watchung Mountain is drift or marsh, excepting along the eastern side of a portion of the Third Mountain, and the details of the structure are somewhat uncertain, but the relations are not likely to be very different from those shown in Pl. II. From the narrow belt of northwesterly and westerly dips in the strata exposed along the highland border it would appear that an anticlinal begins near the southwestern termination of the Second Watchung Mountain outcrops, bears the well defined quaquaversal of the New Vernon trap, and thence extends north-northeast across the marsh and drift covered country to Towakhow Mountain. At the southern end of this ridge the shales are pitched beneath the surface, apparently by a flat anticlinal, which thence probably con-



MAP OF A PORTION OF NORTHEASTERN NEW JERSEY, SHOWING THE RELATIONS OF THE WATCHUNG TRAPS.

tinues under the marsh eastward, and by again crossing the trap sheet causes the cross ridge or east-and-west outcrops, as shown in Pl. III, and discussed in detail on a subsequent page. The axis of the Watchung synclinal is definitely determinable only where it "spoons" up near the southern hooks of the Watchung Mountains; northward its supposed course is covered by marsh and drift, but it appears to have carried the trap beneath the surface, between Riker's Hill and Towakhow Mountain, and appears to have aided in the eastern extension of the cross-ridge of the latter.

In the region southwest of the hooks of the Watchung Mountains the northeastern dips prevail for from four to six miles, irregularly and gradually giving place to the normal northwestern dips, as shown in Pl. II. Westward from north of Pluckamin to the New Germantown trap the structure is anticlinal, as shown in Fig. 11.

The stratigraphic position of the Watchung traps in the series is somewhat uncertain, but for several miles north and south from Paterson the first Watchung sheet lies on conglomeratic beds apparently at the base of the formation and separated from younger members eastward by a great fault having the course shown by K - - - L, Pl. II.

The best known exposures of these supposed basal rocks are at Paterson, as noted by Rogers and by Cook. The latter, in his report for 1882, page 36, discussed the significance of the occurrence of this shore deposit in the center of the formation as follows:

> This conglomerate points to the source of these pebbles as not very far away. Blue limestone must have furnished its pebbles. In the absence of any ledges or outcrops of the rock anywhere near Paterson, the assumption is that it has been covered by the more recent strata, and that the conglomerate deposit was not far from it. Here, then, we can not be very far from the base of the formation, one side or the other.

It has been found that these conglomeratic beds are also exposed some distance south of Paterson in front of the Great Notch, and in considerable force several miles north along Goffle Creek, west of Van Winkle's station, but the country is heavily drift covered and the relations are not readily determinable. In these exposures the conglomerates are composed in greater part of large pebbles of white, gray, and red quartzites, including bowlders up to six inches in diameter of the same material, and of limestone.

The conglomerates are separated from the base of the First Watchung Mountain by an inconsiderable thickness of sandstones and shales, and are succeeded eastward by fine grained materials which dip gently westward towards the coarser beds. At Paterson, a short distance east of the conglomeratic outcrops in the gorge of the Passaic, a well was bored 2,100 feet through fine grained sandstone and shales, and the presence of the fault is suggested by the improbability that the conglomeratic beds, universally characterizing shore deposition in the formation, would be superimposed on or intercalated in such a great mass of fine grained materials.

The relations in the Paterson region are shown in the following figure:

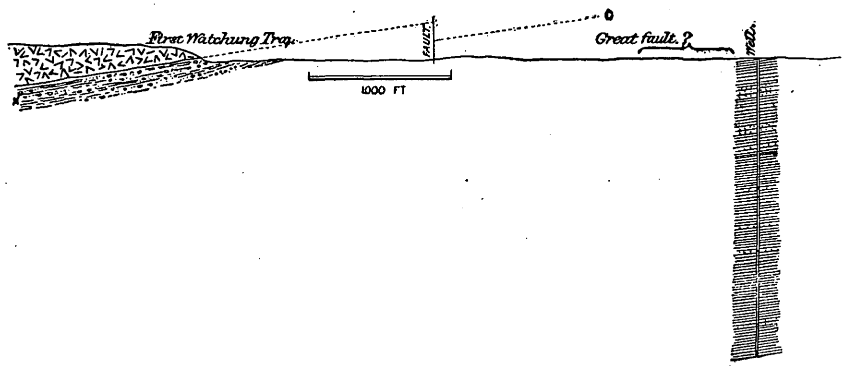


FIG. 1.—Section through Paterson, New Jersey, looking north. X, Conglomeratic beds. C, Projected position of the base of the trap sheet as exposed in the quarries half a mile south of the section line.

The extent of this hypothetical fault is not known; its probable course northward and for some distance southward is heavily drift covered and outcrops are widely separated, but in almost continuous exposures near Montclair and Orange there are no traces of either the conglomerate or the fault line.

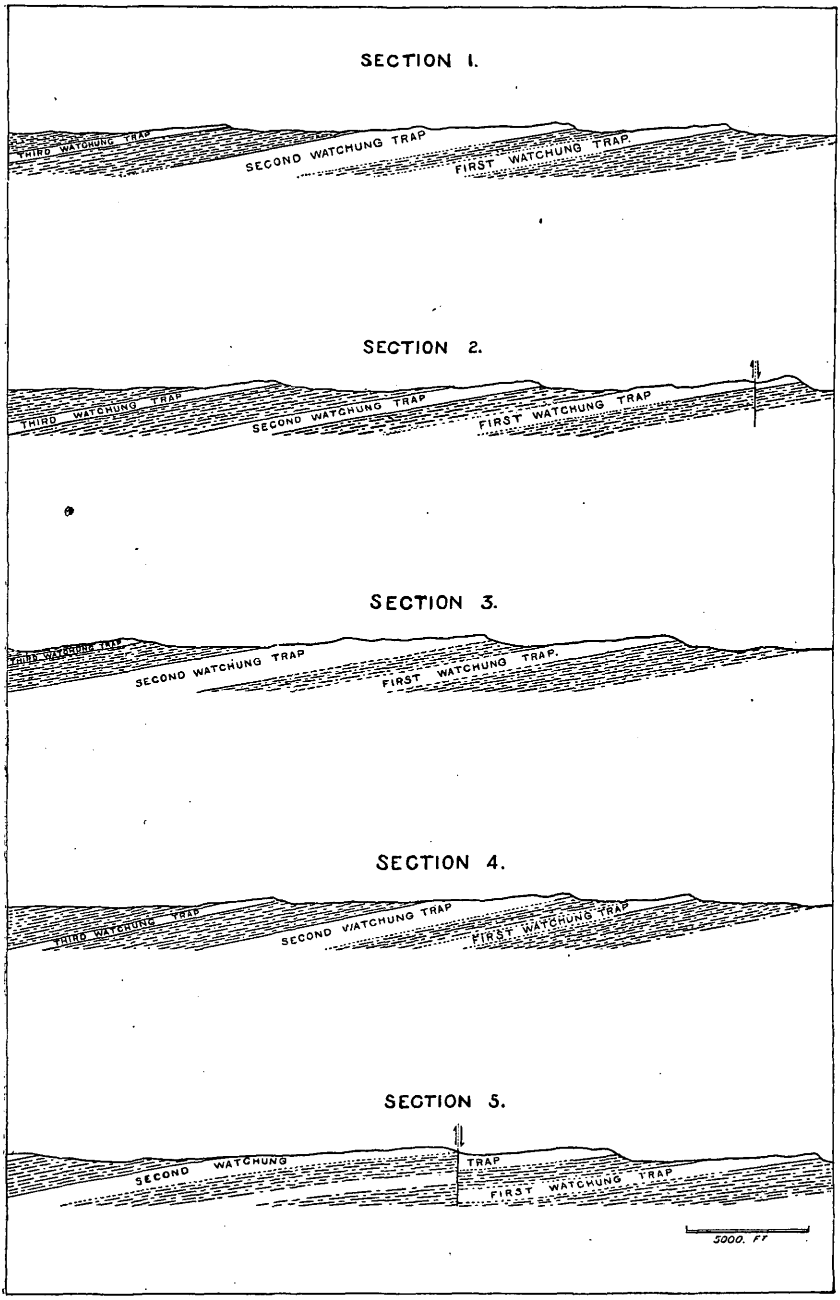
In the region of the southern hooks the base of the first Watchung trap lies on fine grained materials, apparently far above the base of the formation, and, as the sheet preserves a uniform horizon throughout, its position on the basal members northward would indicate that there was a considerable thickness of deposit southward at a time when the Paterson region was near the shore line of the formation.

MUTUAL RELATIONS OF THE WATCHUNG TRAPS.

In Pl. III are illustrated the relations of the trap sheets to each other and to the associated sedimentary rocks. It will be shown in succeeding pages that the bases of these trap sheets preserve a uniform horizon throughout, and the discrepancies in parallelism of the present position of their basal planes, as shown in the figure, are due to dislocations.

It has been suggested that the trap outcrops of the three Watchung ridges were due to a single sheet traversed by longitudinal faults bringing up the underlying strata in the intervening valleys, but this would be inconsistent with their perfectly concentric course and exact parallelism with the strike. Near each end there are unbroken, unfaulted sections from the top of the second Watchung traps to the base of the third, and throughout their course the first and second Watchung sheets are separated basally by an amount which varies so slightly as to preclude even the suggestion of dislocation.

The first and second Watchung traps are separated basally by about 1,200 feet. On section 1 the base of the first Watchung trap down the



SECTIONS ACROSS THE WATCHUNG TRAPS ALONG THE LINES SHOWN ON PLATE II.

dip is apparently 1,200 feet below the base of the second Watchung trap; on section 2, 1,400 feet; on section 3, 1,200 feet; on section 4, 1,150 feet; on section 5, 1,250 feet.

With the exception of section 2, these amounts are practically identical, as there is a considerable plus or minus error in the estimates, and the greater distance indicated in section 2 is due at least in part to known faults. Estimates at a number of points between the sections are invariably near 1,200 feet.

The distance between the present positions of the bases of the second and third Watchung traps varies considerably at the outcrops. On section 1 it amounts to 2,400 feet; on section 2, 1,900 feet; on section 3, 2,400 feet; on section 4, 2,200; on section 5, 2,700 feet. As there is no evidence that deformation has taken place between the two extrusions, these discrepancies must be due to faults in the Second Watchung Mountain area or in the valley westward, and, as will be discussed further on, there is positive evidence of a great fault crossing section 5, and bringing up underlying shales in the center of the trap area. On the line of section 2 the sheets are nearer to each other than elsewhere, and as there is no evidence of faulting in that vicinity, the distance indicated—1,900 feet—is probably very near the amount of actual difference in horizon. This estimate, then, serves as an approximate basis for the determination of the faults which give rise to the apparently greater separation on the other sections; and the thickness of the intervening sedimentary members, as shown in Fig. 2.

FIRST AND SECOND WATCHUNG TRAPS.

General relations.—These two sheets are so intimately connected in structural relations, nature, and position that they may be conveniently considered together. Their outcropping edges constitute the Watchung or Orange Mountains, and as before stated, they represent two great sheets separated by about 1,200 feet of strata, which underlie the narrow intervening valley.

The Watchung Mountains are two long, concentric, and, in places, double-crested ridges, curved at their terminations; the second or inner ridge being recurved for several miles along the highland border of the formation. The ridges are generally elevated between 300 and 400 feet above the surrounding plain country, but notches, depressions, and local elevations occasionally break their continuity of crest line. Owing to the hardness and structure of the trap, the ridges are defined to the eastward and southward by escarpments, which are flanked to a considerable elevation by the sandstones and shales on which the sheets lie. The inner sides are gentle slopes in which the trap extends down to the overlying strata in the valley or plain below. As the ridges closely approximate the trap outcrops in extent, their course and width are fully indicated in Pl. II, p. 16, and hardly need detailed description. The varying widths are due chiefly to the variations in the thickness and structure of the sheets, being narrow where the thickness is less or the dips are steeper and wider where the reverse is the case, or when the sheet is traversed by faults that depress the east side. Erosion, of course, has been an important factor in determining the width of the outcrops, but there is only one instance where a considerable variation in width is due to its agencies alone; this is at Paterson, where the ridge becomes very narrow, decreases in elevation, and is crossed by the Passaic, which falls over its eroded edge into a gorge. The wide depression at Little Falls is similar topographically, and is also traversed by the Passaic, but the trap sheet is comparatively thin in this region, and the diminution in elevation and width is only partly due to erosion. The same is the case with the only other wide depression, which is in the thinnest part of the first Watchung sheet at Millburn and at present the channel of the drainage of a very limited area.

In contour the ridges present little variety; usually the inner slopes are essentially smooth, but subordinate crests, local lines of escarpments, and rounded elevations are found upon them in some regions. The outer sides are generally very precipitous; in the Second Watchung Mountain steep, talus-covered slopes and occasional escarpments mark the edge of the trap sheet. In the First Watchung Mountain long lines of mural escarpments generally extend from a very uniform crest line to a talus and sandstone slope below and vary from only a few feet to a hundred feet in height.

The relations, boundaries, and general structure of the first and second Watchung sheets are well marked for the greater part of their course, but there are some localities in which the outcrops are obscure or lacking and the relations uncertain. At the northern termination of the First Watchung Mountain the heavy mantle of drift covers the region to such an extent that the boundaries and relations can not be definitely determined, but from the occurrence of a number of small and isolated trap outcrops in the high country in the interval, and the general structure of the region, it is thought that the trap masses of the Ramapo Valley are a continuation of the first Watchung sheet. The larger of these masses forms a ridge with a summit over 700 feet above tide-water level, and is separated from the smaller mass by a narrow valley in which some gently west-dipping strata are exposed near the Ramapo. At no other point were sedimentary rocks exposed in their vicinity, and their structure and exact extent are obscured by the heavy flanking of drift. It is possible that the smaller mass is faulted off the larger, but it may be entirely separate and due to a local extrusion.

At the southwestern termination of the Second Watchung Mountain the case is somewhat similar to the one above noted, as there is some uncertainty as to whether the small trap outcrop north of Bernardsville is continuous southward to the second Watchung sheet. The latter pitches below the surface when last seen and the intervening mile and the vicinity of the outlying mass are obscured by drift and detritus, so that no positive evidence could be obtained.

Thickness.—Faults.—The thickness and faults are two subjects which naturally come under one heading, for the estimates of thickness are based on evidence involving a consideration of the indications of dislocation.

In the following figure the thicknesses of the trap sheet and intervening sandstones are estimated from the data furnished by the sections in Pl. III, with deductions for faults indicated by the lack of parallelism in the present positions of the basal planes of the sheets at their outcrops.

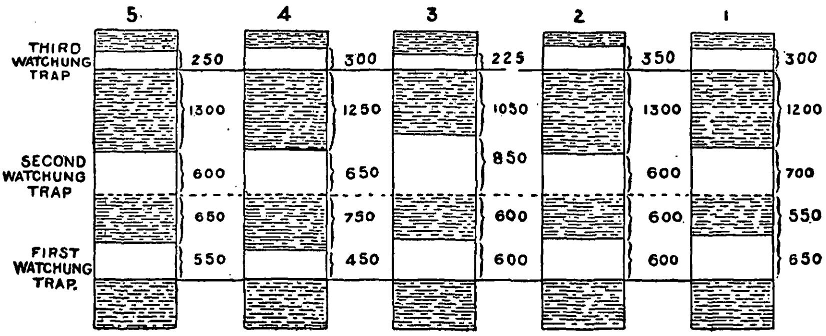


FIG. 2.—Sections illustrating the stratigraphy of the Watchung region along the section line shown in Pls. II and III.

In discussing the relations of the sheets on a preceding page it was shown that the base of the second Watchung trap was stratigraphically 1,900 feet below the third Watchung trap as indicated in section 2, and the first Watchung trap 1,200 feet below the second Watchung trap, which is the mean of allthe measurements when known faults are eliminated. The estimates of thickness of the first Watchung sheet are based mainly on cross-section measurements in which the unknown faults can not be very considerable in amount. With the case of the estimated thickness of the second Watchung sheet, however, the case is different, for the trap outcrop is wider and presents evidence of longitudinal faults in its topography, and in the varying apparent distances of its basal plane from that of the third Watchung trap, from which it was originally separated 1,900 feet throughout, if section 2 is not crossed by faults. The position and extent of the faults indicated by the discrepancies in the other sections across the Second Watchung Mountain are not known with any degree of certainty, and they may in part traverse the sandstone region westward; but in the estimates in Fig. 2 it is assumed for the sake of uniformity that they are in the trap area and uniformly downthrown on the eastern side.

On the line of section 1 the basal planes of the second and third Watchung traps are now 2,400 feet apart at their outcrops, indicating faulting in the intermediate region to the amount of 500 feet, if the original difference in horizon was 1,900 feet. If this faulting is all in the trap area the apparent 1,200 feet of trap represents a sheet approximately 700 feet thick as shown in Fig. 2. In this region the ridge presents considerable evidence of faulting, in its double crests and lines of low longitudinal escarpments presented eastward and rising from prominent joint cracks. On section 2 the trap is 600 feet thick in the narrowest portion of its course, and constitutes a low, smoothly rounded ridge, apparently not traversed by faults.

Southward from Little Falls almost to its termination the Second Watchung Mountain is more or less prominently double crested, and the more marked this feature is the greater the apparent difference in horizon at the outcrops between the base of its trap sheet and that of the third Watchung trap. In the prominent double-crested portion of the ridge in the latitude of Orange, on the line of section 3, the basal distance is 2,400 feet, indicating faulting to the amount of 500 feet; and if the dislocation is in the trap outcrop with the downthrow on the eastern side, the apparent 1,350 feet of trap represents a sheet 850 feet thick. On section 4 the double crest is inconspicuous, the apparent distance between the two trap sheets, 2,250 feet, the faulting 350 feet, and the actual thickness of the apparent 1,000 feet of trap, 650 feet. On section 5 the double crest is very prominent and clearly due to faulting, as shown in Pl. III, for red shale fragments characterize a strip of country between the crests and probably represent underlying strata brought up by the fault. Making allowance for this fault, which would amount to about 600 feet, the second and third Watchung traps are separated basally by 2,100 feet on this section, indicating faulting amounting to 200 feet, which reduces the apparent 800 feet of trap to 600 feet, on the same assumptions as before.

With the first Watchung sheet the case is different, for the estimates are less hypothetical, as cross-section exposures are frequent in which there is little or no room for faults that could not be detected, and the uniform difference in horizon of approximately 1,200 feet between the first and second Watchung traps gives a check on the results. In section 1 the dips, elevation of contact and width of outcrop give 650 feet as the thickness of the first Watchung trap, with 550 feet of overlying strata and no indications of faults. In section 2, at Garret Rock, a thickness of 800 feet is indicated, but deducting 100 feet for observed faults, the amount is reduced to 700 feet. There are also indications of another fault crossing the section in the line of escarpment and double crest which extends along the west side of the ridge from West Paterson, and is very prominent southward towards its termination near the latitude of Montclair. On section 3, at Orange, the first Watchung trap appears to be about 600 feet thick, and the ridge presents no special indications of longitudinal faults. On section 4, near Scotch Plains, the thickness is 450 feet, or considerably less than the average, and the outcrop is noticeably narrower. In the gaps at Scotch Plains, Plainfield, and Chimney Rock, fine sections are exposed across the ridge, but no evidence of faulting is presented, and the thickness is about 500 feet near Plainfield. In the Chimney Rock, section 5, the thickness is 550 feet; thence northwestward the amount increases somewhat and then gradually decreases to the termination of the outcrop.

The faults in Garret Rock, alluded to above, are finely exposed in the bluffs south of Paterson, along the Boonton Branch, Delaware, Lackawanna and Western Railroad. The two principal ones were described and figured by Davis in his paper on the Triassic Traps and Sandstones of the Eastern United States, and are shown in the accompanying Fig. 3.

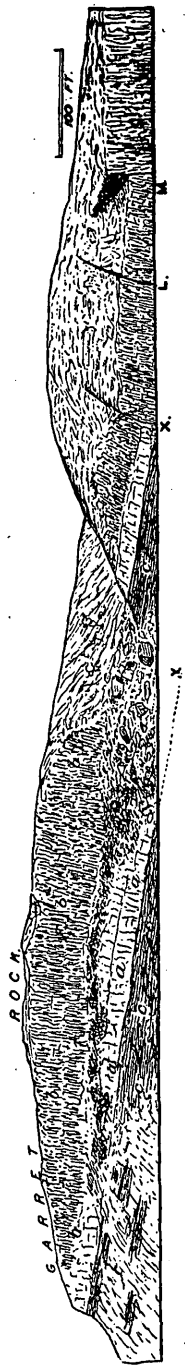


FIG. 3.—Cross-section exposure in the end of the front edge of the first Watchung trap at Garret Rock, south of Paterson, looking south. Y, fault of about 70 feet; downthrow on east side. X, fault of about 12 feet; downthrow on east side. L–M, sunken block (wedge); displacement slight. *a*, trap in large columns. *b*, trap in small columns. *c*, sandstone.

The principal displacement amounts to about 70 feet, with the downthrow on the eastern side, and although the fault plane is not exposed, the beds in its immediate vicinity are not noticeably disturbed. Northward this fault is in the sandstone region east of the trap, and is not traceable, but southward its course appears to be marked by a nearly continuous line of depression, which crosses the Great Notch as a prominent break in the walls, and trending slightly eastward with increased depth, passes out of the ridge into the sandstone country eastward. The amount of dislocation in the notch is less than 150 feet, as the underlying sandstones are not brought up by it.

Columnar structure.—The outcropping edge of the first Watchung trap generally presents mural escarpments eastward in which columnar structure is more or less well defined. One of the finest exposures of columns is at the well known locality west of Orange, of which illustrations have recently received wide circulation. Iddings, in a paper on "The columnar structure in the igneous rock on Orange Mountain, New Jersey," gives a detailed description of the locality and a plate showing the entire exposure. He discusses the genesis of columnar structures in general, and shows that the large and small columns graduate into each other, and do not indicate the edges of successive sheets as suggested by Cook. He also calls attention to the similarity of the first Watchung trap to that which is poured out as a surface flow in recent times, and considers its glassy nature and the disposition of its columns, "which resembles that of many lava sheets in western America," strongly indicative of extrusion.

A few miles north of the Orange columns in some quarries in the northern end of Llewellyn Park, heavily columnar trap graduating into small, radiating columns is finely exposed, and in Paterson there are many outcrops in which this feature is seen, notably at the exposure shown in Fig. 8.

Throughout its course the first Watchung trap exhibits this complex structure more or less distinctly, and on the back of the ridge and in the notch sections the small columns are frequently seen to graduate into heavily bedded rock, forming a part of the original upper surface of the sheet. The bedding is parallel to that of the sedimentary rocks inclosing the sheet, and is often quite distinct, especially on West street, Paterson, and back of Orange and Montclair.

The Second Watchung Mountain seldom presents fine instances of columnar structure, but small columns on bedded trap are finely exposed at and near the Little Falls. Generally the Second Watchung Mountain rock, like much of that of the first Watchung mass, breaks down in wedge shaped prisms and small, irregular columns, and its edge is not often marked by conspicuous escarpment.

Succession of sheets.—When the great thickness of the Watchung trap masses is considered it seems exceedingly improbable that they could represent single outflows. Throughout their extent the trap of both ridges is remarkably uniform in composition and structure, so that it is difficult to obtain evidence of successive flows.

The marked difference in prismatic structure, as described above and shown in Fig. 8, is sometimes very suggestive of successive sheets, but detailed examination has always shown a graduation from the one kind to the other, and the most striking instances of this nature at Orange and Paterson exhibit this graduation very plainly at every point. Throughout the study of the first Watchung sheet, evidence of successive flows was earnestly sought, but without success. In the Second Watchung Mountain, however, indications were found of contacts of the base of one flow with the irregular, vesicular surface of a preceding one, and three exposures were discovered; one near each end of the outcrop, the other at Little Falls. The most marked instance is in the railroad cut, just east of Bernardsville station, where the relations shown in the following figure exist:

FIG. 4.—Section at Bernardsville station, showing superposition of trap at the termination of the Second Watchung Mountain. Looking southwest. Scale, 60 feet to the inch.

The lower trap is similar to the upper mineralogically, but it is somewhat darker and more crystalline, less decomposed, and less conchoidal in fracture. Near the contact it is reddish or reddish brown in color at some points, and is generally vesicular for several inches. The upper trap is a dense bluish gray rock, slightly vesicular at some points and obscurely bedded near the contact. The exact line of contact is not always well defined, and at some places the traps are separated by an inconsiderable thickness of breccia of trap-fragments imbedded in slightly altered argillaceous material. Excepting in this cut, and for a few yards in its vicinity, no other outcrops of the lower trap were recognized. It is possible that this locality exposes the vent through which the newer trap was ejected, but this could not be definitely determined.

At the northern end of the Second Watchung Mountain there is moderately good evidence of perhaps three flows. The first exposures are in the roadside along the upper end of Pompton Lake, where, at several hundred feet above the base of the sheet, there is a cross-section exposure in which a layer of vesicular trap is seen graduating downward into firm rock and is abruptly overlain by similar material apparently at the base of a succeeding sheet. Some distance farther westward vesicular rock is again exposed about 150 feet above the first, and it is similarly succeeded by firm rock, which thence extends to the overlying sandstone a short distance westward. The following section is in part ideal, and it is not by any means certain that the outlined relations actually exist in their entirety.

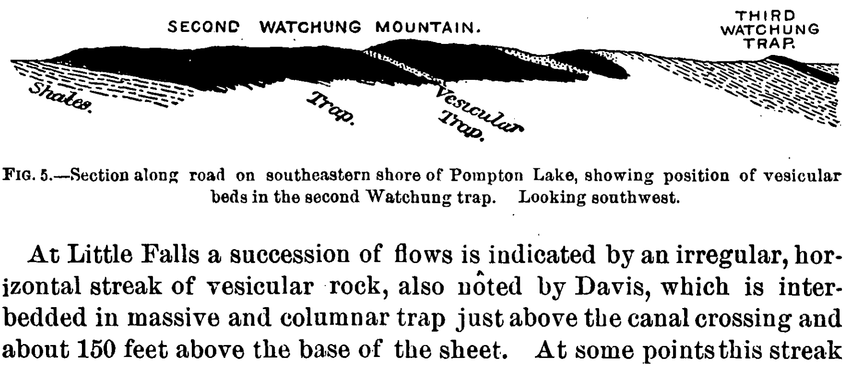


FIG. 5.—Section along road on southeastern shore of Pompton Lake, showing position of vesicular beds in the second Watchung trap. Looking southwest.

At Little Falls a succession of flows is indicated by an irregular, horizontal streak of vesicular rock, also noted by Davis, which is interbedded in massive and columnar trap just above the canal crossing and about 150 feet above the base of the sheet. At some points this streak appears to include some fragmental materials, but the evidences in this regard are not positive. The exposure is a short one and somewhat obscure, and no contact line could be detected, but the occurrence is suggestive of the vesicular surface of one sheet overlain by the base of a succeeding one.

The surface of the trap sheets and their contact relations with the inclosing strata.—In their vesicular and altered surfaces and relations to the inclosing strata the Watchung traps present conclusive evidence of their extrusion, not locally as suggested by Cook, but throughout their entire extent. Although the western slopes of the ridges are in most places deeply eroded, decomposed, or drift-covered, there are many localities in which vesicular or slag-like rock still remains, and near Feltville the irregular, vesicular surface of the first Watchung trap is exposed, overlain by unaltered red shale, separated from the volcanic rock at some points by a trap breccia. In their relations to the underlying strata, the Watchung traps present none of the characteristic features of the palisade sheet, but the more or less altered trap lies with perfect conformity upon practically unaltered, undisturbed shales, and at the same horizon throughout.

The Feltville locality is in a small ravine, across the creek, a short distance northeast of the village and exposes a cross-section for 200 yards along the original trap surface, and through overlying strata on the western slope of the First Watchung Mountain. Owing to the peculiar manner in which some of the trap in this exposure is altered, it was thought for many years to be highly indurated shale, indicative of the intrusive nature of the first Watchung sheet, and in the introduction an account is given of the controversy which this has occasioned. In Rogers's description, report for 1840, page 134, it is stated that the shales and intercalated limestone bed were greatly disturbed and altered by the trap, and Russell in his paper on "The Intrusive Nature of the Triassic Trap Sheets of New Jersey," describes the locality in considerable detail, calling attention to the vesicularity of some of the trap and its rounded slaggy surface, but mistaking its highly altered variety for indurated shale. In several reports Cook alludes to the locality as one exhibiting the contact of the trap and highly altered shales, and appears to consider the breccia a metamorphic product, but he does not give a detailed description of the exposure. In his paper on the "Triassic Traps and Sandstones of the Eastern United States," Davis gives an account of a hurried visit to the locality, in which the unaltered shales are stated to extend down to the vesicular trap surface excepting where a trap breccia intervenes. He considers the occurrence of this breccia strong evidence that the Watchung traps are extrusive, "as it is difficult to understand how it would have been formed except on the surface of a preexistent sheet of lava."

Before making detailed studies of the relations of the Watchung traps, I held the same opinion in regard to the Feltville locality as Russell and Cook, but after the appearance of Davis's paper a microscopic examination was made by Mr. J. S. Diller of the so-called altered shales, and they were found to be highly altered diabase, greatly decomposed, but presenting unquestionable evidence of its igneous nature. In this way it was easy to understand Russell's very natural error, and the significance of Davis's conclusions were for the first time appreciated.

In the following figure (Fig. 6) the more general relations of the Feltville section are shown and the position of the locality is indicated by F on Pl. II, p. 16.

Excepting in the vicinity of X the uneroded trap-surface consists of smooth, low bosses, two or three feet in diameter, sheathed by an inch or two of enamel-like, ropy surfaced, light colored, fine grained diabase. This sheathing is generally filled with shot-like masses of calcite and it graduates downward sometimes into firm or columnar trap, but generally into vesicular rock, often filled with elongated, radial vesicles. In places these bosses are separated from each other by reticulating bands of chloritic matter or decomposed trap an inch or two in width, and extending downward for several inches. Along the southern side of the gorge, at X, the trap surface loses its bossy contour for some distance and becomes a mass of irregular, partly separated, ragged fragments similar to the Aa of the Sandwich Island lavas, as described by Dutton and others. It is at intervals in this portion of the section that the breccia occurs, filling the insterstices and capping the rough surface, as shown in a general way in Fig. 6, and no traces of the rock were found at other points. The breccia consists of masses of more or less vesicular trap of all sizes, from that of a bushel basket down, in a matrix of soft, bright red shale deposit and small fragments of decomposed trap. The greatest development of the breccia is at the so-called "copper mine," where the thickness is eight feet, and it is exposed, graduating upward into the red shales which form the upper two-thirds of the walls of the lower half of the ravine and which are elsewhere frequently exposed down to the trap surface without intervening breccia. Generally these shales are bright red in color, but in the vicinity of Y they are intermixed with trap sand and are so darkened by it that their contact with the underlying brownish red, highly altered trap is hardly recognizable to a casual observer.

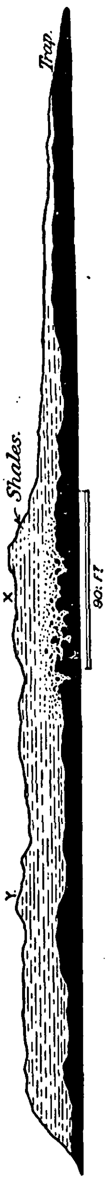


Fig. 6.—Section showing relations of surface of first Watchung trap and its contact with overlying strata along south side of gorge just northeast of Feltville, New Jersey. Looking south.

At the foot of the ravine, and thence southward for many miles down the valley between the First and Second Watchung Mountains the vesicular trap surface and unaltered shales are frequently exposed very near together, but not in contact. Northwest of Plainfield, near the Stony Brook gorge, the trap surface outcrops in the road-side, and the alteration has at some points progressed until the deeply vesicular diabase is almost entirely converted into a bright emerald green mixture of chlorite and serpentine. Two and one-half miles farther southwest, at an old copper mine, near the hamlet of Warrenville, a shaft sunk through the overlying shales penetrated the surface of the first Watchung trap for some distance, but the openings are now filled with water, and nothing could be learned of the relations excepting from the heaps of excavated rocks in the vicinity. The fragments of trap found in these heaps are of an olive green rock with abundant vesicles filled with shot-like masses of calcite, and apparently having an enamel-like surface composed of darker, fine grained, more vesicular material. No traces of intervening breccia were found, and the overlying shales are carbonaceous and sparingly impregnated with malachite, azurite, calcite, and coal, but otherwise unaltered.

Four miles west of Bound Brook, near Martinsville, there is an old opening for copper at which the surface of the first Watchung sheet is exposed, and four miles farther northwest, near Pluckamin, there is another similar locality. In both of these instances the trap was very vesicular and has undergone considerable alteration to chloritic and serpentinous material.

Northward from Feltville, in the glacial drift region, the trap is either glaciated down to the bottom of the valley, or heavily flanked with debris, and although the unaltered, undisturbed, overlying strata are exposed very near the contact at the latitude of Orange, and four miles north of Paterson, the relations at the immediate juncture could not be determined. There is, however, a fine exposure of the vesicular surface of the first Watchung trap in the excavations at the lower end of the Orange waterworks, where the vesicularity extends at least ten feet below the somewhat eroded surface, and the zeolite-filled vesicles often attain an inch or two in diameter.

West and southwest of Paterson the surface of the first Watchung trap has a globulitic, rusty fracture, and is frequently vesicular. Along the Passaic, near the Delaware, Lackawanna and Western Railroad bridge, there is an exposure described by Davis, in which the trap surface is bossy and slag-like, similar to that which predominates in the Feltville ravine, and the rock in the vicinity is vesicular at some outcrops.

Four miles north of the western part of Paterson there is an exposure at the base of High Mountain, in which the shales outcrop within fifteen feet of the first Watchung trap, and about four feet above it vertically. There is no perceptible alteration or disturbance of any kind in the soft argillaceous shales, and the somewhat eroded trap surface presents no traces of vesicularity.

The surface and inner side of the Second Watchung Mountain are more obscured by drift and other detritus than is the case with the First Watchung Mountain, and there are no outcrops of overlying strata near the trap, and fewer localities of vesicularity. In its southwesternmost outcrops and the outlier near Bernardsville vesicular trap is exposed in places, and at the latitude of Montclair the deeply glaciated rock on the western slope of the mountain contains some large quartzitic amygdules, but it is not until Paterson is reached that a vesicular surface is conspicuously exposed. Thence northward at many points the decomposed surface rock is deeply vesicular over wide areas, a feature which is especially noticeable near the northern termination of the mountain towards Pompton Lake.

The base of the first Watchung trap is exposed at a number of localities, notably at Paterson and near Somerville, but also in the copper mines in the gorges northwest of Plainfield and Bound Brook. In all the instances observed the trap is considerably altered, more subject to decomposition than that of the main mass of the sheet, and lies upon unaltered, or very slightly altered, undisturbed shales along a straight or slightly sinuous line. In the copper mines, three miles north of Somerville, the slightly undulating contact plane is exposed over a considerable area by the mining operations, and the relations are finely exhibited. The trap is considerably altered near the contact, and is sparingly vesicular at some points and slag-like at others.

The sandstones are slightly darkened near the trap and impregnated with copper compounds, the results of chemical deposition not necessarily connected with heat. The upper layers are generally slightly flexed to conform to the undulating surface of the trap, and at one point in the mine there is an intervening breccia from half an inch to an inch in thickness, composed of trap fragments imbedded in a matrix of essentially unaltered shaly material. The relations of this singular breccia are shown in the following figure (Fig. 7), and it is thought that its trap fragments were derived by some means from the edge of the advancing trap sheet and then overflowed by it:

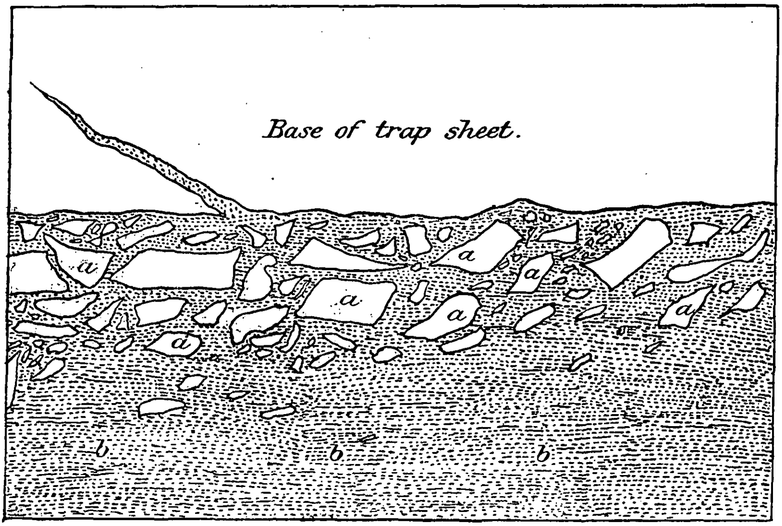


FIG. 7.—Section of breccia immediately below base of first Watchung trap in American Copper Mine near Somerville, New Jersey. *a*, trap fragments; *b*, sedimentary matter. ⅔ nat. size.

In Chimney Rock gorge, northwest of Bound Brook, and in Stony Brook gorge, northwest of Plainfield, openings for copper ore exposed the contacts for some distance, but the workings were not accessible at the time of my visit. Other exposures in their vicinity exhibit the contact along a gently undulating line similar to that in the American Copper Mine above alluded to. Northward from south of Orange to Paterson the entirely unaltered shales and sandstones are exposed at many points along the side of the mountain very near the trap, and perfect conformity exists.

At Paterson there are fine exposures in Garret Rock, in the several sandstone quarries, in the railroad cut behind Barber's mills, and at places in the gorge of the Passaic in which the trap extends down to a sharp contact line without showing conspicuous change in color or texture except occasional vesicles and slightly finer grain or a smaller conchoidal fracture. On the south side of the gorge of the Passaic, just below the falls, there is the exposure shown in the following figure (Fig. 8), in which the contact is very finely exhibited for over a hundred yards:

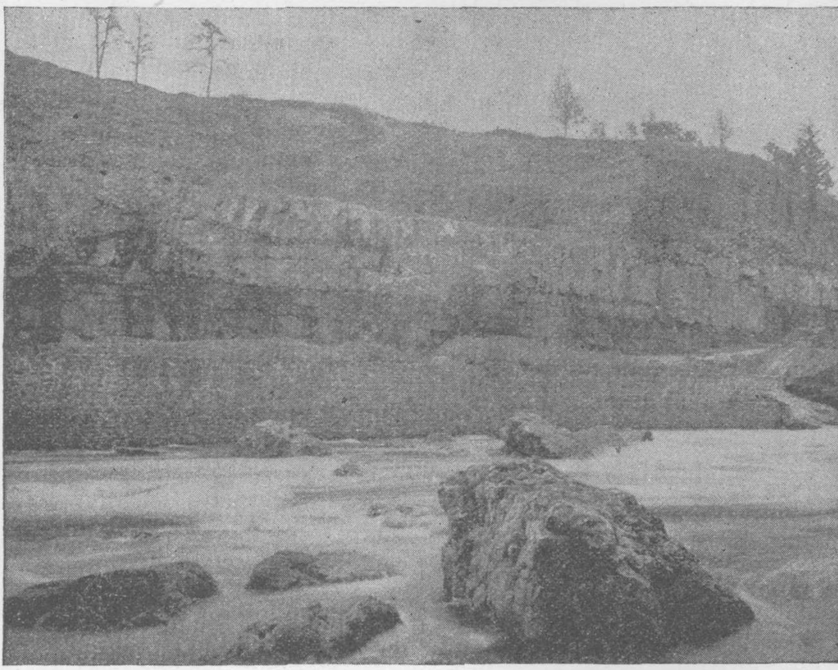


FIG. 8.—Cross-section exposure of edge of first Watchung trap lying on sandstones on the south side of Passaic River, just below the Great Falls, Paterson, looking south. From a photograph.

In this exposure the line of contact is almost perfectly straight throughout, the trap lying upon moderately argillaceous sandstones slightly flexed and darkened at some points, and in places containing cavities apparently due to the weathering out of infiltered minerals. The trap is generally slightly vesicular near the contact and in irregular bands for some distance above, and to the right of Fig. 8 it is altered to a light flesh colored, vesicular rock which occurs at intervals for several yards.

Only two exposures of the base of the second Watchung trap are known, and both afford very satisfactory exhibitions of the contact relations. Some features of the exposures along the Passaic and in the quarries opposite Little Falls were described by Rogers and by Davis, and the other localities are in the quarries near Haledon, two miles north of the western part of Paterson. The finest exposure showing the relations of the trap to the sandstones at Little Falls is the one shown in the following figure (Fig. 9) at the quarry of the Little Falls Brownstone Company:

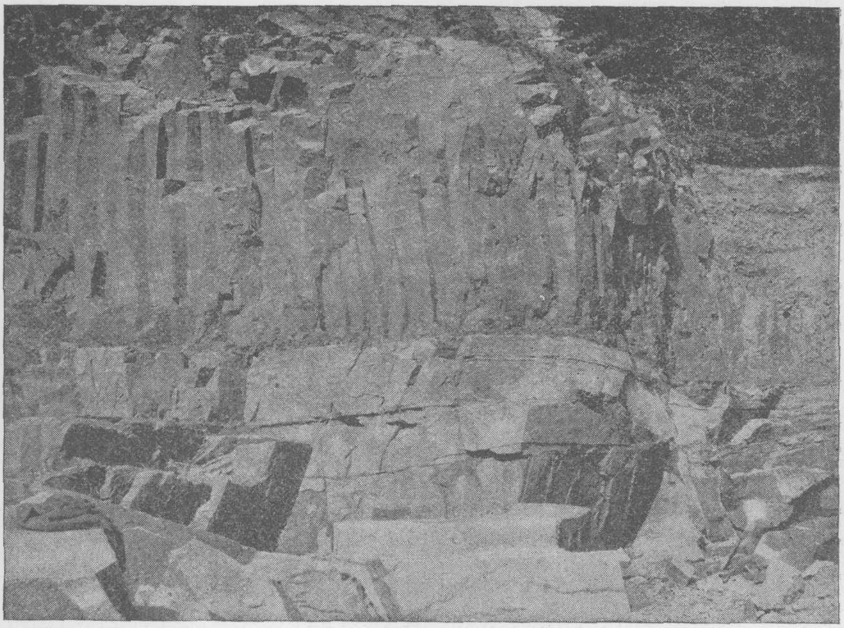


Fig. 9.—Contact of second Watchung trap with underlying sandstones in quarry on north side of the Passaic River below Little Falls. From a photograph.

In the vicinity of this exposure neither the trap nor the sandstones are noticeably altered in texture or in color, and the contact is along a perfectly horizontal line, but westward near the falls and farther eastward down the Passaic, the base of the sheet appears to have overflowed some beds of scoria and tuff. In the outcrops just below the falls on the north side of the Passaic the firm columnar trap at first is intercalated with and then it graduates downward into vesicular and apparently scoriaceous rock, but the exposures are obscure and the exact relations uncertain. A half mile below the falls on the same side of the river there is an exposure of the edge of the sheet in which the relations shown in the following figure (Fig. 10) appear to exist.

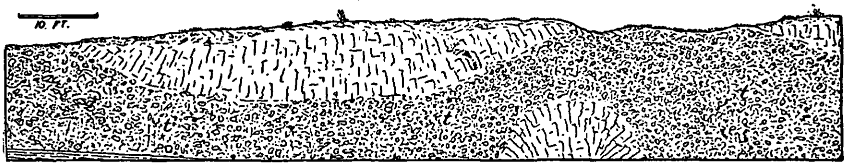


FIG. 10.—Supposed tuff and scoria beds overlain and penetrated by the columnar trap at the edge of the second Watchung sheet on the north side of the Passaic River, half a mile below Little Falls, looking northwest. From a photograph.

The fragmental beds consist of a loose, heterogeneous mixture of vesicular fragments of all sizes and fine grained decomposed tufaceous and ashy materials, all so much decomposed as to render the specific identification difficult. The columnar trap appears to graduate into this bed at the contact, but it appears probable that here we have an anterior fragmentary deposit overflowed and penetrated by lava flows in the manner shown in the figure, in which the features are somewhat accentuated.

Northward from this locality for many miles the drift and talus hide the base of the sheet, and the extent of this supposed fragmental deposit is unknown. The Haledon exposures are in two adjoining sandstone quarries, a mile and a half north of Haledon. In the northernmost of these quarries the columnar trap is vesicular at some points near the contact and includes masses and streaks of chloritic matter in which rounded and angular masses of vesicular trap are imbedded. In the other quarry a couple of hundred yards away the firm, hard columnar trap of the ridge comes down to the unaltered sandstones at some points, but it generally lies on from 10 to 20 feet of a heterogeneous deposit of fragmental material similar in nature and relations to that below the Little Falls, cemented into a breccia by zeolitic, quartzitic, and calcic impregnations.

THIRD WATCHUNG TRAP.

General relations.—The outcropping edge of this sheet constitutes a line of single crested ridges known as Packanack Mountain, Towakhow Mountain, Riker's Hill, and Long Hill, which are shown on Pl. II as trap-covered areas a short distance west of the inner slopes of the Second Watchung Mountain. These ridges are narrow, seldom exceeding half a mile in width, and, although similar to them topographically, are much less prominent and rugged than the Watchung Mountains. Through much of their course they present a steep side eastward, but escarpments are infrequent, low, and irregular, and the line of contact with the underlying sandstone is generally not far below the crest line. The inner slopes are trappean and gentle. The ridges ordinarily attain an elevation of about 200 feet above the surrounding plains, but occasionally somewhat more. Owing to the comparatively inconsiderable thickness of the sheet, slight changes in its thickness, extent, or structure cause breaks in the continuity of its outcrops or considerable deflections in its course, such as are not found in the larger Watchung masses.

The most notable of these deflections is the bowing in the line of outcrop in Towakhow Mountain. The curved course of this ridge is apparently due to a very low anticlinal, or crumple, trending and gently declining northwestward and crossing the sheet in the angle formed by the change in trend. There is a gradual change of dip approaching this corner from the south, and although in the east-and-west or cross-ridge the trap extends down to country level, and the regions north and south are drift and marsh covered, the evidence seems ample that its course is due to flexure. In the north-and-south ridge the sandstone extends up nearly to the crest, dipping about ten degrees to the northwestward conformably under the trap.

The cross ridge terminates in a few miles at a low, wide, marsh and drift-filled gap, through which the Pequannock River crosses the sheet. East of this gap the trap outcrops constitute a curved ridge, which thence extends parallel to the strike and gradually sinks below the drift plain near Pompton. Towards the southern termination of the Towakhow Mountain the sandstone outcrops finally cease and the trap sheet pitches beneath the surface in the gap towards Riker's Hill, apparently passing over the southward extension of the anticlinal to which the cross-ridge is due. The trap in Riker's Hill rises gradually from the plain country, either by slight flexure or by increase in thickness of the sheet, and is a thin capping of trap on gently west dipping shales, which extend nearly to its crest. Long Hill is similarly constituted, and at its southern termination the trap is spread out in the spoon of the Watchung synclinal to cover an ill defined but considerably greater area than shown on the map of the New Jersey Geological Survey.

North of the corner of the Towakhow Mountain there are two poorly exposed outlying outcrops of trap near the highland border, and it seems probable that they are part of the third Watchung trap separated by erosion or continuous under the surface in the interval.

Thickness.—The thickness of the third Watchung trap is somewhat variable, but as its outcrops do not appear to be traversed by faults the amount may be satisfactorily estimated at a number of localities. The sheet gradually rises out of the glacial lake beds near Pompton, and in the deep gorge of the Ramapo River, a half mile south, has a thickness of at least 215 feet. Five miles farther south the amount is near 400 feet, and in Towakhow Mountain near 450 feet in the north-and-south ridge, and at least as much in the cross ridge. In Riker's Hill the thickness is between 200 and 250 feet, but in Long Hill the average is near 250 feet, and at some points it may be 275 feet. (See also Fig. 2.)

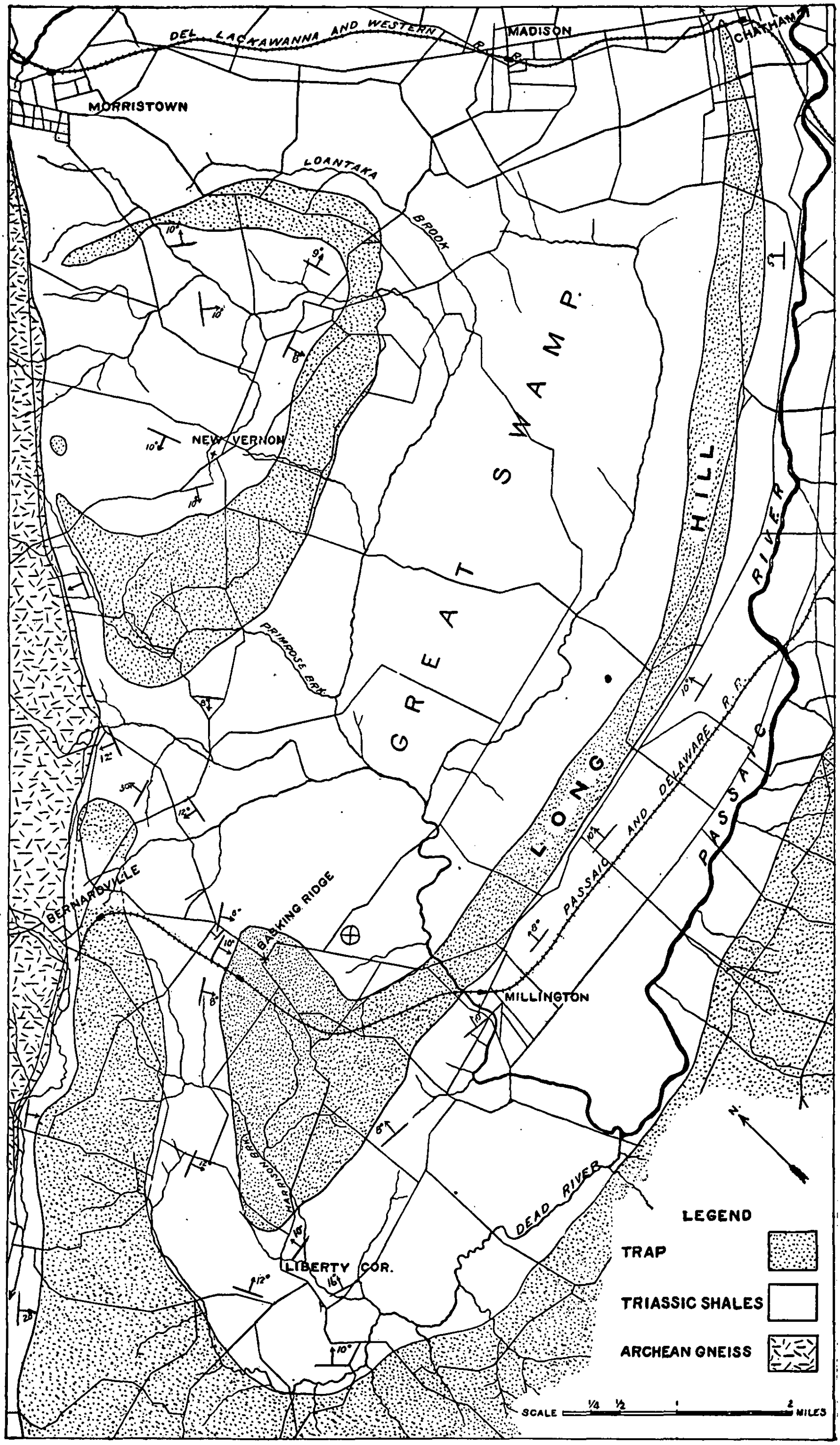
Rock structure.—The third Watchung trap is a fine grained rock, similar in every respect to that of the other Watchung ridges. Its structure is seldom columnar, and ordinarily it breaks down into wedge shaped masses of small size. Although the upper surface of the sheet is deeply decomposed and eroded southward, and bears indications of severe glaciation northward, some vesicular rock still remains. This is an especially noticeable feature near the latitude of Paterson, but is also seen north of Millington, and in the southern hook.

Relations to the associated sedimentary rocks.—Although the third Watchung trap is only seen in contact with underlying strata near its northern and southern terminations, and contacts with overlying strata are not exposed, there is ample evidence to prove that it is an extrusive sheet. The underlying contacts present precisely the same features as those of the other Watchung traps, and at other localities the strata frequently seen very near the trap are entirely unaltered and are conformably overlain by the sheet, the course of which is primarily determined by their flexures. Beginning at the south the shales are often exposed near the trap, and in the gorge at Millington the contact is finely exhibited for several yards. In this exposure the slightly vesicular, decomposed base of the sheet is a sinuous line, perfectly conformable to the bedding of the shales. The latter are entirely unaltered, excepting slight local increases in hardness, and although there is no disturbance in the bedding, some of the layers of shale are slightly bent, distorted, and indistinct for a short distance from the contact. Northward from Millington the sandstones and shales extend along the eastern face of Long Hill and Riker's Hill and the southern part of Towakhow Mountain, sometimes very near the trap, but not exposed in contact. In the gorge of the Ramapo, near Pompton, about a mile south of the northern end of the ridge, there is a fine exposure in which the trap is seen lying on calcareous conglomerate dipping conformably to the southwestward. The exact line of contact is not exposed, but a few inches from it the trap is firm and dense, and the calcareous rock entirely unaltered.

No exposures of contact with overlying strata are known, and in most cases the nearest outcrops on the inner slopes are at a considerable distance from the trap. A mile north of Millington, on the road to Basking Ridge, there are some very argillaceous shales, which at one point outcrop within five or six feet of the surface of the sheet, and do not present the slightest signs of alteration. A mile southeast of Basking Ridge there is another exposure of unaltered shales near the trap, but the exact distance from contact can not be ascertained.

NEW VERNON TRAP.

Three miles northwest of Long Hill, and separated from it by the Great Marsh, is a semicircular trap outcrop which extends to within a few rods of the border of the formation. It is the edge of a lava sheet



MAP OF THE REGION ADJACENT TO THE NEW VERNON TRAP, LONG HILL, AND THE INNER SIDE OF THE TERMINAL HOOK OF THE SECOND WATCHUNG MOUNTAIN.

outcropping up the sides of an irregular quaquaversal, and may be either the attenuated western extension of the third or second Watchung sheets brought to the surface by flexure, or a local extrusion. In Pl. II, the general relations of this outcrop to the others is indicated, and in Pl. IV its structural and areal relations are shown.

With the exception of a couple of narrow drainage gaps the main outcrop line of the sheet is marked by a ridge about 200 feet in height and with a width somewhat greater than that of the trap outcrop.

In contour the ridge is not as steep and rugged as the Watchung Mountains and its steeper inner slope is not marked by escarpments. The ridge is single-crested northward, but towards its southern termination it is divided into knobs and subordinate ridges. The southernmost outcrop is in a small, isolated knoll, and is apparently separated on the surface, although possibly continuous with the main mass under ground. The New Vernon trap is a fine grained rock, very much decomposed superficially, but notably vesicular and slag-like in places on its surface, and very similar on the whole to the rocks of the Watchung ridges. The thickness of the sheet is between 150 and 200 feet, and becomes very slight in the northwesternmost outcrop. There is every evidence that the sheet is perfectly conformable to the sedimentary rocks throughout. The underlying sandstones and shales flank the inner side of the ridge, and, as shown in Pl. IV, their strike is closely parallel to its trend. Outcrops near the trap are infrequent, but in the one or two instances observed there were no traces of alteration. The only exposures of overlying beds are some distance southward, along and near the Passaic River, where the unaltered shales dip as shown in Pl. IV. Southwest of these exposures, to the second and third Watchung traps, the strikes vary from west to northwest, so that the relative stratigraphic position of the New Vernon trap could not be exactly determined; but it is probably connected with either the one or the other eastward under the Great Swamp, or southward below the surface.

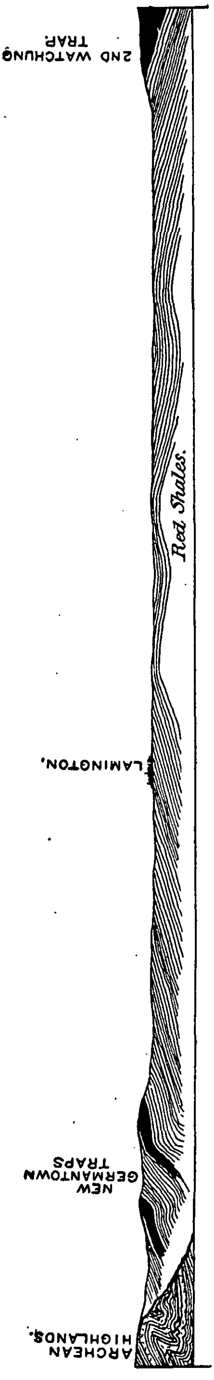


FIG. 11.—Section from west of New Germantown to the crest of the Second Watchung Mountain northeast of Pluckamin, looking north. Scale, 2 miles to the inch.

NEW GERMANTOWN TRAP.

Lying near the border of the formation west of New Germantown, seven miles west of the hooks of the Watchung Mountains, there are two small trap outcrops which are similar to the Watchung traps in their relations, and possibly an extension of these flows; for, as shown in Fig. 11, the intervening country is anticlinal in structure, and, if no faults traverse it, the traps on either side are at approximately the same horizon.

The New Germantown trap outcrops constitute a semicircular ridge inclosing a prominent central knoll, as shown in Fig. 12.

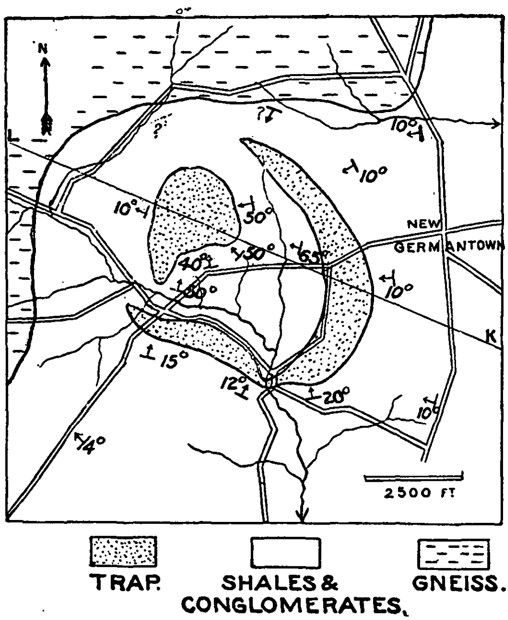


FIG. 12.—Map of the New Germantown trap region.
L —— K, line of section shown in Fig. 11.

The outer ridge consists of a trap sheet lying conformably between unaltered shales with its curved course determined by a shallow trough or partial centroclinal having the relations shown in the figure. The trap presents its steeper face to the east and south and its outcrops terminate by the thinning out of the edges of the sheet. At greatest its thickness is about 250 feet. The sheet is exposed in cross-section along North Rockaway Creek, but at no point is it seen in actual contact with the inclosing strata, although there are outcrops at some points very near the trap in which the shales are entirely unaltered and undisturbed in bedding.

The central knoll is abrupt and high, but its surface and slopes are so covered with trap fragments that its structural relations are not entirely determinable. The dips in the adjoining strata indicate the structure shown in Fig. 11, and from the absence of alteration in the beds it seems improbable that the trap mass is a dike or intrusive sheet.

The trap of both the curved ridge and the knoll is fine grained rock, similar to most of that of the Watchung Mountains, and although vesicularity was not observed in the deeply decomposed and eroded surface of the sheet, and contacts with inclosing strata were not seen, there seems little doubt that the rock was extruded contemporaneously with the deposition of the sedimentary members of the formation.

PALISADE TRAP.

General relations.—This great mass of intruded diabase forms one of the most conspicuous and best known topographic features in New Jersey. Its comparatively narrow outcrop extends as a high ridge with palisadal front for thirty miles along the western side of the Hudson River from New York Bay to Haverstraw, and thence around a huge hooked course to the Highlands.

The palisade trap above the present surface is in greater part a thick sheet, which was intruded up the west-dipping strata from a dike which follows at or near the western flank of the outcrop. This dike-and-sheet structure is best exposed in the railroad cuts and tunnels across the ridge at Weehawken and near Haverstraw, and is shown in the sections in Figs. 13 and 14, viz:

FIG. 13.—Section showing the structure of the palisade trap along the line of the West Shore Railroad in the tunnel and cuts west of Weehawken, New Jersey, looking north.

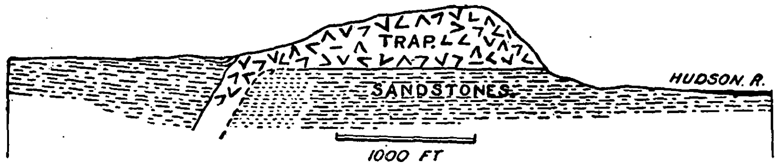


FIG. 14.—Section similar to preceding, but three miles south of Haverstraw, New York, looking west.

For many miles along the Hudson River the base of the sheet is frequently exposed, and while it preserves a practically uniform horizon near the base of the formation, many local irregularities are seen in which the trap crosses underlying strata laterally up or down, in some instances for over a hundred feet. In the hook extending from Haverstraw westward the sheet ascends in the formation by successive steps, and at its northwesternmost outcrop at the Highland border presents some evidence of having been extruded.

Beginning at the south the palisade trap is first found in wells near the Fresh Kills, on Staten Island, but it soon comes to the surface and constitutes a hill extending to the Kill von Kull. On Bergen Point the outcrop is inconspicuous for some miles, but finally develops into a ridge which gradually increases in elevation northward and is characterized by an escarpment on its eastern side. This ridge reaches the Hudson River at Weehawken and thence continues northward with palisadal front to the State line, its elevation increasing in the interval from 225 to 550 feet.

In Rockland County, New York, the topography of the ridge becomes somewhat irregular, a deep notch crossing it at Piermont, north of which it rapidly increases in elevation and width. Near Nyack the elevation decreases, and towards Rockland Lake the ridge becomes very narrow for a short distance. Thence northward the Hook Mountain is a high, rough, single crested ridge, bearing the abrupt knobs or increased elevation known as the High Torne, 1,008 feet above tide and the Low Torne, 900 feet above tide. Towards its termination the ridge gradually decreases in altitude, and is crossed by a wide depression extending down to country level near the line of the New Jersey and New York Rairoad.

In contour the Palisade Mountain and its prolongations is generally a single crested or slightly corrugated ridge, with gentle western slopes, often flanked by overlying strata, and with an escarpment eastward in which a greater or less thickness of trap caps the underlying strata.

The columnar wall, which is so characteristic of the ridge, begins in Jersey City, and for some miles the columns are moderately well defined, but along the Hudson River from Fort Lee to the State line the great even crested wall at the edge of the sheet is a continuous line of huge columns extending down for three to four hundred feet to the steep talus along the river. The following figure (Fig. 15) gives a general

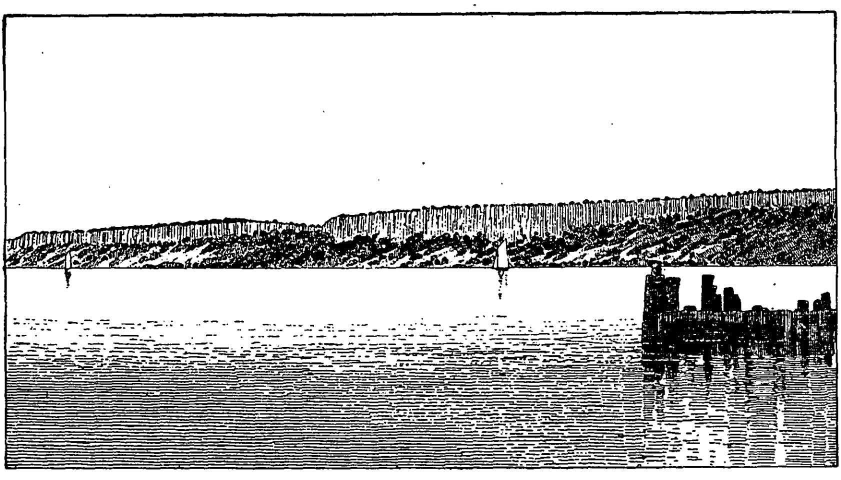


FIG. 15.—The Palisades of the Hudson opposite Hastings, New York. From a photograph.

idea of the evenness of the crest line and escarpment, but very inadequately represents the grandeur and prominence of the exposure.

The palisade trap is remarkably uniform in constitution, and although its texture varies somewhat, it is a normal, almost glassless diabase throughout. Near its contact with the inclosing sediments it is fine grained, sometimes for a considerable distance, and different portions of the sheet vary somewhat in texture, but the predominating rock is a moderately coarse grained, dense gray rock in which the constituent minerals may be discerned. Immediately at its northwestern termination, the surface of the sheet is vesicular for a few rods of its course, and the rock is very similar to that of the Watchung flows. Otherwise it is unlike the fine grained, glassy, extrusive rocks, and at no other point presents the slightest vesicularity.

So far as known the palisade trap sheet is the result of a single intrusion, continuous from beginning to end, but it may possibly be connected under ground with the smaller posterior sheet at Granton, and it is undoubtedly the source of the several small sheets which are intruded in the immediately underlying strata at Weehawken, King's Point, and near Haverstraw.

There is some probability that the palisade trap reappears southward in the Lawrence Brook trap, which is along the extension of its projected line of outcrop. The interval between the Staten Island outcrops and those at Lawrence Brook is mostly covered by cretaceous clays under which the Newark is known to extend for some distance, and it is possible that the trap continues southward and is similarly overlapped. The small trap masses near New Brunswick occur in this region, and in Cook's report for 1882, page 59, reference is made to a belt of indurated shales found in excavations in the Raritan River, a little below Martin's Dock, which may indicate the presence of the extension of the palisade trap. Union Hill, just northeast of Sufferns, may also be an extension from the edge of the palisade trap, but the intervening region is drift-covered, and the relations are uncertain.

Structural relations in the palisade region.—The palisade trap is not flexed to any great extent, and although there are in its area a number of topographic and structural features suggestive of dislocation, only two well defined faults were found.

In its course along the Hudson River nearly to Haverstraw the sheet lies on strata dipping gently westwardly and striking parallel to the general trend of the ridge. Local variations in direction and amount of dip are not unusual, but their influence is in most cases confined to increasing or decreasing the elevation of the contact line in the face of the cliff, although in some cases causing slight deflections in the trend of crest line. The increased width of the ridge near Nyack is in part due to the thickening of the trap, but the dips in that region are very low and aid in widening the outcrop. North of the State line the strata are inclined due west in most instances, and the average trend of the ridge is north for over 10 miles. Near Haverstraw the great hooked outcrop begins, and its structural relations are somewhat complicated. The

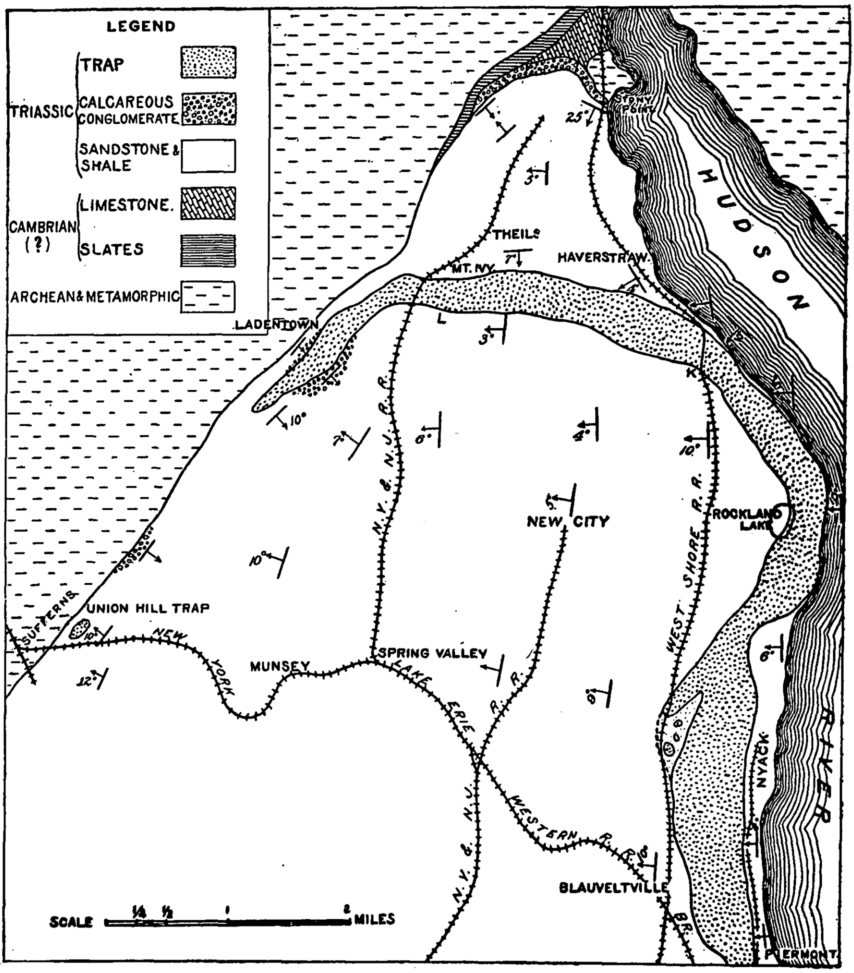


FIG. 16.—Map of Rockland County, New York.

similar great hooks of the Watchung Mountains, it will be remembered, are due entirely to flexures, but in this instance the structure of the associated strata facilitates the curved outcrop but is not its principal cause. Primarily the hooked outcrop is determined in greater part by a gradual deflection in the course of the dike from north and south, finally to due east and west, but at the same time the base of the sheet ascends laterally westward several hundred feet. If this was not the case the sheet would be carried below the present surface by the inclination of the gently west dipping monocline into which it was intruded. These changes in elevation in the sheet may possibly be due to or aided in greater or less part by two faults, the presence of which is suggested by the topography of the Long Clove and the Short Clove. These two deep gaps cross the ridge near Haverstraw, in the very region where the principal changes in position are effected.

The dike structure is plainly exposed in the inner side of the hook from L to K, being finely exhibited in the railroad cut at K, as shown in Fig. 26. Elsewhere its presence is indicated by the steeper inclination of the trap slopes than that of the adjacent strata frequently exposed in its vicinity, although in some part, at least, the appearance may be due to faulting. On the outer side of the ridge along the Hudson River, southeast of Haverstraw, the dips are very gently to the westward in most cases, but southwestern dips occur occasionally. South of Haverstraw the west-southwest dips are general, and it is here that the face of the sheet is either intruded upward across the edges of the strata in several step-like irregularities or is faulted so as to preserve a considerable elevation in the bluff notwithstanding the tendency of the dip to carry it downward. West of Haverstraw there are no outcrops near the trap until on the road-side near Theils, where, as shown in the map, some pebbly conglomerates dip gently southward. In the region northwest of Haverstraw the shales dip at very low angles to the west and north, and near the Highland border the calcareous conglomerates are involved in a shallow synclinal which extends southward and crosses the palisade trap west of L in a wide depression through which the New Jersey and New York Railroad passes. The recurved course of the termination of the trap outcrop is due to this syncline, which is well defined near Ladentown, where its relations are as shown in Fig. 17.

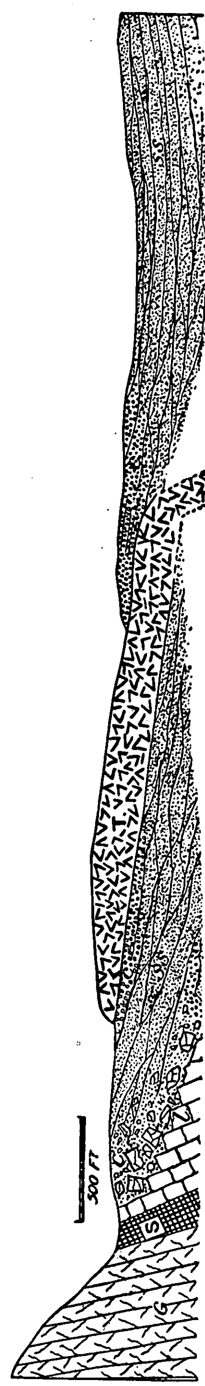


FIG. 17. Cross-section near Ladentown, New York. T, Palisade trap. C, calcareous conglomerate. L, cambrian (?) limestone. S, slates. G, gneiss. SS, sandstones and pebble conglomerates. Looking north.

The horizon held by the sheet at its southwestern termination is not far from the top of the formation, which in this region has no great thickness.

Faults.—Wherever the palisade trap is exposed in cross-section it appears to be traversed by small faults which offset its horizontal joint planes, and there are several longitudinal depressions and subordinate escarpments on the Palisade Mountain which are possibly due to dislocation. In studying the palisade trap it was soon discovered that a longitudinal fault extended along Bergen Hill from Bergen Point through Jersey City heights to the latitude of Hoboken, and another was found in the ravine behind King's Point north of Hoboken extending to and across the West Shore Railroad tunnel, as shown in Figs. 13 and 19.

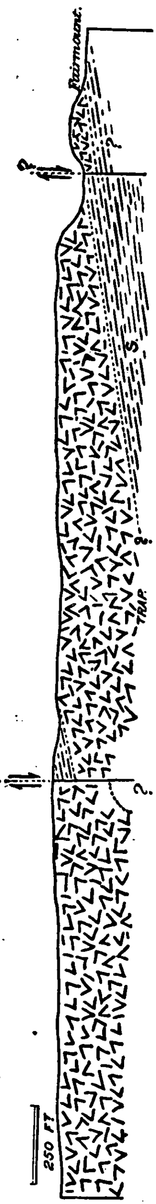


FIG. 18.—Section across the palisade trap in Bergen Hill, Jersey City. S, sandstone. Looking north.

The first indications of the Bergen Hill fault, as it may be conveniently designated, are in Bayonne City, on Bergen Point, where a narrow strip of sandstone is obscurely exposed, extending along the center of the trap outcrop and apparently protected from erosion by the fault scarp. Southward from this exposure a strip of red soil extends for several miles, and northward a depression soon begins which crosses the Morris Canal cut as a break in the continuity of the trap walls. At the next section across the hill, in the cut of the Newark and New York Railroad, the line of fault is indicated by a wider and deeper break in the walls than at the canal, while in the cuts of the Pennsylvania Railroad the break is 700 feet in width, and was found to be underlain by thinly bedded sandstones dipping towards the trap wall on the western side. Cook, in the Geology of New Jersey and on the accompanying map, called attention to the occurrence of the sandstones in the Pennsylvania Railroad cut; and again, on the map of 1874, sections are given in which the trap of Bergen Hill is represented as two sheets separated by sedimentary beds. Russell, in his paper on Hudson County, concurs in this opinion, but Davis, in his paper on the Triassic trap and sandstones of the eastern United States, suggests that the sandstones may owe their presence to a fault similar to the one in Garret Rock.

A half mile north of the Pennsylvania Railroad cut, in the two tunnels, the line of fault is marked by a narrow belt of greatly disturbed and decomposed trap, and a short distance north of the tunnels thinly bedded sandstones were found near the surface in excavating for the reservoir. Thence northward for several miles there are indications of the continuance of a debris-filled depression, but the termination of the fault could not be located. The amount of the dislocation is not known, as it has simply brought down some of the overlying strata on the eastern side, so as to be protected from erosion by the fault scarp of hard rock, and the absence of outcrops of inclosing strata on either side of the trap sheet renders the exact relations undeterminable. The foregoing section (Fig. 18) shows the position and nature of the fault in the Pennsylvania Railroad cut.

The absence of sandstones in the tunnel sections is ample proof that the trap is not in two sheets separated by a layer of sandstones, and that the amount of the fault is not sufficient to bring up the underlying strata. On the above figure are also shown the supposed relations of a small trap outlier in Jersey City, locally known as Fairmount. Its length is only a few hundred yards, and it is completely separated from Bergen Hill by tide marsh. Russell, in his paper on Hudson County, suggests that it is due to a local anterior intrusion from the palisade trap mass, but it is now better exposed for study, and appears to be part of the edge of the main trap sheet separated by a fault, as shown in the figure.

A short distance north of Hoboken the prominent King's Point is at the southern termination of an anterior trap ridge, which thence extends for several miles northward, and finally coalesces with the main ridge. The intervening depression holds the little Awiehawken Creek which rises near Guttenberg, flows through a marsh-filled depression for some distance, and thence down a narrow and deep ravine to empty into the Hudson just below King's Point. In his memoir on Hudson County, Russell appears to consider this anterior ridge due to the change of horizon of the base of the trap, which takes place at its southern end, or to its bifurcation; and Davis, in his paper on the triassic traps and sandstones, page 270, suggests that it is due in part to the resistance to erosion offered by an increased thickness of the trap sheet, possibly aided by a fault similar to the one at Garret Rock, Paterson. The finding of shales in the ravine back of the ridge, and in the tunnel below the marsh-filled depression, affords an entirely satisfactory explanation of the structural relations which are shown in Fig. 19, and also in Fig. 13, p. 37.

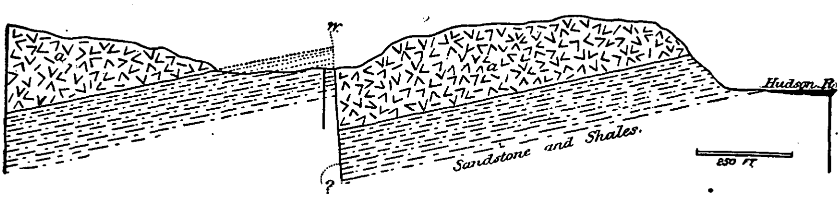


FIG. 19.—Cross-section north of Weehawken, New Jersey, at H - - - C. on Fig. 21, looking north.

The strata in the ravine are continuous with those underlying the main ridge southward, which are observed to abut against the trap of the back of the anterior ridge, and in the tunnel two miles farther north the same relations exist. In the ravine at W, Fig. 19, a well was driven 125 feet into the indurated shales without meeting trap, which is ample proof that bifurcation or longitudinal change of horizon has not taken place. The extent of this fault is not known beyond the limits shown in Fig. 21; southward it may pass either east or west of the serpentine of Castle Hill, Hoboken, but northward it probably dies out towards Guttenberg. Near Piermont there are some suggestions of a fault diagonally from southwest to northeast with downthrow on the eastern side, but its presence could not be established.

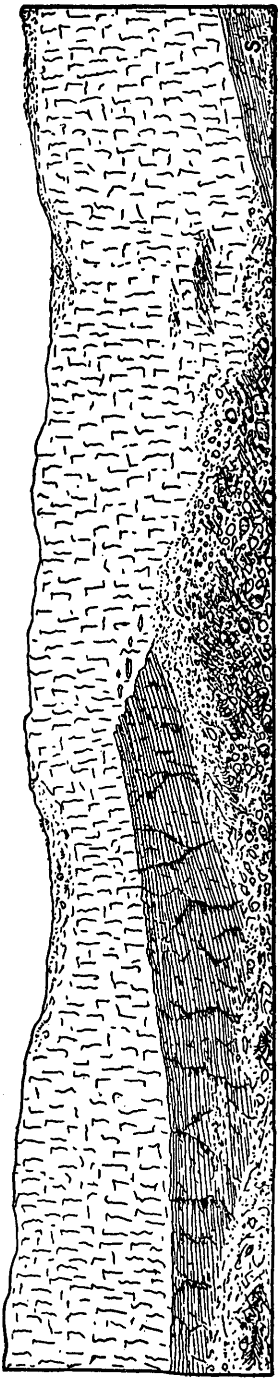


FIG. 20.—Lateral descent of base of palisade trap across edges of strata north of Hoboken, New Jersey, looking northwest. Scale, 150 feet to an inch. From a photograph.

In the great hook farther north, near Haverstraw, the ridge is crossed by two depressions, the "Long Clove" and the "Short Clove," of which the topographic configuration suggests dislocation, but no positive evidence of faulting could be obtained.

Thickness.—There are few localities in which the thickness of the palisade trap sheet may be satisfactorily estimated, for there is a continual possibility of longitudinal faults, and when the dike structure extends to the country level more or less of the upper part of the sheet has been removed by erosion. Bearing in mind the Bergen Hill fault and supposing the underlying sandstones to be at tide-water level with a gentle dip westward, which no doubt is approximately the case, the thickness of the sheet at the latitude of Bergen Hill would be about 300 feet. Near Weehawken, as shown in the tunnel section, Fig. 13, p. 37, the sheet is apparently 400 feet in thickness and the amount appears to gradually increase to about 700 feet near the State line. Near Piermont there is a considerable decrease for a short distance, and then an increase to 800 or 850 feet, but as the entire surface of the sheet is exposed to erosion in this region the thickness was greater originally. In the Hook Mountain the thickness is probably near 600 feet on the average, but varies, and there is not less than 850 feet of trap in the escarpment at High Torne. Farther westward the thickness gradually decreases, and it is not over 200 feet at Ladentown and about 30 feet at the terminal outcrop.

Relations to underlying strata.—Exposures of the base of the palisade trap are frequent along the Hudson River from north of Hoboken to Haverstraw and many details of its relations are exhibited. The sedimentary rocks at the contact are generally the argillaceous shales overlying the basal arkose, and they are in most cases greatly increased in hardness and darkened in color for many feet from the trap. The two rocks are always welded together along the contact, although the line of junction is frequently weathered out, owing to an increased tendency to decomposition which exists at the contact in some localities. Descending plates and dikes of trap are of comparatively frequent occurrence and slight irregularities, in which the trap breaks across the ragged edges of the strata for a short distance are found in nearly every exposure.

The first outcrops of underlying strata are north of Hoboken, where the contact line gradually rises above tide-level, and is entirely conformable to the stratification of the highly altered shales. Owing to the dip of the strata and the trend of the outcrop, a considerable altitude in

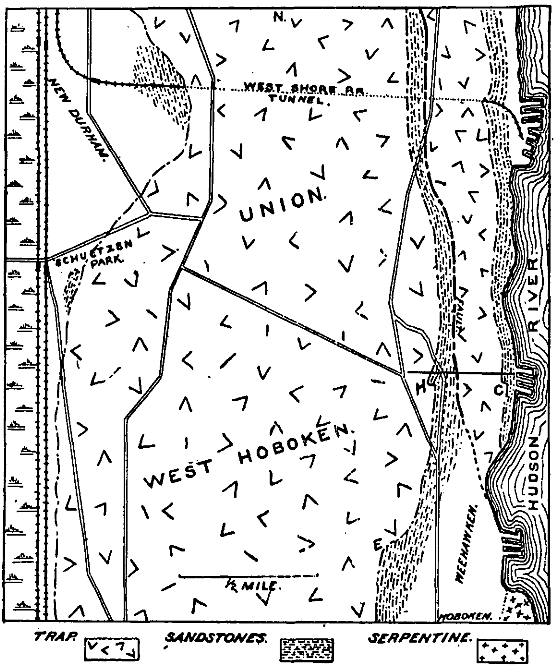


FIG. 21.—Map showing the relations of the palisade trap north and northeast of Hoboken, New Jersey.

the cliff is soon attained, when, as also noted by Russell, the trap breaks abruptly across their edges and descends about 180 feet, as shown in Fig. 20 at the locality indicated by E in Fig. 21.

The cross-contact is an exceedingly ragged one, the trap penetrating the shattered edges of the shales and including some of their great fragments for some distance. Owing to the increased thickness of the harder rock, the escarpment advances eastward for several hundred feet, forming the bluff on which the "observatory" is built. At the southeastern corner of this bluff the underlying strata again emerge from below the surface, as shown in the right-hand corner of Fig. 20, and are thence exposed for some distance northward. Around the eastern side of the bluff to the "100 Steps" the trap lies on the arkose along an irregular contact plane, one of the most noticeable irregularities of which is exposed along the road below the "100 Steps." This arkose is slightly altered to a hard gray rock near the contact, and a short distance south of the "100 Steps" it is penetrated for a few yards by a trap sheet five feet below the main mass and about a foot in thickness.

North of the "100 Steps" the ravine described on page 43 extends up into the ridge, and the line of escarpment offsets to the shore of the Hudson River at the prominent headland of King's Point (at C on Fig. 21).

At the southern end of this point the bluffs are trap from base to summit, but a few rods northward the base of the sheet comes up from tide water level, below which it was carried by the fault described on page 43, and crosses the strata as shown in Pl. V.

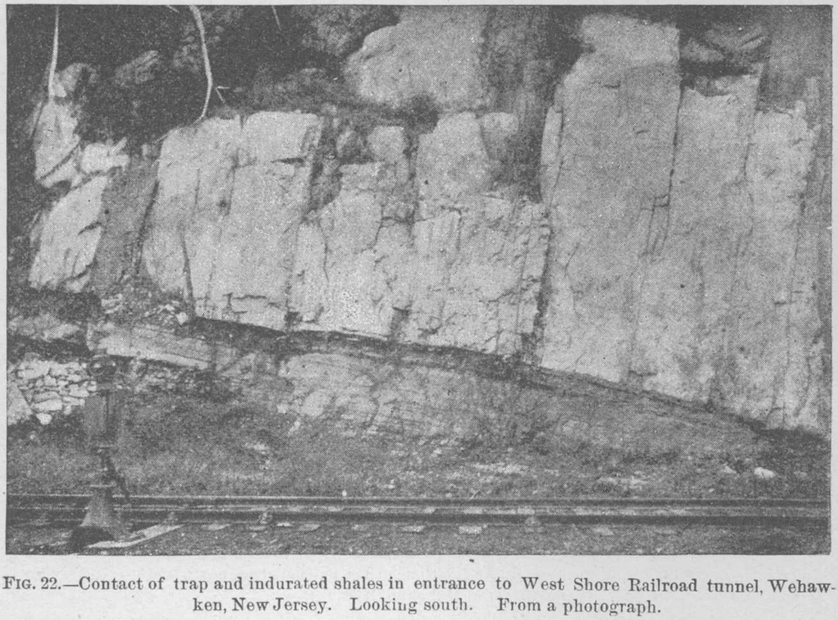
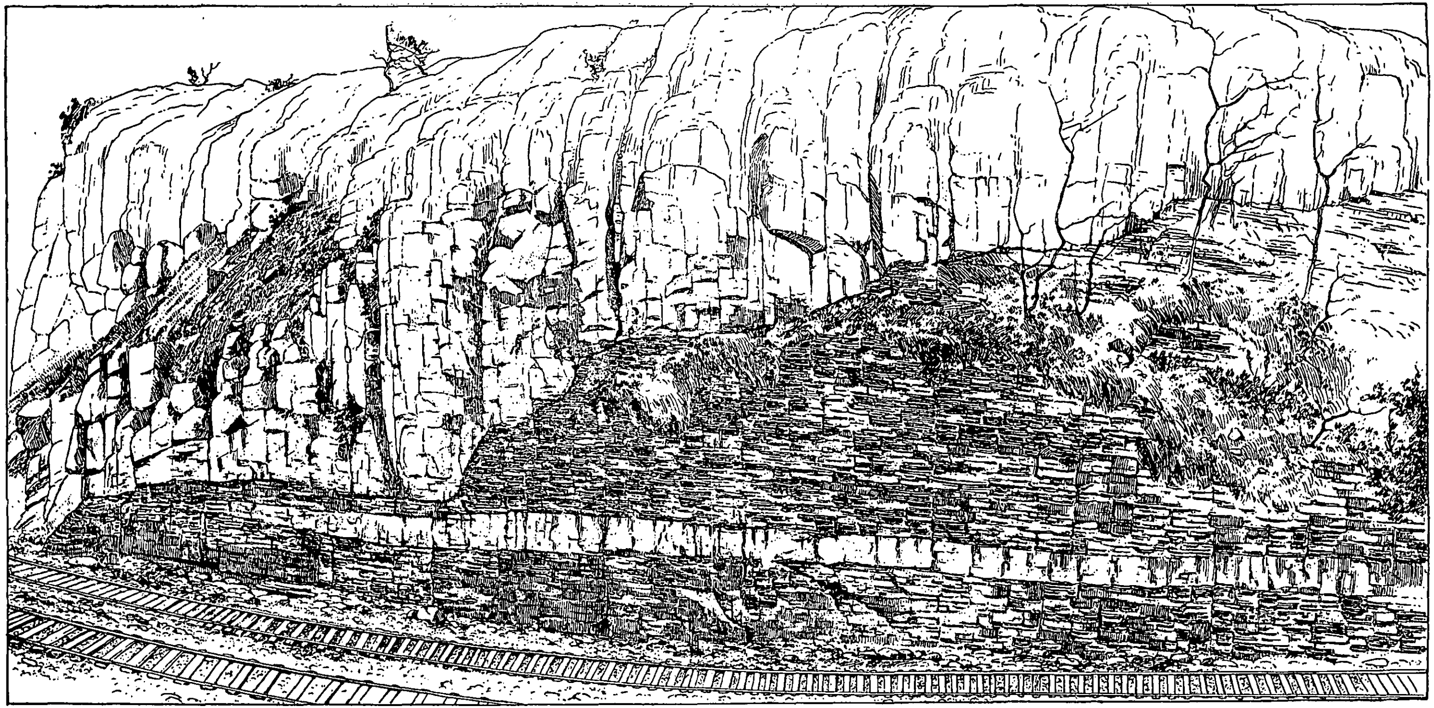


FIG. 22.—Contact of trap and indurated shales in entrance to West Shore Railroad tunnel, Wehawken, New Jersey. Looking south. From a photograph.

In this ascent the trap ascends to approximately the horizon at which it was first observed below the "observatory," and this relation is apparently preserved for many miles northward. As the ascent is lateral to the course of the trap it probably extends into the ridge for some



LATERAL ASCENT OF BASE OF PALISADE TRAP ACROSS EDGES OF STRATA IN KING'S POINT, WEEHAWKEN, NEW JERSEY, LOOKING WEST.
From panoramic photograph.

distance, and on the west side of the fault, in the ravine, there are some indications of its presence, but the exact relations are not exposed.

The unconformity at King's Point is described and figured by Russell 1880, Cook 1882, and Davis 1883, and Russell suggested that it might be due to bifurcation of the mass in which an anterior sheet had extended eastward, but the ascent is entirely lateral and the well boring near the fault referred to on page 43 shows that no bifurcation has taken place.

The small trap sheet shown in Pl. V is an offshoot from the main mass, and extends for about half a mile northward, preserving a uniform horizon throughout, with the exception of some slight local irregularities.

At the eastern entrance to the West Shore Railroad tunnel, two miles north of King's Point, there is a fine cross-section exposure, showing the relations of the trap to the underlying strata, as shown in Fig. 22.

Northward from the tunnel for some distance outcrops are infrequent, but the line of contact appears to remain essentially unchanged in position until near Guttenberg, where there are some indications of either a slight fault or a change of horizon. The relations at this point are not determinable on account of the drift and debris, and a slight local decrease in dip may be the cause of the apparent irregularity.

In the road below the quarries of Guttenberg there is a dike in the arkose underlying the trap, exposed as shown in the following figure:

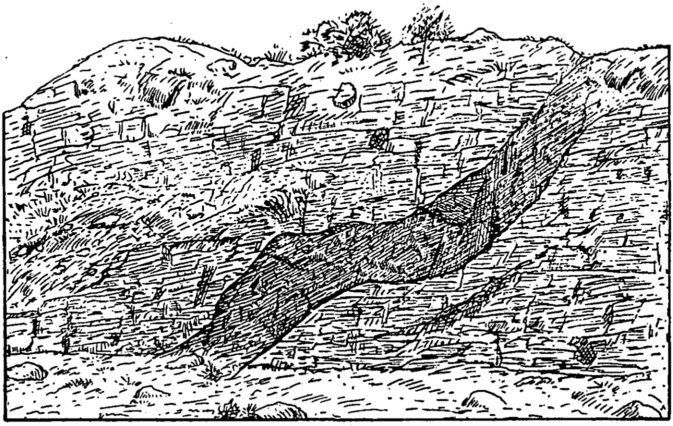


FIG. 23.—Dike in arkose below the quarries at Guttenberg, New Jersey. Looking northwest. From a photograph.

This dike appears to be connected with the palisade trap, and is a precisely similar rock, but whether it is an ascending dike or an offshoot from the trap above is not known.

At Fort Lee landing there is a break in the continuity of the crestline, a shallow depression extends up into the ridge, and the line of escarpment offsets several rods to the eastward to form the "Bluff" which marks the beginning of the palisadal front, thence extending northward uninterruptedly beyond the State line. Near the lower end of the depression behind the "Bluff" there is an obscure exposure in the road-side, in which the trap breaks down across the edges of the intensely indurated shales and the base of the sheet in the "Bluff" is apparently about 75 feet below the horizon, which it held southward. It seems probable that in this instance there is a descent of the trap laterally across the edges of the shales for some distance, as in the King's Point exposure, for there are no indications of a fault in the depression, and the dip remains unchanged throughout in the exposures below along the river.

From the bluff northward to the State line there are numerous exposures of the contact and its vicinity, but there is no evidence of noteworthy irregularity. Near Sneden's Landing, a mile north of the State line, a change in trend of the ridge to due north brings the contact line to tide-water level, and the underlying strata are not exposed again until at Piermont where they reappear conformably underlying the trap. Just south of the village the base of the sheet appears to have ascended across the strata for some distance, but the exposures are obscure and some local changes of dip or a small fault may cause the apparent change in position.

In the road just above Upper Piermont the base of the sheet is exposed for some distance and sends a small offshoot obliquely downward and outward into the sandstone for twenty or thirty feet. Another similar occurrence of this kind is exposed in a quarry behind Haverstraw, where two small offshoots extend obliquely into the underlying strata and terminate by thinning out. From Piermont northward for some distance the contact is high above the river, but near Nyack the strike gradually attains a direction west of the trend of the ridge, and although outcrops near the contact are not exposed for two miles the altitude of the base of the sheet probably decreases.

North of Nyack the trend rather abruptly changes to the northeastward, and in the prominent Hook Mountain the escarpment regains the shore of the Hudson, exposing the underlying strata up to a considerable elevation above the river. Whether or not there have been irregularities in the contact line in the two miles of debris-covered interval is not known, but the trap has not changed its horizon in the formation to any considerable extent.

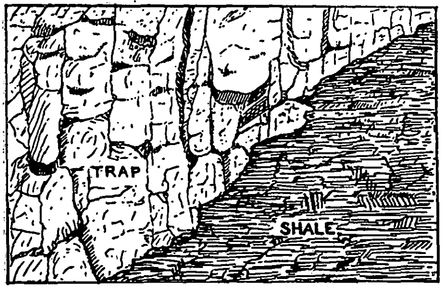


FIG. 24.—Lateral ascent of the base of the palisade trap across edges of strata, two miles north of Nyack, New York.

Northward along the river the contact is easily traceable, and retains a uniform altitude for about two miles, when it comes down about 30 feet to tide-water, and so continues for about 500 feet, to ascend again to approximately its original position. The transverse contact is exposed at the northern end of the irregularity, having the relations shown in the preceding figure.

At Rockland Lake some distance northward, another irregularity of similar character is indicated, and a small exposure of ragged uncomformity was exposed below the landing in 1884, but otherwise its vicinity is heavily covered with debris and talus.

About half way between Rockland Lake Landing and Haverstraw there is a small trap sheet in the arkose thirty or forty feet below the palisade sheet, and its relations are shown in the following figure:

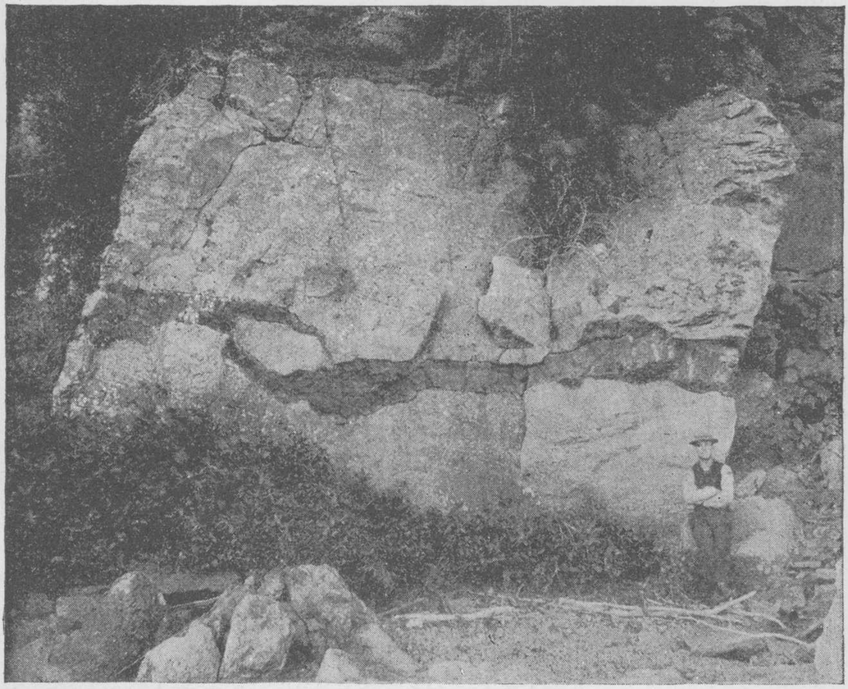


FIG. 25.—Trap sheet in arkose under palisade trap, on the shore of Hudson River, four miles south of Haverstraw, New York, looking west. From a photograph.

This anterior sheet varies in thickness from 3 inches to a foot, and may be traced for a short distance from the locality shown in the figure. The rock is a fine grained diabase, and has not altered the inclosing arkose to the least degree, but on the contrary the trap is slightly vesicular at some points along the contact.

The relations of the palisade trap to the underlying strata in the region of the great hook near Haverstraw are not well exposed, and there is considerable uncertainty in regard to the position of the contact and its changes of horizon. In discussing the structure of the region it is stated that the course of the sheet was not determined by the structure of the inclosing stata, as in the hooks of the Watchung Mountains, but by the crescentic course of the dike, aided to a considerable extent by the structure, but attended by unconformities by which a change of horizon is effected aggregating at least several hundred feet. Owing to the talus and debris, none of these unconformities are exposed, but at some points the base of the sheet is seen lying with perfect conformity on the sandstones which strike in some cases parallel to the trend of the ridge, and in others to the west-northwest. Between the West Shore Railroad tunnel and the foot of the High Torne the base of the sheet appers to ascend at least 150 feet, while just behind Haverstraw its base is 200 feet above the river, or approximately 300 feet above the position the contact would have held if it had followed the dip in this vicinity. As before suggested, it is possible that these irregularities are due in part or entirely to faults passing through the Short Clove and the Long Clove. These "Cloves" are deep depressions extending across the ridge, and they are approximately at the points where the changes of level take place.

West of Haverstraw the underlying strata are not exposed within half a mile of the trap until near Theils, where, as before noted, some pebbly conglomerates on the roadside dip gently southward directly under the edge of the sheet, and this conformable relation may prevail along the entire northern side of the hook. In the wide gap at Mount Ivy the surface of the sheet is at country level, probably being brought down by the marginal synclinal which crosses it in this vicinity. To the southward, underlying strata again come up, dipping gently to the southeastward with perfect conformity under the sheet, but not exposed in actual contact. Near Ladentown the calcareous conglomerate is exposed near the trap, but it presents no sign of alteration, and the pebbly conglomerates exposed within two feet of the trap farther southward are entirely unaltered.

Relations to overlying strata.—Owing to the extensive denudation to which the surface of the palisade trap has been subjected, overlying strata seldom extend far up its inner slope, and they are generally either removed down to the level of the detritus covered plain westward, or hidden by the heavy masses of drift which often extend for long distances along the western side of the ridge. There are, however, a sufficient number of scattered exposures along its course to indicate the structure of the trap and throw some light upon the mechanism of its intrusion.

In New York the only exposures of overlying strata are near the northwestern termination of the trap outcrop, where the relations shown in Fig. 17 prevail, and in a small outcrop of highly indurated, gently west-dipping shales, half way up the slope, in the road from Valley Cottage station to North Nyack. Elsewhere the trap either slopes gently down to the level of the back country, as in the vicinity of Rockland Lake and across the ridge from Nyack, or forms steep, rugged slopes having greater inclination than the dip of the strata in the adjoining outcrops, and indicating the extension above the surface of the dike portion of the mass. These steep, inner slopes are very conspicuous along the east-and-west ridge, southwest and west of Haverstraw, where the sandstones near the trap dip at very low angles to the westward, and southeast of Nyack, where similar conditions prevail to within a couple of miles of the State line, although in these instances the possibility of faulting is not entirely out of the question. In the cut just south of the West Shore Railroad tunnel, south of Haverstraw, there is a fine exposure of the back of the dike crossing the shales, as shown in the following figure (Fig. 26), and indicating the structure shown in Fig. 14, p. 37:

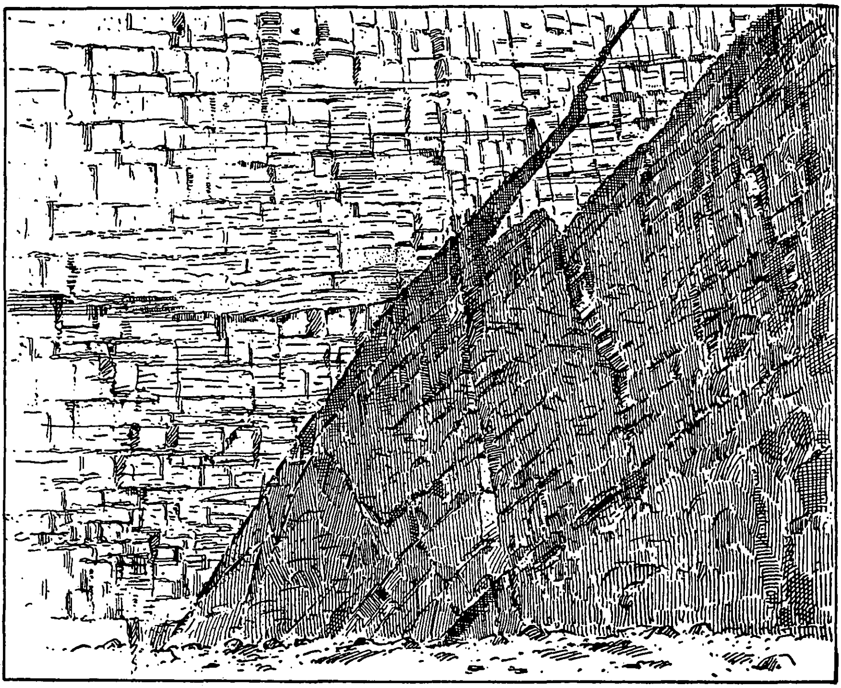


FIG. 26.—Exposure of back of dike of palisade trap in cut at southern entrance to West Shore Railroad tunnel, 3 miles south of Haverstraw, New York, looking west. From a photograph.

A short distance west of the tunnel a small area of intensely indurated shales is exposed in the roadside at the base of the ridge, and dips away from the trap nearly vertically, being apparently flexed to conform to the side of the dike.

For many miles southward from the State line into New Jersey the dike of the palisade trap does not appear to reach the present surface, and along the western slope of the ridge the sheet is overlain with essential conformity by highly indurated shales and sandstones. Two miles east of Closter is a series of exposures of indurated strata near the trap, in which only slight local unconformities are apparent, and on the road from Closter to Alpine a perfectly conformable contact is exposed.

Davis describes the locality in the stream bed near Floraville, southeast of Englewood, where the indurated shales are exposed in conformable contact with the trap, and a mile south, near and on the road from Leonia to Fort Lee, there are numerous small, thin patches of intensely indurated shales lying on the surface of the sheet.

Along a stream, about a mile northeast of Granton, there is a fine exposure of the strata immediately overlying the trap, and although the exact point of contact is not exposed, considerable unconformity exists both in dip and strike, probably indicating the presence of the dike. Two miles farther south, the back of the dike is exposed in the cut of the West Shore Railroad, as shown in the following figure (Fig. 27), and having the relations shown in Fig. 13, p. 37.

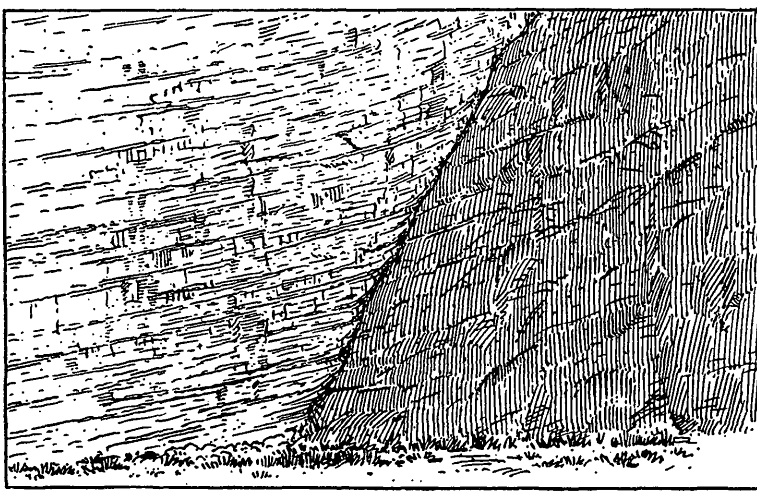


FIG. 27.—Exposure of back of dike of palisade trap in cut at western entrance to West Shore Railroad tunnel between New Durham and Weehawken, New Jersey, looking north. From a photograph.

In this exposure the strata are inclined to the northwestward 10 degrees, and the back of the dike slopes west-southwest > 60 degrees, so that the course of the dike is oblique to the strike of the strata. The rock in contact with the dike at this locality is arkose, greatly shattered at most points and considerably disintegrated, owing to the decomposition of its feldspathic constituent, but in places there is a welded, ragged contact showing unmistakably that the sharp break is not due to faulting. Between New Durham and Homestead Station (Schuetzen Park) the course of the dike is bowed eastward, as shown in Fig. 21 and on Pl. I, and its northwestwardly trend in the West Shore Railroad cut is part of this deflection, which may be connected with the change in horizon of the base of the sheet, on the other side of the ridge at Weehawken, as described on page 46.

In the small quarry, near the base of the hill, about 500 yards southeast of Homestead station, there is found the last exposure of overlying strata in New Jersey, in a mass of highly indurated, gently west-dipping shales, welded to the trap along a conformable contact line, indicating the extension of the sheet westward again to the base of the hill, and the descent of the dike below the surface. Opposite Jersey City the gentle trap slope extends down to the marsh or drift deposits, and on Bergen Point is the shore of Newark Bay. On the northwestern corner of Staten Island, and on a small island in the Kill opposite, there are exposures of unaltered, overlying, thin-bedded sandstones, dipping at a low angle westward, but they are at some distance from the trap, and nothing further is known of their relations.

As stated on page 42, there is a strip of overlying shales extending along the fault line up Bergen Point to the reservoir in Jersey City. In the exposures at Bayonne City Pennsylvania Railroad cut and the reservoir, they are entirely unaltered in texture or color, but are not exposed near their contact with the trap.

On the southwestern corner of Fairmount, in Jersey City, just east of Bergen Hill, there are some thin, irregular streaks of sedimentary material mixed with the trap, probably remnants of overlying strata, but the means by which they were included and their source are not known.

UNION HILL TRAP.

A short distance northeast of Suffern, New York, there is an isolated trap ridge very near the western border of the formation. It rises 150 feet above the surrounding country, and presents its steepest face to the eastward. It is in line with the northwesternmost outcrop of the palisade trap, as shown on Fig. 16, and is possibly due to an extension of that sheet brought up again by flexure or change in horizon. Its structural relations, so far as known, are shown in the following figure:

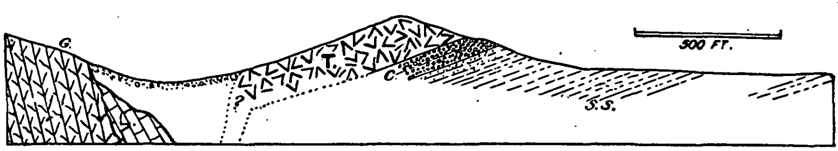


FIG. 28.—Section across Union Hill, northeast of Suffern, New York. Looking north. T, trap of Union Hill. C, conglomerate. SS, sandstones. G, gneiss. L, limestone (?).

No overlying strata are exposed, and the underlying rocks are heavy beds of quartz conglomerate, extending up to about 100 feet above the plain on the eastern side of the ridge, and dipping W. $>$ 10°, under the trap sheet. The thickness of the latter is about 100 feet. It is a moderately fine grained diabase, presenting no evidence of vesicularity at any point, and rather more like the intruded traps than those extrusive in nature. The manner in which it terminates north and south and its exact horizon in the formation are unknown.

GRANTON TRAP.

Midway between Jersey City and Hackensack a small, intrusive trap mass constitutes a short ridge just across the turnpike from the western slope of the Palisade Mountain, and lying parallel with it. In Fig. 29 its areal and apparent structural relations are shown. Its striking resemblance in structure to the palisade trap is one of the most interesting features.

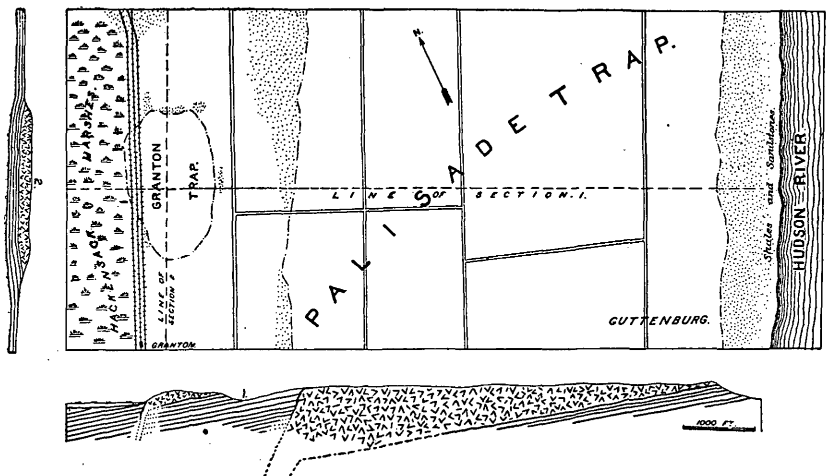


FIG. 29.—Map and sections showing relations of Granton trap to Palisade trap.

On the steep western side of the ridge the back of the dike is exposed in the West Shore Railroad cut, breaking almost vertically across the shales, of which only a small mass remains. On the eastern and northeastern sides the sandstones separating this trap from that of the Palisades dip northwestward conformably under the edge of the sheet. On the southern side of the ridge there are no outcrops. No overlying strata remain on the sheet and its outcrop terminates northward, southward, and eastward in escarpments, so that its former extent and the relations of its original north and south edges to the dike and the inclosing strata are not determinable. As its inner side is not exposed at either end of the ridge, the thickness of the dike is not known, and as there are no traces of its extension to the north or south it probably terminates within the present trap-covered area.

The rock of the posterior ridge is a moderately fine grained basalt, very similar to much of that of the adjacent palisade mass. It is dense and homogeneous throughout and presents no traces of vesicularity. The adjacent shales are greatly altered, and the trap is fine grained at the contact and welded to the sedimentary material. The thickness of the sheet now remaining is probably near 125 feet, but as the entire surface has been eroded more or less deeply, the original thickness may have been considerably greater.

SNAKE HILLS TRAP.

Big and Little Snake Hill are two knobs rising abruptly from the tide marsh some distance west of the inner slope of the palisade trap in Bergen Hill, near the latitude of Hoboken. The smaller hill is a trap outcrop covering a few acres to a maximum height of 76 feet, and nothing is known of its structural relations. The larger hill is half a mile farther west, along the eastern shore of the Hackensack River, and covers approximately a square half mile. Its elevation varies between 125 and 200 feet, and its central mass of trap is flanked in part by small remnants of sandstones and shales. It has steep slopes on all sides but the northern, which is drift-covered and gradual, and its structural relations are quite similar to those of the Granton ridge.

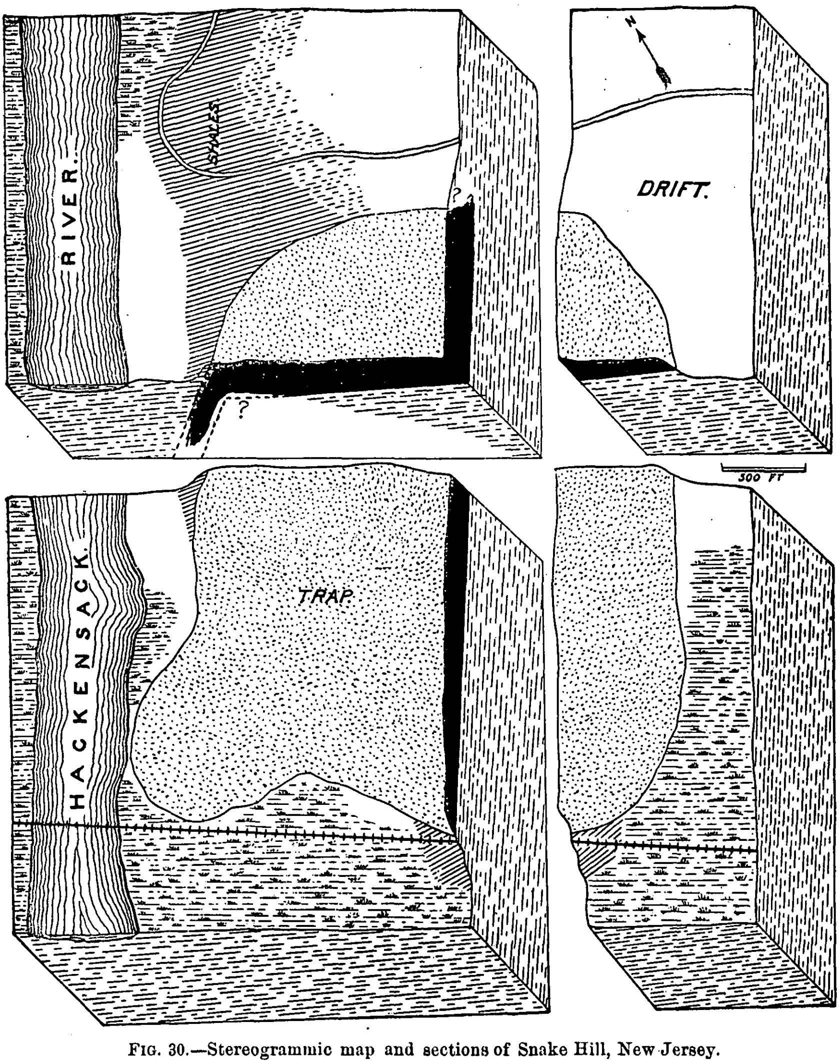


FIG. 30.—Stereogrammic map and sections of Snake Hill, New Jersey.

The trap forming the precipitous eastern side of the hill is a sheet with an irregular bedded structure, underlain southward by sandstones and shales which dip N. 30° W. > 14°, in the railroad cut. On the northern side of the cut the contact with the trap is exposed, and the line of junction, though somewhat ragged, is essentially conformable to the bedding. The dip soon carries the underlying strata beneath the surface westward, and the southwestern corner of the hill is entirely trap. On the western slope the sandstone and shale outcrops begin again as shown on the map, Fig. 30, and extend northward to the drift mantle, which obscures all but the trap boundary to the north and northeast. In the quarry near the southern termination of these sandstone outcrops the edges of the strata are exposed abutting against the back of the dike which rises along the western slope of the hill to join the sheet, which thence appears to extend eastward as shown in the cross-section. Formerly this unconformity was finely exposed at the center of the quarry, as shown in the following figure (Fig. 31), but in 1886 the only exposure was an obscure one in the northern end of the quarries.

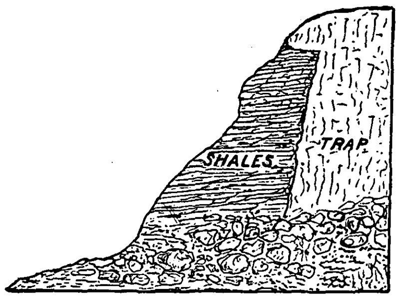


FIG. 31.—Partial cross-section at one time exposed in western side of Snake Hill, showing the back of the dike. Looking north.

The dips in this vicinity are N. 20° W. > 15°, and at some points the disturbance is considerable in amount.

The extent, thickness, and exact relations of the dike are uncertain, for its inner side is not exposed, but it does not appear to extend north and south beyond the area of the elevation, and probably is not over 20 or 30 feet thick at the greatest. The sheet is undoubtedly intrusive, as shown by its ragged contact with the shales in the railroad cut and by the alteration of the strata in the immediate vicinity of the sheet wherever exposed. The Snake Hills trap is exactly similar to the typical Palisade rock, and it has been suggested by Credner and by Russell that it is a posterior offshoot from the same mass. As the entire surface of the sheet has been exposed to erosion, the original thickness is not determinable, but there now remains about 200 feet, which is in greater part above country level.

ARLINGTON TRAPS.

Along the eastern slope of the sandstone ridge which bounds the Hackensack meadows, three miles west of Snake Hill, there are several small trap sheets, the extent of which is shown on Fig. 32.

Beginning at the south, the first exposure is in a small opening just north of the railroad, where the edge of a sheet six feet in thickness is seen conformably intercalated between beds of coarse sandstone, which are not perceptibly altered in its vicinity. A few rods farther north, at A on the map (Fig. 32), the edge of this sheet was exposed again in

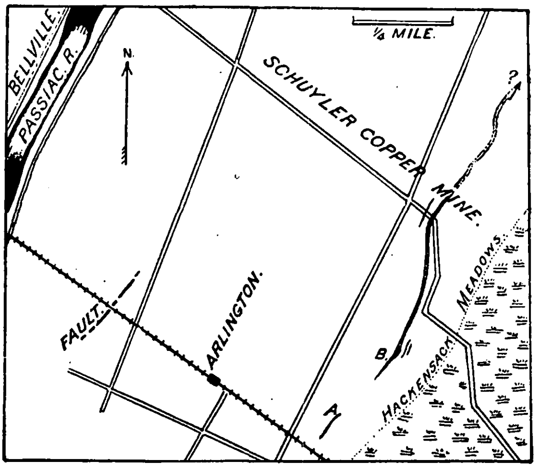


FIG. 32.—Map of the region near Arlington and the Schuyler copper mine, north of Newark, New Jersey.

excavations for copper in Westlake's quarry, and its relations are shown in the following figure:

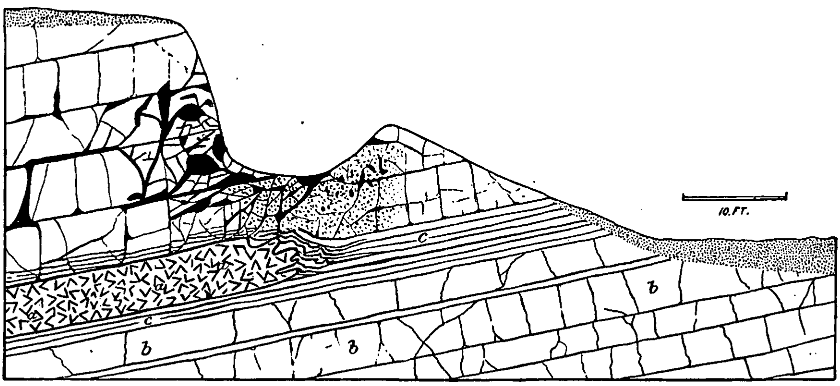


FIG. 33.—Cross-section at A on Fig. 32, in Westlake's quarry, looking north. The black blotchings and dottings represent seams and impregnations of copper ores. *a*, trap sheet; *b*, sandstone; *c*, shales.

The writer was present during the uncovering of the trap, and sketched all the details shown in the figure. The sheet has forced its way forward near the junction of shales and sandstones, lifting the latter, and probably causing the fissures which held the plates and bunches of chalcocite. The trap is a fine grained, dense, bluish gray rock, five feet thick, and with smooth surfaces to which the strata were generally found welded. The adjoining shales are intensely altered, but the alteration only extends for a few feet from the trap.

Beginning in the cemetery and thence extending northward for about a mile, a trap sheet is exposed at intervals to the old Schuyler copper mine, and may be an extension of the sheet just described. At B on the map it is associated with two smaller trap masses apparently having the relations shown in the following figure, the dike ascending along a line of fault and sending off a small sheet eastward :

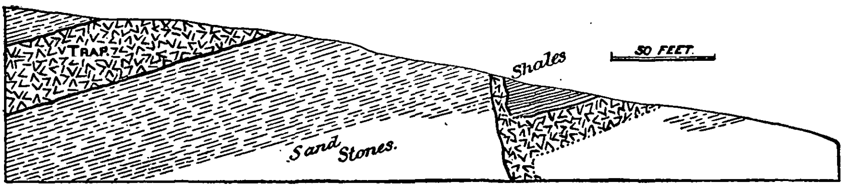


FIG. 34.—Cross-section of trap outcrop in cemetery at Arlington, New Jersey. At B on Fig. 32, looking north.

The main sheet in this vicinity is exposed in contact with sandstone, in which it is conformably intercalated, and there is comparatively little disturbance in the bedding or alteration in color or texture. North of the cemetery the edge of the sheet forms a mural escarpment along the turnpike, and its thickness is increased to 20 feet. A short distance westward in this vicinity there is a small sheet in the overlying strata, which crosses the road as shown in the map. After crossing the turnpike the main sheet pitches beneath the surface and forms the floor of the old Schuyler mine, which sends a net-work of galleries through the cupriferous sandstones near the contact. It was hoped that in this mine the structure of the trap could be studied, but the workings were found to be fallen shut in the parts of greatest interest, and the edge of the sheet could not be reached. Generally in the mine the surface of the sheet is smooth and comformable to the gently dipping sandstones, but there are irregularities in which the strata are crossed for a few feet, and the sheet sends several offshoots up into the sandstone. It is stated that the trap surface was followed westward for a half mile in the mining operations, and that at one point it is traversed by a fault of considerable amount. It is possible that this fault is an extension of the one so finely exposed in the New York and Greenwood Lake Railroad cut, near Arlington, and shown in the following figure :

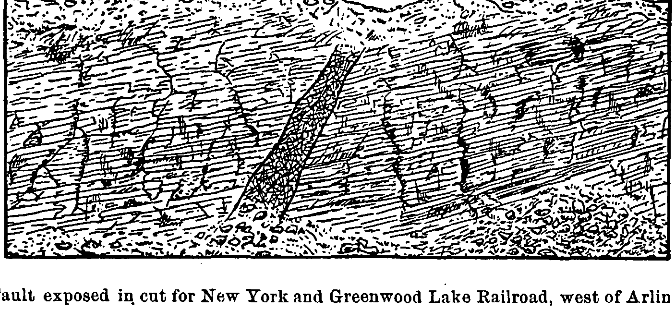


FIG. 35.—Fault exposed in cut for New York and Greenwood Lake Railroad, west of Arlington, New Jersey, looking north. From a photograph.

Cook and Russell have described some features of this fault, and its amount has been estimated at about five feet, but after a very careful reexamination of the monotonous succession of sandstones and shales on either side, the writer is convinced that it may be much greater. The disturbance is considerable, and a width of from 6 to 8 feet is occupied by fault-rock composed of slickensided fragments, coated with chloritic matter, calcite and quartz. The hade is 20 degrees to the westward and the down-thrown side appears to be the eastern. The trend is north-northeast and south-southwest, as shown on the map, and although the fault is not traceable on the surface, it very likely extends to the Schuyler mine. Russell considered the fault-rock of this dislocation the result of metamorphism, which is also stated to extend for some distance on either side, indicative of the presence of trap below, but, excepting the coating mentioned above, the rock is not altered in appearance, and its hardness is not perceptibly increased.

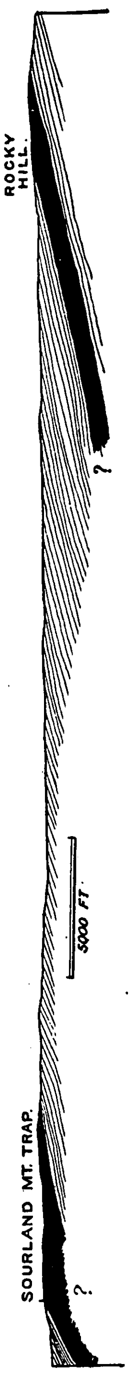


FIG. 36.—Section through Rocky Hill at gap of Millington River across to Sourland Mountain, looking northeast.

LAWRENCE BROOK, TEN MILE RUN MOUNTAIN, ROCKY HILL, PENNINGTON MOUNTAIN, BALD PATE, AND JERICHO HILL TRAPS.

A series of trap outcrops extends from the Cretaceous border six miles southwest of New Brunswick, west-southwestwardly, diagonally across the southern corner of the New Jersey Newark area into Pennsylvania, a distance of 25 miles. They are in the region to which I have given the least attention, and their structural and stratigraphical relations are not well exposed for study. Pls. I and VI and Fig. 37 indicate the position and extent of the several members of the series, and their relation to the palisade trap was discussed on a preceding page.

With the exception of the Lawrence Brook outcrops, which are at country level, the traps of the series give rise to sharply defined ridges, rising three or four hundred feet above the red shale country, and consisting of a thick trap sheet, more or less heavily flanked by the highly altered, gently west-dipping strata into which it was intruded.

In the gap by which the Millington River crosses Rocky Hill at Rocky Hill Station there is a typical cross-section exposure in which the relations are as shown on the right in Fig. 36.

Whether or not the breaks in the line of outcrop that isolate Pennington Mountain are due to discontinuity in the trap is not definitely known, but the sheet is probably continuous, and its presence under the surface indicates the belt of altered shales in the intervening gaps.

The trap is uniform in character throughout, being in greater part a coarse grained, blue gray rock, similar to that which predominates in the palisade outcrop, and similarly fine grained and bedded in structure near its contact with the sedimentary rocks. The latter are always more or less highly altered, frequently for a hundred feet vertically above the sheet, and this alteration is especially noticeable and interesting at the copper mine near Griggstown, Rocky Hill gap, and Lawrence Brook, as described by Rogers and Cook. There are a number of irregularities in the course of the Lawrence Brook, Ten Mile Run Mountain, and Rocky Hill trap which are not entirely due to changes in structure of the inclosing strata and a progressive ascent westward, in its horizon in the formation; for at Lawrence Brook the sheet lies near the basal beds at the Cretaceous border, and at Hopewell, 1,000 feet higher if faults do not intervene. In the following figure (Fig. 37) these features are shown, and it will be seen that the trap crosses the strike for some distance south of Hopewell, and at the northwestern end of Ten Mile Run Mountain.

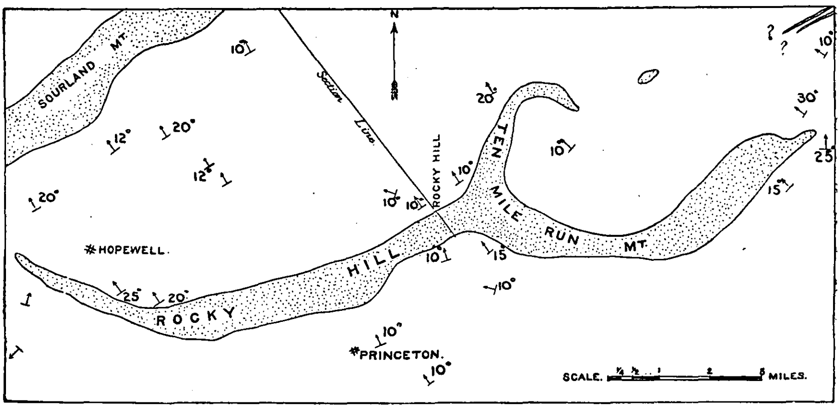


FIG. 37.—Map of Rocky Hill, Ten Mile Run Mountain, Lawrence Brook trap and vicinity.

Unfortunately I did not have an opportunity to study the question in detail, and do not know whether the unconformities are exposed in the shales which underlie the trap along the southern slope of the ridge, or in those on its other side. The structure of the crescentic outcrop east of Rocky Hill is not definitely known, and while its form is very suggestive of a cross synclinal or of centroclinal flexure, it is apparently due to a bifurcation of the sheet or of the course of its feeder, and progressive changes of horizon in the trap at the southern part of the Ten Mile Run Mountain.

In the interval between the western end of Rocky Hill and Pennington Mountain the strata are considerably disturbed in position and altered in color and texture. At its westernmost exposure the Rocky Hill trap thins out and pitches beneath the surface, apparently to pass over the point of a low northwest pitching anticlinal and reappear in Pennington Mountain, as suggested by the dotted lines in Pl. VI.

Pennington Mountain consists of a trap sheet, conformably capping northwest dipping, altered shales, which extend up its steep eastern side and flank its western slope. The trap thins southwestwardly and retreats down the dip to sink below the surface, but probably reappears again in Bald Pate. This irregular ridge is similar in structure to Pennington Mountain, but is apparently traversed by a fault or flexure causing its wide, northern lobe. The trap of Bald Pate reappears on the Pennsylvania side of the Delaware as Jericho Hill, the hooked termination of which is due to flexure, as described by Lewis, and indicated in Pl. VI.

SOURLAND MOUNTAIN TRAP.

This great intruded sheet and its heavy flanking of indurated shales constitute the prominent flat topped mountain extending from Neshanic to the Delaware River, and thence into Pennsylvania to the great medial fault which cuts it off very near its natural termination. Throughout its course the ridge rises steeply to about 200 feet above the adjacent plain, with a width averaging near four miles, and with both slopes approximately the same in inclination. The trap outcrop occupies the center of the elevation, varying in width as shown in the map, and the belt of hardened and darkened sedimentary rocks forms the edge of the plateau and the corrugated slopes.

Along the Delaware, south of Lambertville, the trap sheet is finely exposed in cross-section, and the following figure shows its relations to the associated strata and to the other trap sheets of the Delaware River region.

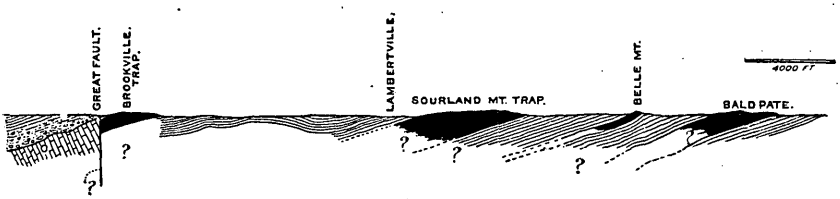


FIG. 38.—Section along the northeast side of the Delaware River from Titusville to Stockton, New Jersey, on line L —— K, Plate VI. O, lower Paleozoic limestone overlain by basal Newark conglomerateand sandstones.

In the main, the trap-sheet preserves essentially the same horizon throughout, but east of Ringoes there is a sharp deflection in the line of outcrop, which is due to a temporary change of horizon, amounting to about 250 feet vertically, and slightly aided by flexure.

The strata inclosing the sheet dip to the northwest in the main, at angles between 12 and 18 degrees, the principal variation being near the northern end of the ridge, where the dip is only about 5 degrees and the width of outcrop correspondingly increased, and along the Delaware, where the amount is about 22 degrees. A singular feature in the structure of the Sourland Mountain trap sheet is the comparatively greater inclination of the strata on its western flanks than that of the underlying beds and those in the plain country to the westward. This structure is not apparent throughout the course of the ridge, but is the most noticeable between the deflection near Ringoes and its northern termination. East of Ringoes the dips are at first 10 to 12 degrees, but as the slope of the ridge is ascended they progressively increase finally to 25 degrees, while on the eastern side the amount is about 12 degrees throughout. It seems probable that this increase in dip indicates the structure shown by the dotted line A in the following figure, but it is also possible that it is due to a general longitudinal flexure, as shown by B.

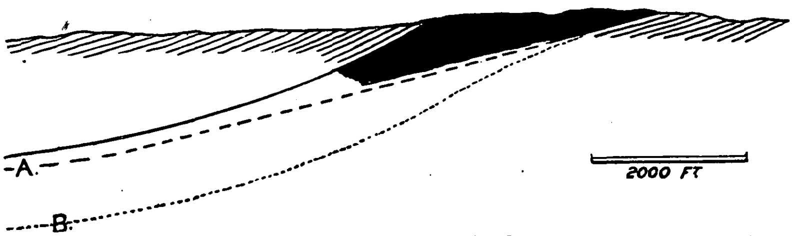


FIG. 39.—Section across Sourland Mountain from Ringoes to Snydertown, New Jersey, on line C——X, Pl. VI.

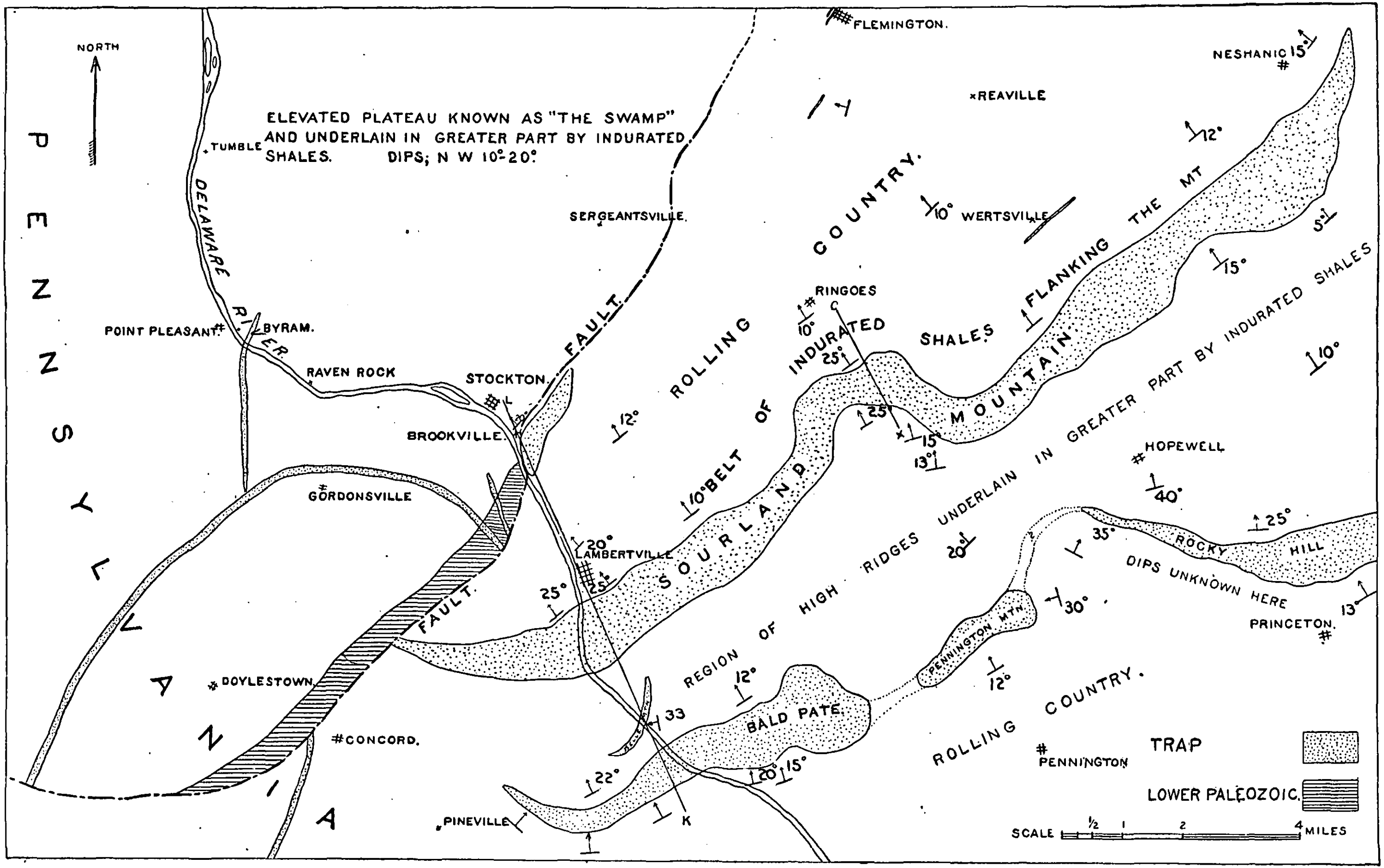
The thickness of the Sourland Mountain trap appears to be generally near 700 or 800 feet, but along the Delaware the amount is nearly 1,500 feet if the sheet is not traversed by faults. Its northern termination near Neshanic is due to thinning out, and the mechanism of its increase in thickness southward is not known, as it may be due either to wider separation of the inclosing beds by flexure or to progressive lateral unconformities to their edges. The terminal outcrops in Pennsylvania were not studied.

The rock of the sheet is rather coarse grained, except near its contacts, where it is often very fine grained, and is in general very similar to the palisade trap and the rock in the ridges to the east and south. It appears to be the result of a single intrusion and to occupy a horizon considerably above that of the palisade trap.

Contacts of the trap with the inclosing strata were not found and would be very dificult to recognize in hand specimens on account of the intense induration. This alteration of hardness and color of the shales is one of the most characteristic features of the ridge, and it is due to their hardness that the altered beds constitute so considerable a portion of its flanks. The alteration seldom extends for less than 200 feet above the trap, and 30 or 40 feet below, but generally prevails in both directions for five or six hundred feet vertically. At Lambertville, and on the opposite side of the river as described by Rogers, and near Rocktown, southeast of Ringoes, nodular alteration products are conspicuous in considerable variety.

TRAP OF CUSHETUNK AND ROUND MOUNTAINS.

Ten miles west of the hooks of the Watchung Mountains is the prominent ridge of Cushetunk Mountain, which extends in an irregular



MAP OF THE DELAWARE RIVER REGION.

horse-shoe shaped course to the border of the formation, as shown in Fig. 40.

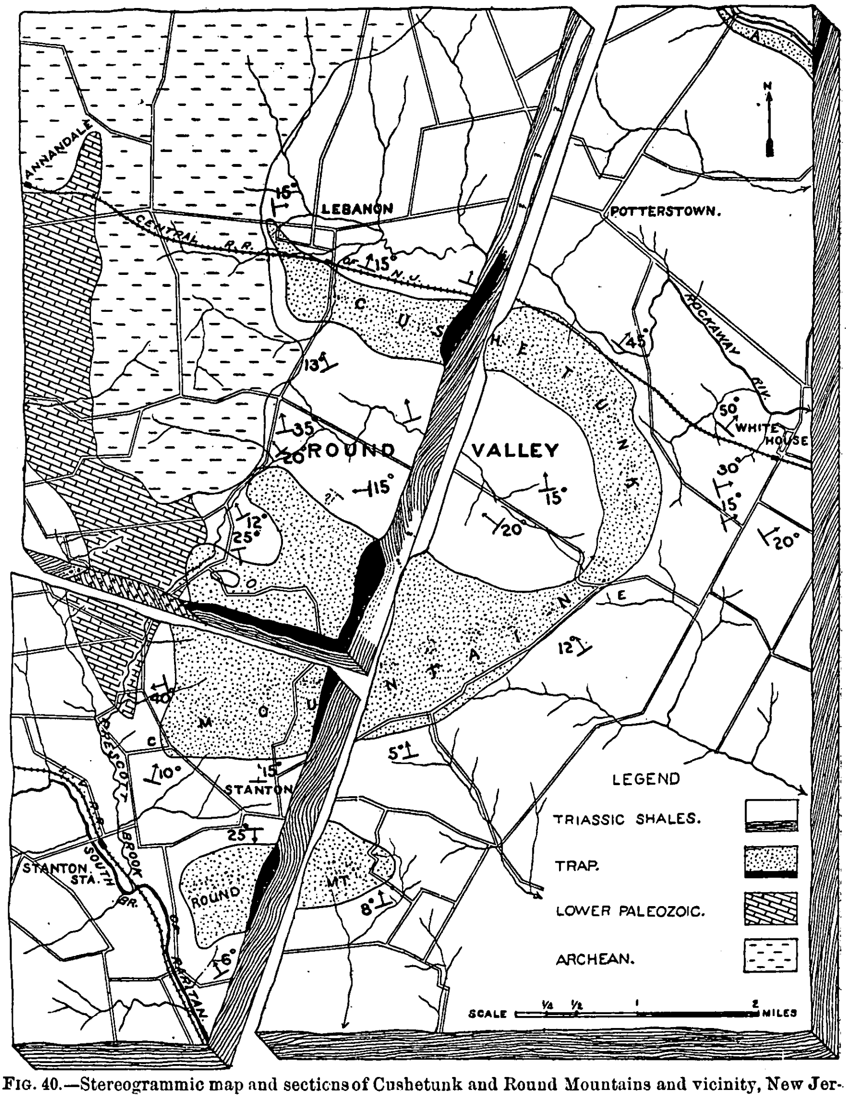


FIG. 40.—Stereogrammic map and sections of Cushetunk and Round Mountains and vicinity, New Jersey. A, part of New Germantown trap.

Excepting at its western ends the portion of Cushetunk Mountain bordering the inclosed, oblong, red shale valley is of unbroken crest line, generally elevated between 650 and 850 feet above tide and having a steep inner slope. In its broad lobe southward the slopes are gentle to the west and south but steep to the southeast, and a depression extends up into the mountain from the westward.

Round Mountain rises pyramidally to an elevation of 608 feet above tide, with moderately steep slopes on all sides, and is separated from Cushetunk by a depression extending down to 345 feet above tide.

The structural relations of the region are complicated by flexures and irregularities of intrusion, and outcrops of the sedimentary rocks are not sufficiently numerous in the vicinity of the traps to yield data for the satisfactory determination of all the relations. As shown in the cross-sections, the trap appears to have constituted one wide sheet, considerably flexed, and with the form of its present outcrops mainly determined by the removal of the trap from the crests of anticlinals. In the northern ridge of Cushetunk the trap is a sheet extending down between the strata northward and northeastward for an unknown dis-distance in the slightly flexed monocline. In the vicinity of E the sandstones are not exposed within a half mile of the trap, and the relations are uncertain, but the inner edge of the sheet comes to the surface in a synclinal which begins near that point, and thence with increased width and depth extends westward, as shown in the medial longitudinal section in Fig. 40. Southwest and west from E, around the outer edge of the mountain, the strata dip gently beneath the eroded edge of the sheet until near C, where the trap pitches beneath the surface, and so continues along the wide western border of the outcrop. Just north of the center of the cross-section the edge of the sheet comes to the surface again and is exposed, overlapping the bordering Paleozoic limestone for some distance, as shown in the following figure:

FIG. 41.—Contact of Cushetunk trap and Cambrian (?) limestone near Prescott Brook, 2 miles east of Allentown, New Jersey. Looking north. From a photograph.

Up the depression just east of this overlap, patches of shale are inclosed by the trap outcrops, but their relation is not exposed, and just northward there is a considerable embayment of strata apparently below the sheet in horizon brought up by a low, local anticline.

In Round Valley the strata are not exposed near the trap, and few dips were observed that would aid in determining the relations. On the north side of the valley the dips are towards the trap; at the eastern end no outcrops are found within half a mile of the ridge; in the center northwestern dips prevail, but they become more to the westward south of the valley road, and at one point near the trap the dip is apparently steeply to the southwestward in an obscure outcrop, as shown by the dotted dip-mark in Fig. 40. Notwithstanding the scarcity of positive evidence it seems probable that Round Valley is an irregular anticline, with its axial plane dipping northeastward and pitching northwestward.

The trap of Round Mountain lies in a well defined synclinal or spoon, and is separated from Cushetunk by a local anticlinal shown in the cross-section.

The Cushetunk trap appears to be an intrusive sheet, as it is undoubtedly unconformable to the inclosing strata at some points, and has caused extensive alteration in their hardness and color. In the railroad cuts between Lebanon and White House the conformable overlying strata are indurated at several points for some distance from the trap, and near Stanton the underlying beds are hard and black for a thickness of at least 150 feet. Contacts with the sediments were not found, but north of Stanton the line of juncture was only obscured by a narrow belt of debris, and might have been discovered by a more careful search than I had time to make.

The thickness of the Cushetunk trap could be determined even approximately only in the northern part of the ridge, where it averages near 400 feet. In the southern outcrops the original thickness of the sheet was reduced by erosion, as its entire surface is exposed, but north of Stanton the amount is at least 900 feet, if the dip is constant and no faults intervene. The surface of the sheet in Round Mountain is similarly exposed to denudation, but a thickness of at least 350 feet of trap remains. Near E, and from C northward, the uneroded edge of the sheet is very thin, and the northern ridge appears to end westward by thinning out near Lebanon.

The Cushetunk trap is a dense, coarse grained, gray rock, excepting at its edge near C, where it is fine grained and more like an extrusive rock in appearance and topography.

SMALL SHEETS IN THE RARITAN RIVER REGION.

Martin's Dock.—The occurrence of two thin sheets or trap intercalated in the shales near this point is described and figured by Cook,[1] and by Davis, in his Triassic Trap Memoir, page 276 and figure 52, and in Cook's report for 1882 a photo-lithograph is given of a portion of the exposure. I can add but little to this information. The exposure is on the north bank of the Raritan, two miles below New Brunswick, and the following figure represents the general relations.

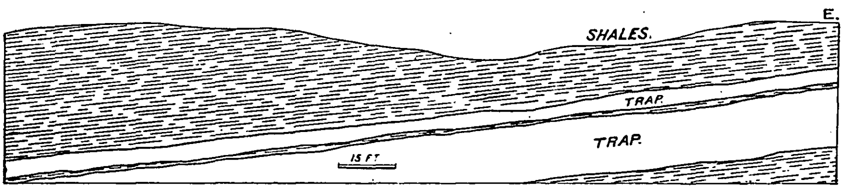


FIG. 42.—Cross-section exposure of trap sheets along the Raritan River near Martin's Dock, New Jersey, looking north.

The upper bed varies in thickness from 18 inches to 2 feet, the lower bed from 13 to 15 feet, and the separating strata is generally about a foot thick. The trap is a uniformly fine grained, blue gray rock, slightly denser and finer grained at the contact. Its surface and contacts are slightly irregular locally, but essential conformity prevails. The alter-

[1] Geology of New Jersey, 1868, p. 202.

ation in color and hardness in the inclosing shales is confined to within a few inches of the contact on either side, and no evidence of fusion was found. The intrusion has caused no noticeable disturbance in the strata except a slight breaking or offsetting of the beds at the contact line, and the two sheets are entirely separated as far as exposed. No evidence could be found bearing on the sequence of their intrusion, and it is possible that the separating shaly bed is a local inclusion in a single trap mass.

New Brunswick.—Cook[1] refers to the occurrence of trap southwest of New Brunswick, in the cut of the Pennsylvania Railroad, and at the old Raritan copper mine. The first exposures from the north are in the railroad cut, a short distance north of the "straight turnpike," where there appears to be a sheet approximately five feet in thickness intruded in the shales. The outcrop is an obscure one, and the trap is a mass of fragments inclined parallel to the dip of the strata. South of this sheet in the cut there is another and smaller trap mass, equally obscure in its relations and similarly composed of a fine grained, gray rock. Trap fragments, apparently representing the extension of both of these dikes, were found at intervals in the fields for a couple of miles to the southwestward, and at the old openings of the Raritan copper mine there is an outcrop just west of the shaft, apparently the northernmost trap, and, judging from the fragments, the other sheet was pierced by the shaft. No attempt was made to trace the traps farther southward, and they may possibly be connected with the Ten Mile Run trap, with the western arm and outlier of which they are in line. Continued northeastwardly they would cross the Raritan about at Martin's Dock, and appear to be at the same horizon as the two sheets at that place.

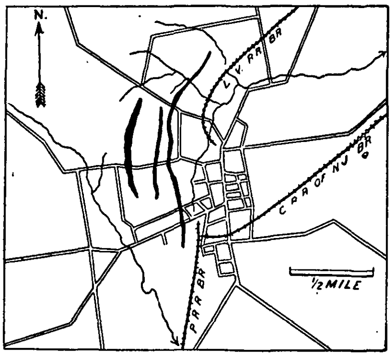


FIG. 43.—Map of Flemington, New Jersey, and vicinity, showing the extent and position of the three trap masses.

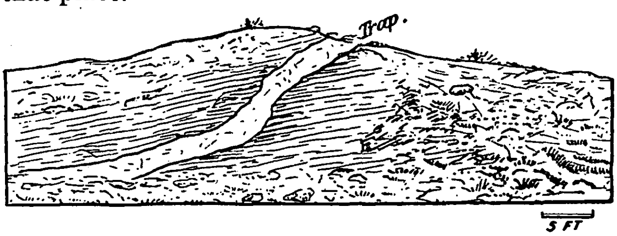


FIG. 44.—Trap sheet just east of Wertsville, crossing road to Stoutsburgh, looking north.

Flemington.—In the vicinity of Flemington there are several lines of trap intrusion, which are referred to in part by Rogers and by Cook.

[1] Geology of New Jersey, p. 204, and in the report for 1882, p. 59.

The principal mass constitutes a ridge just west of the town and extends north and south for less than half a mile, not reaching either the Clinton or the Stockton turnpike. The exact relation of the trap to the sandstone is not exposed, but from the structure and induration of the adjacent strata it is thought the trap constitutes a sheet thirty or forty feet in thickness, intruded up the northwest dipping beds of shales. Parallel to this trap and between it and the town are two smaller lines of outcrop, having the positions shown in Fig. 43. The easternmost trap forms a prominent outcrop on the Stockton road near the Pennsylvania Railroad depot, and was also found in the old copper mine near by. An extension of apparently the same trap is fairly well exposed in a run just north of the Clinton turnpike, where it appears to be a thin sheet intercalated in slightly altered shales.

Three miles south of Flemington, near Copper Hill, fragments of trap in the fields possibly indicate the southward extension of the Flemington intrusions.

Wertsville.—Six miles southeast of Flemington, and a few rods east of the road from Neshanic to Ringoes, there is a trap sheet, which was traced for about a mile parallel to the Sourland Mountain sheet, and distant from it a mile and a quarter. The best exposure observed is on the road east of Wertsville, where the relations are as shown in the accompanying Fig. 44.

The thickness of the sheet is about two and a half feet, and while the trap is in the main conformable to the west-dipping shales, it crosses them for several feet in the exposure. The rock is fine grained basalt, considerably decomposed.

Neshanic.—In the cut of the Lehigh Valley Railroad, about half a mile west of Neshanic station, there is a cross-section exposure of a small intruded trap sheet. Its thickness varies from two to three feet, and it is essentially conformable to the gently northwest-dipping strata, although on the northern side of the cut it crosses their edges at a low angle. The shales are somewhat darkened in color and hardened immediately adjacent to the trap, but the alteration is not extensive. The intrusive rock is a fine grained, bedded basalt, uniform in texture throughout. It could

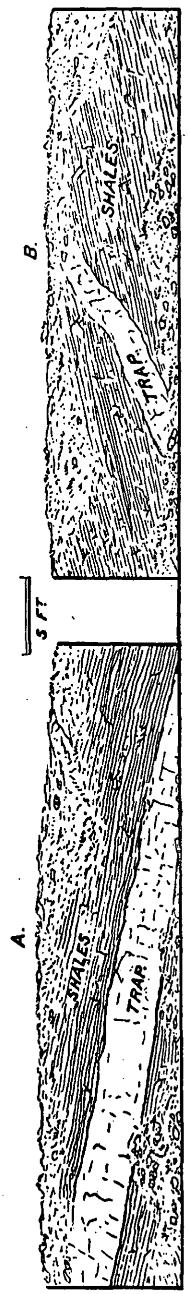


FIG. 45.—Cross-section exposures of trap sheet in railroad cut half a mile west of Neshanic Station, New Jersey. A. On south side of cut. B. On north side of cut. From a photograph.

be traced on the surface for only a few yards in either direction from the cut. Its position is shown in Pls. I and VI, and its relations in the accompanying Fig. 45.

SMALLER TRAP MASSES OF THE DELAWARE RIVER REGION.

Point Pleasant.—This trap outcrop was alluded to by Rogers in his final report on New Jersey, page 150; Cook in Geology of New Jersey, page 192, and in his report for 1882, page 63; H. C. Lewis in Am. Phil. Soc. Proc., vol. 22, page 454, and by Davis, in Triassic Traps, etc., page 277. Cook suggests, 1882, that there are two interbedded trap masses, and Davis describes the locality in considerable detail, announcing the presence of seven trap sheets, two south of Byram station, one at the quarry just north, and four in a ravine some distance northward. My examinations have convinced me that there is but one trap sheet, and the other supposed ones are heavy beds of highly altered shales. Several specimens of each were obtained and a microscopic examination showed very plainly the clastic nature of all but the coarsely crystalline rock of the conspicuous outcrop south of Byram station. This trap is an essentially conformable sheet between 100 and 125 feet in thickness, intruded between beds of shales which are altered for a short distance below, and for nearly half a mile (500 feet vertically) above the sheet. The exact contact of trap and shales was not observed, but in a ravine extending east from near Byram there is an exposure near the line of upper contact and possibly the junction could be found on careful search. The dips throughout are gently to the northwest, and there is no evidence of disturbance caused by the intrusion. The trap outcrop extends east of Byram about a mile, and southward in Pennsylvania, according to Lewis, about five miles. The rock is very similar to the typical palisade trap and is fine grained near the contacts and coarser in the center. Its general relations are shown in the following section, and its extent and relation to other traps in Pl. VI.

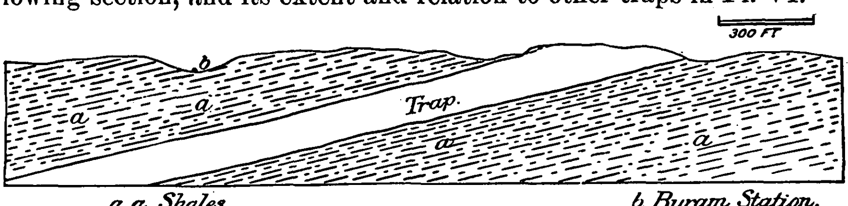


FIG. 46.—Cross-section showing the relations of the Point Pleasant trap at Byram, New Jersey, looking northeast.

Belle Mountain.—Belle Mountain, an abrupt, narrow ridge on the east side of the Delaware, between Sourland Mountain and Bald Pate, is the edge of a small intruded trap sheet. Its length in New Jersey is about half a mile, and it extends across the river into Pennsylvania for about two miles, appearing to end in either direction by thinning out. Its course is somewhat oblique to the strike of the inclosing strata, but it does not appear to have caused any considerable amount of disturbance or alteration. The rock is coarse grained, and similar to that of Bald Pate, and its relations to the other trap masses in this vicinity are shown in Pl. VI, p. 60, and Fig. 38, p. 61.

Brookville.—Midway between Lambertville and Stockton there is a trap outcrop rising abruptly from the Delaware and extending six or seven hundred yards along the river, and thence northeastwardly for a mile and a half. It is an irregular sheet of coarse grained diabase, and has caused considerable disturbance and alteration in the associated strata. It lies very near the great fault which brings up Cambrian and Ordovician rocks in the center of the formation in Pennsylvania, and it was Lewis's opinion that the trap had been intruded in the fault rock of this great dislocation. Exposures are few and unsatisfactory in its vicinity, and the relations are not entirely determinable, but it seems probable to the writer that the fault passes just northwest of the trap which appears to be entirely inclosed in Newark shale. The trap does not cross the river into Pennsylvania, at least on the surface, and may be cut off by the fault which crosses its course at the Delaware.

SMALL DIKES.

Besides the offshoots descending from the base of the palisade trap, several dikes were incidentally discovered in the progress of the work, and Cook[1] calls attention to the Blackwell's mills' dike.

Blackwell's mills.—On the east bank of the Millstone River, near this place, two miles above Millstone, there is a fine, cross-section exposure of a dike which was found to extend four miles westward, and Cook has traced it in the opposite direction nearly to the Raritan, along the course shown on Pl. I. The dike does not appear to mark a line of dislocation, but extends nearly parallel to the strike of the region and has not caused any considerable amount of alteration or disturbance. The following section shows the relations in the Millstone River exposure:

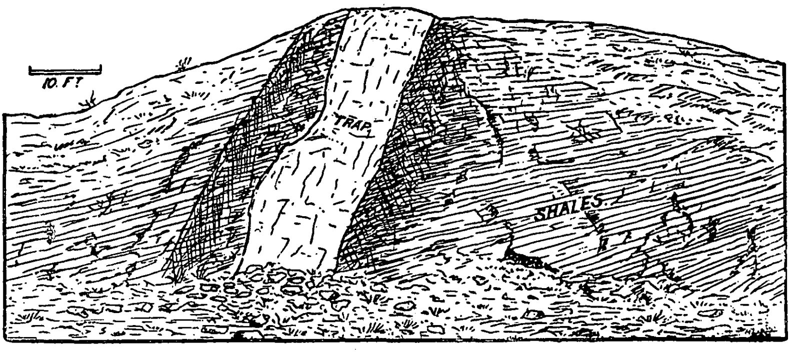


FIG. 47.—Trap dike in bank of canal 2 miles south of East Millstone, New Jersey, looking northeast.

The trap is a fine grained, dark colored rock, with a slight tendency to bedded structure parallel to the walls, and the adjacent shales are

[1] Geology of New Jersey, page 204.

darkened and altered in blotchings of black, brown gray, dark red, and dull green.

Hackensack.—About a mile east of Hackensack, on the road to Leonia, there is a small exposure of trap the exact relations of which could not be definitely determined on account of the drift and debris. It is on the crest of the first ridge east of the Hackensack River, in west-dipping red shales, which are somewhat hardened and darkened in its immediate vicinity. The exposure is about ten feet in width, and could only be traced for a short distance along a north by east course. The exact line of its contact with the shales is not exposed, and it may constitute either an irregular sheet three or four feet in thickness or a dike, as suggested in the following figure:

FIG. 48.—Trap sheet or dike two miles east of Hackensack, New Jersey. Looking north.

South Branch.—Five miles southwest of Somerville, on the road from South Branch to Neshanic, and a half mile south of the former place, a small trap dike is inconspicuously exposed. Its thickness is about a foot, and its relations are shown in the following figure:

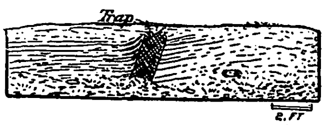


FIG. 49.—Trap dike in shales near South Branch, New Jersey. Looking east.

The rock is a fine grained basalt, greatly decomposed at the outcrop, and although the associated shales are not appreciably altered, those on the northern or upper side are bent upward, as shown in the figure. The strata in the vicinity dip N. 10° E. > 10°, and the dike appears to trend northeast and southwest.

Three Bridges.—About four miles northeast of Flemington, and a half mile northeast of Three Bridges station, there is a small trap outcrop on the road to Centreville. Its extent appears to be inconsiderable, and its relations to the shales could not be determined. It has caused considerable alteration in the adjacent strata, but has not disturbed their gently northern dip. The trap is a fine grained, dark blue-gray rock, similar to the other dike rocks of the formation.

Stanton station.—Midway between Clinton and Flemington, one mile due west of Stanton station, there is a small trap outcrop in the road but its relations and extent are unknown.

SUMMARY.

In their genetic relations, the traps of the New Jersey region belong to two classes; first, the extrusive sheets contemporaneous with the inclosing strata and typified by the great lava flows constituting the

Watchung Mountains; and, second, intrusive sheets and dikes, which attained their present positions subsequent to the deposition of the formation and of which the Palisade trap is a typical example.

The extrusive sheets are characterized by their perfect conformity to the underlying strata, the deep vesicularity and alteration, or slag-like aspect of their upper surfaces, the unaltered and undisturbed condition of the inclosing strata, the presence of trap breccias at the contacts, the altered and frequently vesicular condition of the rock at their bases, the evidence of successive flows, their relations to anterior tuff deposits, and their distinctive columnar structure and petrography.

The intrusive sheets are characterized by irregular lower contacts in which the trap cuts across the ragged edges of the strata for greater or less distances, the intense alteration in the inclosing strata, the increased density and fineness of grain and the bedded structure in the trap near the contacts, and the absence of vesicularity and breccias.

In the Watchung Mountains, erosion, glaciation, and drift cover cause scarcity of outcrops of the original upper surfaces, but there are many localities scattered along their course in which deeply vesicular trap is exposed, and others in which unaltered and undisturbed strata outcrop very near the contact. The only actual overlap well exposed is in the ravine at Feltville, where the trap surface is in greater part vesicular and slag-like and the soft, red argillaceous shales fill the irregularities excepting at one point, where there is an intervening trap breccia filling the interstices in an "Aa"-like portion of the surface.

Contacts of the Watchung traps with underlying strata are exposed at intervals along the outer sides of the ridges and absolute conformity prevails throughout. The trap is frequently vesicular and altered and lies on the unaltered or very slightly altered strata along a straight or gently sinuous line, in one case with a trap breccia intervening.

At two points in its course the second Watchung trap is exposed, overlying beds of loose, eruptive materials, apparently scoria and tuff, and at other localities the sheet is seen to be composed of successive flows, the base of one lying on the vesicular surface of a preceding flow, in one case with an intervening layer of trap breccia at some points.

In thickness the first Watchung trap varies from 450 to 650 feet; the second from 600 to 850 feet; and the third from 225 to 350 feet in the main, and the area inclosed by the outermost hooks is about 500 square miles, no doubt in greater part underlain by trap, so that the Watchung sheets represent lava-flows of no mean volume. Apparently the extrusions were continuous throughout, for, excepting the intercalated breccia above alluded to, no intervening or overlapping sedimentary materials were discovered. The absence of fragmental volcanic deposits, excepting the local beds at the base of the second Watchung sheet, is a noteworthy feature, and the first extrusions were not attended by ejections of scoria, ash, etc., or at most in sufficient amount to extend to the present lines of the outcrop. The eruptions which gave rise to the Watchung traps were no doubt very similar to those of some of the great lava-flows of the western part of the United States, which appear to have welled forth from long fissures without attendant craters or the ejection of fragmental materials.

The great hooks characterizing the southernmost outcrops of the Watchung traps are entirely due to flexure, and the bowed course of their northern terminations and of Towakhow Mountain are due to the same cause.

In the vicinity of Paterson the first Watchung trap lies on conglomeratic members, apparently representing the base of the formation, separated from the younger members eastward by a great fault amounting to at least 2,000 feet. It would appear from this that the formation thickens southward, for, at the southern hook the trap lies on a thickness of at least 1,500 feet of fine grained strata of which the lowermost members must be some distance above basal beds.

The New Vernon trap, across the Great Marsh from the Watchung Mountains, is apparently an extension of one of the Watchung flows brought up by the partial quaquaversal which determines its crescentic course, and it is similar to them in every respect, but not so well exposed for study, while the New Germantown traps farther southwestward, but at the same horizon, are undoubtedly extrusive and may be remnants of another extension of the Watchung flows.

The palisade trap is the best exposed instance of intrusion on a large scale in New Jersey, and although it is in greater part an essentially conformable sheet throughout, the supply dike from which the sheet extends eastward up the dip, reaches the surface northwest of Hoboken and in Rockland County, New York, along the inner side of the ridge.

For many miles along the Hudson River the palisade sheet is exposed in contact with the underlying strata near the base of the formation, and while the relations are essentially conformable throughout, local irregularities are frequent in which the ragged edges of the strata are crossed laterally up or down for over 150 feet in one instance, and trap offshoots are sent down or out into the underlying beds. In the vicinity of Haverstraw the crescentic course of the dike causes a corresponding deflection of the line of outcrop, and although this is greatly aided by the structure of the underlying beds and possibly by faults, the base of the sheet has to cross the strata for several hundred feet in order to preserve its position above the surface, and at its terminal outcrop, an occurrence of vesicular rock, suggests that the sheet was finally extruded.

At its contacts with inclosing strata the palisade trap becomes fine grained, very dense, and bedded in structure, and the sedimentary rocks are darkened and hardened often to a considerable distance.

A short distance west of the palisade trap, near the latitude of the city of New York, are the posterior trap masses of Granton and Snake

Hills, similar structurally to the palisade trap in consisting of a dike, and a sheet extending eastward up the dip.

While it seems probable that the palisade trap continues southward to reappear in the series of outcrops which extend from Lawrence Brook through Rocky Hill and Pennington Mountain to Bald Pate and Jericho Hill on the Delaware, it is possible that it is due to an entirely separate intrusion. The trap of this series of outcrops from Lawrence Brook to Jericho Hill is similar to the palisade sheet structurally and petrographically, and is apparently a continuous mass not reaching the surface in the gaps that isolate Pennington Mountain. It is heavily flanked with indurated shales and crosses the strike of the inclosing strata, both at intervals in its westerly course and in the hooked outcrop of Ten Mile Run Mountain.

Sourland Mountain consists of a thick sheet of coarse grained diabase, heavily flanked by highly indurated shales, and follows the strike of the inclosing strata excepting in a local bowing near the center of its course where it crosses and recrosses the strike for a short distance.

Cushetunk and Round Mountains are the remnants of a wide, thick, intrusive sheet considerably flexed, and eroded through at the anticlinals so as to give the singular horseshoe-shaped course to Cushetunk Mountain and isolation to Round Mountain. The indurated strata associated with this trap are crossed by it at some points, and along the western border for a short distance the edge of the sheet overlaps the lower Paleozoic limestones and presents some evidence of having been extrusive.

The smaller trap masses along the Delaware, at Belle Mountain, Brookville, and Point Pleasant are all local intrusive sheets intercalated between highly altered strata, and near Neshanic, Martin's Dock, and Arlington are other intrusive sheets, finely exposed in cross-section. The other trap masses in the New Jersey region are some small sheets and dikes near and northeast of Flemington, the dike so finely exposed near Blackwell's Mills, the dike near Hackensack, and the sheets south of New Brunswick.

The ages of the intrusive sheets of the formation are difficult to estimate. Davis has called attention to the raggedness of some of the contacts as evidence that the intrusion was effected before the development of joints by the uplift of the formation, and this certainly seems very probable.

As the stratigraphy of the Jura-Trias of the New Jersey region is not worked out, the horizons of the trap masses are not known, and the sequence of their intrusion is indeterminable from any evidence now in hand. The palisade trap lies just above the basal arkose, which is known to overlap the crystalline rocks in wells in Jersey City, and as the first Watchung trap lies on basal beds near Paterson, it might be suggested that the two sheets are not far distant in horizon, but in the absence of definite knowledge of the comparative age of the basal rocks at Paterson, and the structure and configuration of the buried Newark shores in the intervening region, the relative positions of the two sheets can only be conjectured.

At Lawrence brook the supposed southward continuation of the palisade trap is not far above the base of the formation, but in Ten Mile Run Mountain and Rocky Hill the strata are crossed so that at the Delaware the sheet is apparently 10,000 feet above the Trenton gneisses, but probably there are intervening faults which might decrease this estimate very greatly.

Sourland Mountain trap is apparently high in the formation but its exact or relative horizon can not be determined until the stratigraphy and structure of the region can be worked out, and the same is the case with the other traps of the Delaware region, and the Cushetunk and the Arlington traps.

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AKERLY, SAMUEL. An essay on the geology of the Hudson River and the adjacent regions. New York, 1820, pp. 69, pl. 12°.

Gives a general sketch of the extent and salient features of palisade rocks, pp. 27–34, and a section along the Hudson River, showing the relations of the underlying strata at some points. Refers to the occurrence of amygdular rock and "rocks resembling volcanic scoria," near the falls of the Passaic. Discusses the nature of the Palisade and Newark Mountains, and seems inclined to consider them volcanic, pp. 62–64.

BRITTON, NATHANIEL L. On the geology of Richmond County, New York. Annals New York Acad. Sci., vol. 2, 1881, pp. 161–182, 2 pls.

Describes the outcrops of the trap, p. 169, and shows its extent on the map, plate 15.

COOK, GEORGE H. Geology of New Jersey. 1868, pp. 176–194, 195, 200, 201, 202–205, 207, 215–218, 230, 231, 337, 676–679.

Principally devoted to a detailed description of boundaries, the position of contact lines, and topography, pp. 176–194. Calls attention to the cause of the peculiar topography of Sourland Mountain, pp. 191, 192; the anticlinal structure in Round Valley, p. 193; bedded structure in trap at Martin's Dock, Belleville, and near Plainfield; columnar structure in Morris Hill, Paterson, and elsewhere, and trap dikes at Blackwell's Mills, Flemington, and near New Brunswick. Gives a cross-section of the palisade trap, p. 200, and discusses the mode of its intrusion. Gives list of joints in Bergen Hill, pp. 202–205. Describes and gives analyses of some of the traps of each the principal trap masses, pp. 215–218. Discusses the genesis of the traps and their relative ages, p. 337. In describing copper ores of the formation, pp. 676–679, refers to trap at the Schuyler mine and the exposures of base of first Watchung trap in mines near Plainfield and Somerville. On the accompanying map the trap boundaries are shown and cross-sections given across the formation.

——— Geological survey of New Jersey. Annual report of the State geologist for the year 1874, pp. 56, 57.

Announces discoveries of grains of metallic iron in trap of Bergen Hill.

COOK, GEORGE H. Geological survey of New Jersey. Annual report of the State geologist for the year 1879, pp. 20, 32, 34.

Includes a general statement of the distinctive features of the trap outcrops Calls attention to an exceptional instance in which curved outcrop is not due to flexure in the great hook of the Palisade Mountains in New York, "where the trap has broken directly across the beds of stratified sandstone," p. 32. Considers all the traps intrusive.

——— Geological survey of New Jersey. Annual report of the state geologist for the year 1881, map in pocket. Shows the trap boundaries.

——— Geological survey of New Jersey. Annual report of the State geologist for the year 1882, pp. 19, 22, 23, 31, 32, 43–66, map in pocket. The descriptions of the traps in this report, covering 23 pages, consist mainly of brief references to the more general features of the outcrops, their extent, topography, rocks, columnar structure, nature of the exposures, and the alteration and some of the relations of the associated sedimentary members, but in some cases the structural relations are briefly considered as follows:

Palisade trap.—Description and photo-lithograph of relations at Weehawken. Notes overlying strata at Homestead station and Alpine, the frequency of lower contacts, the occurrence of sandstone between trap outcrops at Bayonne City and in Bergen cut, and estimates the maximum thickness of the trap at 400 feet at Alpine and 200 feet at Weehawken.

Snake Hills.—Notes occurrence and dips of adjoining shale outcrops, and considers it probable that the trap has broken across the strata.

Watchung Mountains.—Discusses connection with traps of Ramapo Valley. Calls attention to the parallelism of outcrops to strike; some of the relations of underlying strata at Paterson, Plainfield, and Somerville; the elevation of contact line in outer side of First Watchung Mountain; overlying rocks near Warrenville; the shale fragments near Mount Horeb, in the Second Watchung Mountain, indicating the possibility of an interval between the two sheets of trap rock lower contacts and columns near Little Falls, and the occurrence of cellular rock surface in some places along western slopes on the ridges.

Pompton, Preakness, and Hook Mountains, Riker's Hill and Long Hill.—Calls attention to some relations of underlying strata near Pompton, in Hook Mountain and Long Hill, occurrence of cellular rock on back of the ridge near Mountain View and outliers of trap west of Pompton Plains. Estimates the thickness of the trap near Vreeland's quarry as at least 300 feet. Discusses cause of the east and west ridge of Hook Mountain, and considers it due to "a series of offsetting northeast and southwest dykes connected by outflows through fractures across the strata."

Basking Ridge trap.—Calls attention to the uncertainty of its boundaries and to the occurrence of an outlier near Bernardsville, having cellular rock on its eastern slope.

New Vernon trap.—Refers to outcrops of cellular rock on its surface at some points, and is of the opinion that the trap has broken across the strata through part of its course.

Martin's Dock trap.—Description and photolithograph of the outcrop and references to the trap exposed south of New Brunswick. Calls attention to belt of indurated shales crossing the Raritan below Martin's Dock.

Ten Mile Run.—Rocky Hill trap. Calls attention to the unconformity of intrusion indicated by the curved course of these outcrops.

Sourland Mountain.—Refers to some structural features and the alteration in the strata along its flanks.

Point Pleasant trap.—Discusses its extent underground and states opinion that there are two sheets.

Cushetunk Mountain.—Considers trap unconformable to strata at some points, and to have been intruded along axial lines.

COOK, GEORGE H.—Continued.

New Germantown trap.—Considers trap unconformable at some points.

The trap boundaries on the map only differ from those on the map issued with the preceding report in having the New Vernon outcrops continuous.

—— Geological survey of New Jersey. Annual report of the State geologist for the year 1883, frontispiece, pp. 22–25, 164–166.

Reviews Davis's conclusions in regard to the extrusive nature of the Watchung traps and states his opinion that all the traps of the New Jersey region "were intruded after the sedimentary rocks had been elevated to their present inclined position." Describes a lower contact of the second Watchung sheet at Haledon and gives a photolithograph of the exposure. Calls attention to altered strata associated with the Lawrence Brook, Ten Mile Run, Sourland Mountain, Palisade and Schuyler Mine traps as noted in the report for 1882, and on the back of First Watchung Mountain near Pluckamin, Feltville, and Warrenville. Does not consider the occurrence of cellular trap a decisive proof of extrusion and thinks the curved courses of the traps indicative of intrusion.

—— Geological survey of New Jersey. Annual report of the State geologist for the year 1884, frontispiece, pp. 23–28.

Description and photolithographs of the columnar trap near Orange. States opinion that the trap is intrusive and suggests the possibility that the small-columned rock represents the edge of a separate sheet. Calls attention to the occurrence of cellular trap on the back of the First Watchung Mountain at the Orange water-works.

—— Geological survey of New Jersey. Annual report of the State geologist for the year 1885, p. 122.

Refers to a well 297 feet deep in the palisade trap in Union, and one near Montclair through the first Watchung trap into the underlying sandstones.

—— Geological survey of New Jersey. Annual report of the State geologist for the year 1886, pp. 125–127.

Discusses briefly the nature of the traps and states his opinion that all are intrusive, excepting perhaps, locally, where they may have reached the surface and overflowed.

—— and SMOCK, JOHN C. Geological survey of New Jersey. Map of northern New Jersey, 1874.

Shows the trap areas of northern New Jersey and Rockland County, New York, and gives a cross-section from Jersey City to Morristown, showing the structural relations of the Palisade and Watchung traps.

COOPER, T. On volcanoes and volcanic substances, with a particular reference to the origin of the rocks of the floetz trap formation. Am. Jour. Sci., vol. 4, 1822, pp. 205–243.

Describes the occurrence of columnar and amygdular "basalt" at the falls of the Passaic and is of the opinion that it was poured out over "the old red sandstone" and similar in nature and origin to the other traps of the New Jersey region.

COZZENS, ISSACHAR, Jr. A geological history of Manhattan or New York Island, New York, 1843, pp. 114, pl. 9, 8°.

Gives a section along the Hudson from Jersey City to Weehawken, showing the position of the Palisade trap and underlying strata, plates 2, 3, and a section at Pompton across the third Watchung trap, pl. 8. Refers to the Palisade and Watchung traps as unconformable volcanic rocks, p. 111, and describes the columnar structure and extent of the former, p. 48.

CREDNER, HERMANN. Geognostische skizze der Umgegend von New York, Zeitschr. Deutsch. geol. Gesell., vol. 17, 1865, pp. 388–398, pl. 13.

Describes some of the more obvious features of the Palisade, Staten Island and Snake Hill trap outcrops. Considers palisade trap intrusive and the Snake Hills due to offshoots from the main trap mass.

DARTON NELSON H. On the disintegrating sandstones of New Durham, New Jersey. Trans. New York Acad. Sci., vol. 2, 1883, pp. 117-119.

Describes the relations and lithology of the strata lying against the back of the dike of the palisade trap in the cut at the west end of the West Shore Railroad tunnel at Weehawken.

DAVIS, WILLIAM MORRIS. Brief notice of observations on the Triassic trap rocks of Massachusetts, Connecticut, and New Jersey. Am. Jour. Sci., 3d series, vol. 24, 1882, pp. 345-349.

Refers to the palisade trap as undoubtedly intrusive and the trap of the Watchung Mountains as probably extrusive. Calls attention to the breaking of the dikes and intruded sheets across the strata without relation to the present joint planes as evidence indicating that the intrusion was effected before the formation was tilted.

——— The structural value of the trap ridges of Connecticut Valley. Proc. Boston Soc. Nat. Hist., vol. 22, 1882, pp. 116-124.

Refers to some general features of the trap ridges, and instances the palisade trap as a typical intrusive sheet.

——— On the relations of the Triassic traps and sandstones of the eastern United States. Bull. Mus. Comp. Zoöl., Harvard College, vol. 7, No. 9, 1883, pp. 249-309, pl. 9-11.

Besides a general review of former opinions on the subject, describes a series of typical localities in New Jersey, pp. 269-279, and discusses the evidence indicative of the intrusive origin of the trap of the Palisade, Sourland Mountains, Martin's Dock, Point Pleasant, etc., pp. 244-295, 296, 301, and the extrusive nature of the Watchung traps, pp. 291, 294, 300, 302.

Palisade trap.—Describes upper contact near Englewood, lower contact at Fort Lee, and the unconformity and indurated shales at Weehawken. Suggests that King's Point and the occurrence of sandstones in the Bergen Cut are due to faulting.

Watchung traps.—Describes lower contact at Paterson, faults in Garret Rock, amygdular and ropy trap surface southwest of Paterson, lower contacts and tuff deposits at Little Falls, and the surface of the first Watchung trap in contact with overlying unaltered shales and breccia at the Feltville locality, indicating the extrusive nature of the sheet. Suggests that irregularities in columnar structure of First Mountain may be due to successive flows, p. 300.

Martin's Dock.—Detailed description.

Point Pleasant Station.—Describes main trap mass south of the station, and six others in the shales northward.

EMMONS, EBENEZER. Agriculture of New York, vol. 1, 1846, p. 200, map.

Gives a section of the Palisades near the State line, and states that the intrusive nature of the trap is indicated by the manner in which it is intercalated in the sandstone layers and by the alteration that it has produced.

GRATACAP, LOUIS P. Fish remains and tracks in the Triassic rocks at Weehawken, New Jersey. Am. Naturalist, vol. 20, 1886, pp. 243-246, pl. 12, 13.

Describes strata underlying the palisade trap at the locality, and gives a section showing the position of the contact line in the entrance of the West Shore Railroad tunnel.

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Gives a description and sketch of the columns and discusses columnar structure.

IDDINGS, JOSEPH P. The columnar structure in the igneous rock on Orange Mountains, New Jersey. Am. Jour. Sci., 3d series, vol. 31, 1886, pp. 321–331, pl. 9.

Describes and figures the columns and discusses the origin and nature of columnar structure. Shows that the variations in structure are not indicative of successive sheets and gives an account of the petrography of the rock, the glassy nature and disposition of the columns of which are thought to indicate a surface flow and not an intrusion.

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Describes the extension of the Bald Pate, Belle Mountain, Sourland Mountain, and Point Pleasant traps into Pennsylvania, and some of the relations of the Brookville trap and the great medial fault in New Jersey.

MATHER, WILLIAM W. Geology of New York, First Geological District, 1843, pp. 278–283, 627, pls. 1, 5, 34, 45.

Describes the palisade trap in Rockland County and Staten Island, some of the irregularities of lower contact along the Hudson River south of Haverstraw, and the alterations of the underlying strata, pp. 278–282. Considers the trap an ancient lava, "that has flowed through the rocky fissures in dikes, while this portion of the continent was still beneath the waters of the ocean," and similar in origin and relations to the other traps of the New Jersey region, p. 283. It is thought that the trap was "probably erupted at the epoch of the marl and green sand deposits of New Jersey," p. 627.

PIERCE, JAMES. Account of the geology, mineralogy, scenery, etc., of the secondary region of New York, New Jersey, and the adjacent States, 1820. Am. Jour. Sci., vol. 2, pp. 181–199.

Describes the general features of the more prominent trap masses of the New Jersey region, especially the Palisade and Newark Mountains.

ROGERS, HENRY D. Report on the geological survey of the State of New Jersey, 1836, pp. 188, pl., 8°, Philadelphia.

All the information in regard to the traps in this report is republished with additions in the report for 1840, excepting a plate of sections showing the supposed relations of the larger trap masses.

——— Description of the geology of the State of New Jersey, being a final report; Philadelphia, 1840, pp. 301, map, pl., 8°.

Briefly describes the course, topography, and rocks of the principal trap masses of New Jersey, the altered strata at Lambertville, New Hope, The Swamp, Lawrence Brook, on back of First Watchung Mountain northwest of Plainfield (at Feltville), Rocky Hill, Moore's Creek, Sourland Mountain, and Point Pleasant, and the contacts at Paterson, Little Falls, and the copper mines near Somerville. Discusses the relations of the traps to the sedimentary members, the date and mode of extrusion, induration, and the origin of the copper ores, pp. 114-171, map, plate.

RUSSELL, ISRAEL C. On the intrusive nature of the Triassic trap sheets of New Jersey. Am. Jour. Sci., 3d series, vol. 15, 1878, pp. 277–280.

Refers to alteration of strata underlying the palisade trap at Paterson and near Plainfield, and describes a locality near Feltville where the bossy, vesicular surface of the first Watchung trap is exposed, overlain by highly altered shales and a thin bed of metamorphosed limestone. Calls attention to the occurrence of the trap breccia and suggests that it may "have a history somewhat similar to that of the 'friction breccias' mentioned by Van Cotta," considers the curved courses of some of the New Jersey traps indicative of unconformable intrusion.

RUSSELL, ISRAEL C. On the occurrence of a solid hydrocarbon in the eruptive rocks of New Jersey. Am. Jour. Sci., 3d series, vol. 16, 1878, pp. 112–114.

Describes the albertite-like substance occurring in elongated vesicles, in the trap at the locality described in the preceding paper, and discusses its origin.

—— The physical history of the Triassic formation of New Jersey and the Connecticut Valley. Annals, New York Acad. Sci., vol. 1, 1878, pp. 220–254.

Includes some general statements in regard to the relations and nature of the traps and a discussion of their supposed former connection with those of the Connecticut Valley region.

—— The geology of Hudson County, N. J. Annals, New York Acad. Sci., vol. 2, 1880, pp. 27–80, pl. 2.

Describes contacts and their irregularities at the base of the palisade trap along the Hudson from Jersey City to Bull's Ferry, the dike at Guttenberg and some of the relation at Snake Hill. Gives an ideal section of the palisade trap and its supposed offshoots, to which Snake Hills, Fairmount, King's Point sheet, and the posterior ridge of Bergen Hill are thought to be due. Alludes to occurrence of trap at the Schuyler mine, and describes the fault rock and its supposed metamorphism in the cut west of Arlington.

—— On the former extent of the Triassic formation of the Atlantic States. Am. Naturalist, vol. 14, 1880, pp. 703–712.

Includes general statements in regard to the palisade and Watchung traps and allusions to the evidence of their intrusive nature. Calls attention to altered strata on top of First Watchung Mountain along Johnson's drive near Plainfield, New Jersey.

WURTZ, HENRY. Progress of an investigation of the structure and lithology of the Hudson River palisades. Proc. New York Lyceum, vol. 1, 1871, pp. 99–105.

Advances the hypothesis that the palisade trap is a metamorphic rock throughout, and appears to consider the other traps of similar nature, excepting that of the First Newark Mountain, which it is suggested may be eruptive in part. Considers the highly altered strata underlying the palisade trap transition beds. Describes the petrography of the trap of Bergen Hill.

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