# THE NEWARK ROCKS OF NEW JERSEY AND NEW YORK[1]

THE Newark rocks extend across the northern part of New Jersey, forming a belt which is about thirty-two miles wide

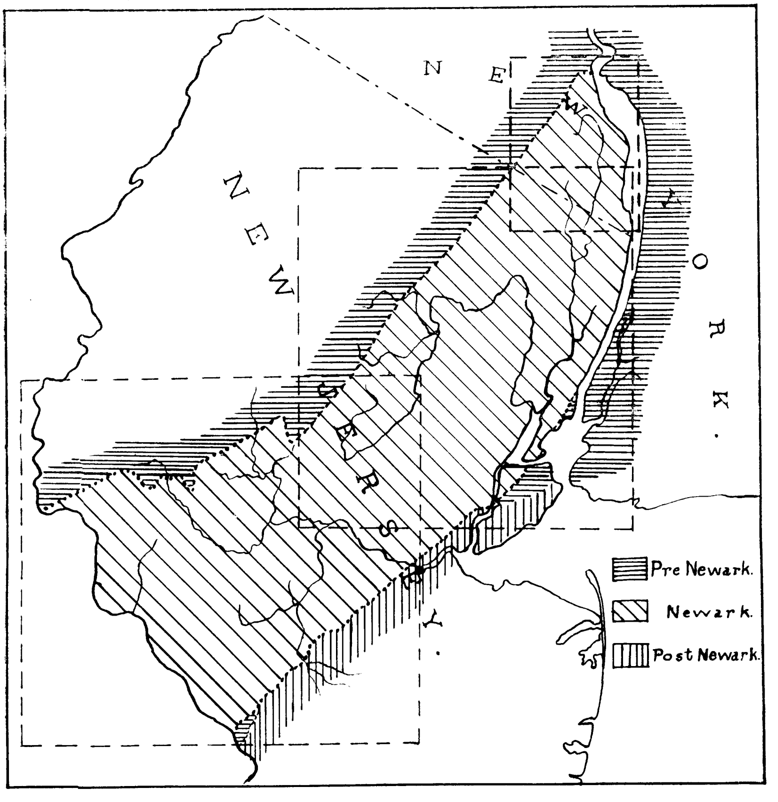


FIG. 1.—Newark area of New Jersey and New York.

along the Delaware River, and fifteen miles wide at the New York state line. In Rockland county, New York, the Newark area forms a right triangle, the apex of which is near Stony

[1] More detailed accounts are given in the following papers: Annual Report of

Point and the hypotenuse along the Hudson River. The southeastern boundary from Trenton northeastward to Staten Island is for the most part formed by overlying beds, Cretaceous and younger. Near Trenton, however, the underlying Philadelphia gneiss outcrops for a few miles. The waters of the Kill von Kull, New York Bay and Hudson River form the boundary from Staten Island northward. The northwestern boundary is irregular and is formed entirely by older rocks — crystallines and Paleozoic shales and limestones. The general position of these rocks and their relations to the older and new formations are shown in Fig. 1.

## THE ROCKS

The Newark series consists of sedimentary and igneous rocks. The former are chiefly shales, sandstones and conglomerates; the latter, diabase, to which the more general term trap has usually been applied. Along the Delaware River (Fig. 2) the sedimentary rocks are divisible, on lithological grounds, into three groups, which have been called Stockton, Lockatong, and Brunswick.

*Stockton group.*— The basal beds of the series are found at Trenton where they rest unconformably upon the older crystalline rocks. They consist of (*a*) coarse, more or less disintegrated arkose conglomerates; (*b*) yellow, micaceous, feldspathic sandstone; (*c*) brown-red sandstones or freestones, and (*d*) soft red argillaceous shales. These are interbedded and many times repeated, a fact which indicates rapidly changing and recurrent conditions of sedimentation. Although there are many layers of red shale in this subdivision the characteristic beds are the arkose conglomerates and sandstones, the latter of which afford valuable building stones.

In addition to the cross-bedded structure which often pre-

the State Geologist of New Jersey for 1896, pp. 25 *et seq.*; Annual Report of the State Geologist of New Jersey for 1897, pp. 23 *et seq.*: JOUR. GEOL., Vol. V, pp. 541–562. A detailed account of the New York area will be published in the Annual Report of the State Geologist of New York, and a briefer summary in the Annual Report of the State Geologist of New Jersey for 1898.

vails in the sandstones, ripple-marks, mud-cracks and impressions of rain-drops occur. The rapid alternation from conglomerates to shales and *vice versa*, the changes in composition in individual beds, the cross-bedding, ripple-marks, etc., all indicate very

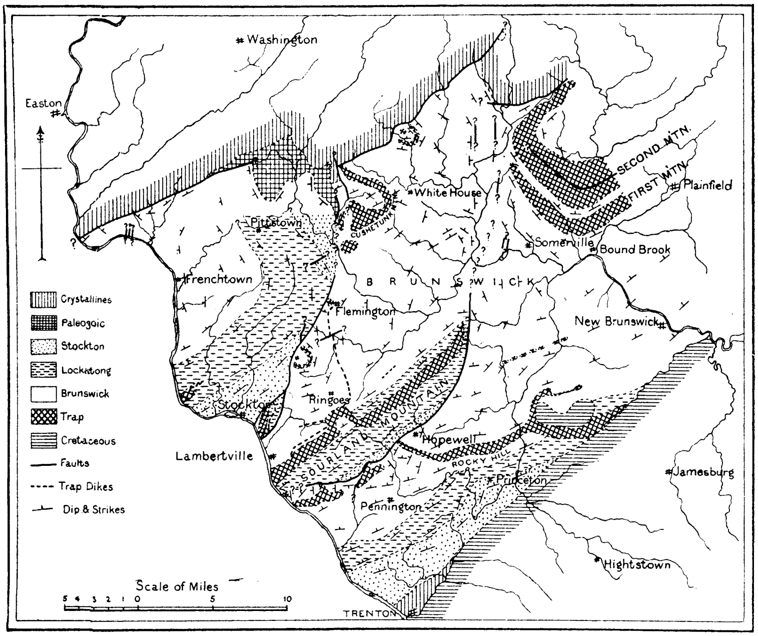


FIG. 2.—Subdivisions of the Newark rocks in Western New Jersey.

clearly that these beds were deposited in shallow water in close proximity to the shore. The bulk of the material of which they are composed was derived from the crystalline rocks on the south and southwest, but where they were found to rest upon Silurian shales, limestones and quartzites, as was the case along the northwestern border north of Flemington, material from these formations has determined their local character. The regions of the Stockton beds form gently rolling lowlands.

*The Lockatong group.*— These rocks overlie the Stockton beds conformably. They consist of (*a*) carbonaceous shales, which split readily along the bedding planes into thin laminæ, but have no true slaty cleavage; (*b*) hard, massive, black and bluish-purple argillites; (*c*) dark gray and green flagstones; (*d*) dark red shales approaching a flagstone; (*e*) and occasional thin layers of highly calcareous shales. There are all gradations between these somewhat distinct types, so that the varieties of individual beds are almost countless. Both ripple-marks and mud-cracks occur at all horizons, showing that shallow water conditions prevailed throughout the time of their deposition. On the other hand, the absence of strong currents or violent shore action is indicated by the extreme fineness of the material.

The Lockatong beds are ridge makers, owing to their superior hardness and consequent resistance to the agents of degradation. In this particular they are surpassed only by the trap rocks. Sourland Mountain is composed largely of these rocks, although its backbone is formed by the outcropping edge of a trap sill. The high plateau in Hunterdon county, between Flemington and Frenchtown, which rises 300 to 500 feet above the adjoining region, is due also in large measure to the comparative indestructibility of these hard argillites and flags. They give rise to a rather heavy wet clay soil, often swampy unless artificially drained. The surface is quite thickly strewn with slabs of argillite and flagstone and on the steeper slopes rock outcrops are generally abundant.

*The Brunswick beds.*— In general this group consists of a monotonous succession of very soft argillaceous red shales which crumble readily to minute fragments, or split into thin flakes. Much of it is porous, the minute, irregular-shaped cavities being often partially filled with a calcareous powder. Calcite veins and crystals are common in some layers. Locally lenticular masses of green shale occur in the red. In size these range up to a foot or two in diameter, and vary in shape from nearly spherical to lenticular masses, narrowing down to thin sheets along cracks. They are undoubtedly due to chemical changes resulting in the leaching of the shale.

Although the majority of this series are soft red shales, there are some hard layers, chiefly near the base, and occasional beds of fine-grained sandstone and flagstones, some of which afford valuable building material. Massive conglomerates along the northwestern border are in part the shoreward correlatives of the red shales.

Evidence that the shales were deposited in shallow water is abundant. Ripple-marks, mud-cracks and rain-drop impressions occur at many horizons. In some quarries imprints of leaves, of tree stems, or the stems themselves are frequently found. The numerous reptile tracks which have made the Newark beds famous occur chiefly in this subdivision. Typical exposures occur along the Raritan River, particularly near New Brunswick. The Brunswick beds are easily disintegrated and the fineness of the residuary material renders its transportation easy. Consequently the region underlain by these shales forms a lowland of faint relief, much of which has an elevation of only 100 to 200 feet above sea level. This plain is best developed in the drainage basin of the Raritan River, from New Brunswick northwestward to Flemington and White House. These rocks form also the western and lower part of the Hunterdon plateau in the vicinity of Frenchtown.

Owing to two great faults these three subdivisions each occur in three belts in the western part of New Jersey as shown by Fig. 2.

*Lithological changes in these types.* — Important lithological changes occur in all these beds as they are traced along their strike. As the northwestern border of the formation is approached, near Pittstown, the subdivisions lose their distinctive characteristics and merge along the strike into coarse sandstones and massive conglomerates. This change is most striking in the case of the Brunswick and the Lockatong groups, where red shales or black argillites change to sandstones and then into conglomerates, the pebbles of which are frequently six or eight inches in diameter. Under these conditions it is impossible to differentiate and limit these groups in this part of the field. Before considering these border conglomerates more fully, other modifications in the beds will be noted.

Important changes are found to occur as the beds are traced along the strike northeastward into New York. The Stockton beds disappear beneath the later deposits a few miles east of Princeton. But owing to a slight change of strike they come to the surface again on both sides of the Palisades from Hoboken

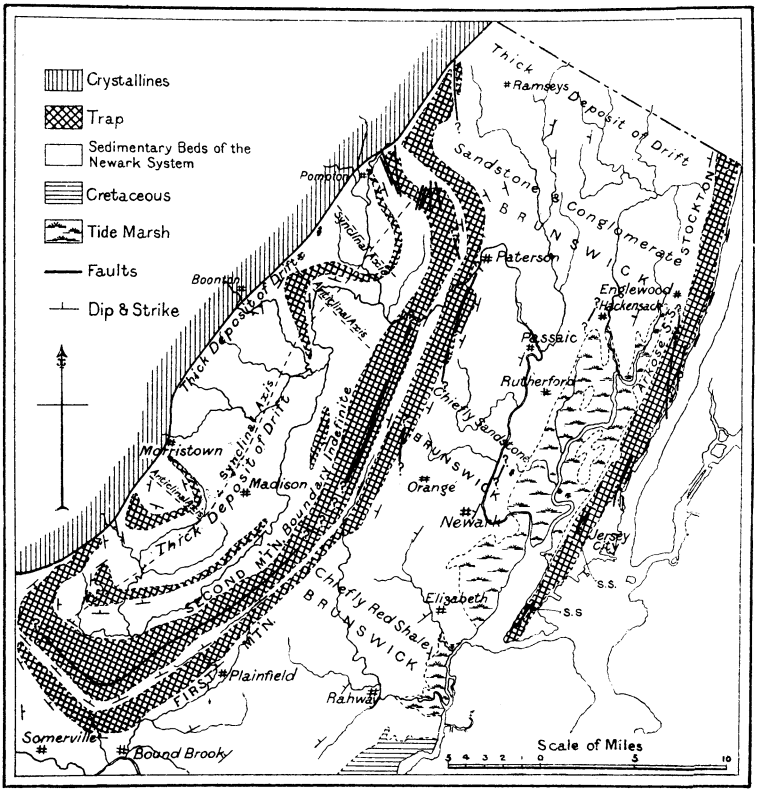


FIG. 3.—Newark rocks of Eastern New Jersey.

northward (Fig. 3). They are exposed in many places along the foot of the Palisades near the water's edge, and in a few localities where the glacial drift is thin, the typical arkose sandstone has been found on the west side of the Palisades. These rocks are correlated with those of the Trenton area for the following reasons. Lithologically, they are almost exactly identical; in both there are coarse arkose sandstones locally conglomeratic; in both, red shales and reddish-brown free-stones, and in both, these layers are several times repeated. Second, both occupy the same position stratigraphically. Near Trenton they are found resting upon the older crystalline rocks. In Jersey City wells bored near the water front strike gneiss and schist. At Stevens Point, Hoboken, the crystalline rocks outcrop, and, as is well known, they underlie the whole of Manhattan Island, just across the river. A little over half a mile back from the water front, in Jersey City and Hoboken, wells, which penetrate the glacial drift, reach sandstone and shale, some beds of the former being unmistakably coarse arkose. Third, minute crustaceans (*Estheria ovata*) have been found[1] in the shale beds at Weehawken and Shady Side along the Hudson River, and again in similar relations in the quarries near Trenton. Owing to the intrusion of the Palisade trap sheet some members of the group have been metamorphosed into hard, black and greenish flinty rocks, called hornfels by some German petrographers. Their occurrence, however, is limited to the neighborhood of the trap, and their presence in nowise affects the correlation of these beds with those near Trenton.

The Stockton beds certainly persist into New York, but the typical coarse arkose sandstone beds apparently thin out, and north of Nyack the group cannot be ide[illegible]d with any degree of certainty. The trend of the strata apparently carries the beds of this subdivision beneath the Hudson River.

Northeast of Princeton the outcrop of the typical Lockatong group grows narrower and the thickness less. Either the rate of deposition was slower to the northeast during the time represented by the Lockatong beds elsewhere, and therefore they are thinner here, or else, the rate of deposition being the same as elsewhere, the conditions favoring the deposition of black argillite and shale did not last so long to the northeast of Princeton as nearer the Delaware. A few miles northeast of Princeton the Lockatong beds also are covered by the Cretaceous deposits, but they have been traced by borings as far as

[1] NASON, Annual Report of the State Geologist of New Jersey, 1888, pp. 29–33.

the Raritan River. They do not, however, appear in the region west of the Palisades and north of Newark (Fig. 3). In the region in which they would be expected to occur the broad Newark and Hackensack meadows are found. The Lockatong beds are always ridge makers, rising above the level of the rocks on either side, and therefore it is impossible to suppose that they underlie these great tide-water meadows. There can be no doubt but that the argillites do not exist in the northern region. It is hardly probable that sedimentation ceased entirely in this northern area while the argillites were being deposited in the southwest, since there is no evidence of such oscillations of sea level or of unconformity. It seems more probable that the conditions favoring their formation did not prevail in the northern part of the basin; that here the red shales and sandstones were deposited contemporaneously with the argillites and flagstones to the southwest, and that, could we trace the latter from the point near Princeton, where they disappear beneath the Pensauken and Cretaceous deposits, we would find all the steps in their transition to the soft red shales.

The Brunswick beds likewise change in texture towards the northeast. They are predominantly soft argillaceous shales from the Delaware River as far as Elizabeth. In some layers an increase in coarseness is noticeable, which continues northeastward along the strike, until in the vicinity of Newark and Orange the beds are chiefly sandstones. Many of these beds resemble the brownstones of the Stockton series, so closely in fact that hand specimens can be distinguished with difficulty, if at all, from much of the sandstone at Trenton and Stockton. But their stratigraphical position in the Newark series seems to be far above that of the Stockton beds. The facts on which this conclusion is based are as follows. The trap sheet forming First Mountain is extrusive in origin. That is, it is an overflow sheet,[1] and, therefore, its base is conformable to the

[1] This might not be the case had the lava flowed over an eroded land surface, but evidence will be given below to prove that the lava flow was subaqueous, and therefore contemporaneous with the deposition of the adjoining shales. Its base therefore represents a constant horizon.

bedding of the sandstones, and represents a constant horizon. This being the case it gives us a reliable datum line. The position of the sandstones near Newark and vicinity in reference to the trap agrees with that of the Brunswick *shales* further south, and not with that of the Stockton sandstones. Second, they are too far removed from the base of the series, which follows the Hudson River, to be classed with the Stockton beds. Thirdly, when traced southward along the strike as closely as possible, considering the limited number of outcrops, they appear to grade into soft argillaceous shales.

Still further north layers of conglomerate appear interstratified with the sandstones and shales. In addition to well-marked beds of conglomerate, many layers of the sandstone contain pebbles scattered through them. The pebbles are chiefly of quartzite or sandstone, quartz, slate, limestone, feldspar, and rarely of flint. Not a single gneissic or granitic pebble was found, although careful search was made for them. The coarse sandstone and conglomerates, with some shale beds, continue through Bergen county, N. J., and Rockland county, N. Y. Since this phase of the Brunswick group is more resistant than the argillaceous shales in the Raritan basin, the topography is quite different. Where the Brunswick beds are soft red shales, the surface is a gently-rolling lowland, having an average elevation of from 100 to 200 feet above tide. With the appearance of the coarser and more resistant beds the general elevation becomes greater, and in place of the gently-rolling lowland, we find a series of ridges and valleys following very closely the trend of the beds. Toward the New York state line the higher of these sandstone ridges attain elevations of 450 to 625 feet above tide, the local relief being from 200 to 300 feet.

Owing to the disappearance of the Lockatong beds as a group possessing distinctive features, and the change in the Brunswick group due to the appearance of thick beds of brown sandstone and of coarse conglomerate, it is not practicable to differentiate on a map these groups as sharply as could be done in the western part of the area. Their general distribution is indicated on the maps shown in Figs. 3 and 4.

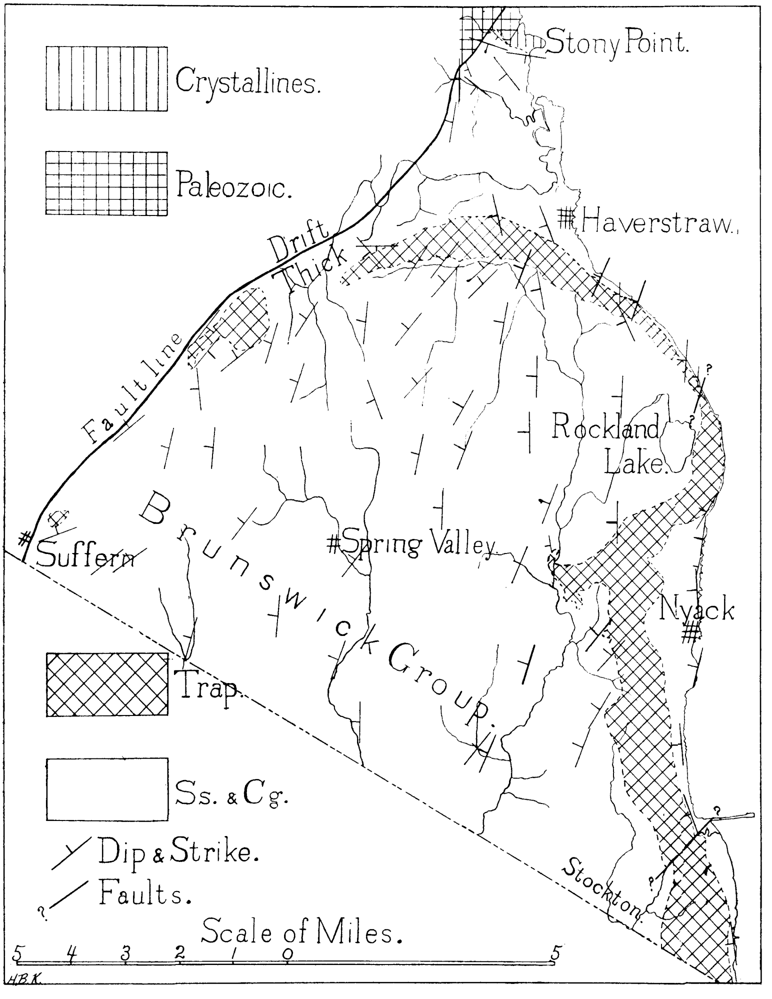


FIG. 4.—Maps of the Newark Series in Rockland County, New York.

*Border conglomerates.*—Beds of coarse conglomerate occur at a number of points along the northwestern border. Some of these are composed chiefly of quartzite, others of limestone, and in one case of gneissic and granitic material. The quartzite conglomerate contains a few pebbles of limestone, shale, and gneiss, but almost the entire mass of the rock is made up of quartzite or sandstone pebbles, which are well rounded and frequently six or eight inches in diameter. They are best exposed in the "pebble bluffs" along the Delaware River about five miles above Frenchtown. The conglomerates are interstratified with sandstones and shales, forming lenticular beds, which thin out within a few rods, to be replaced by beds of a different texture. This alternation and rapid change betoken shore conditions. The quartzite conglomerate is also well developed (*a*) in "the Barrens" northwest of Pittstown, (*b*) south of Clinton, (*c*) four miles north of Peapack, where there is an outlier called Mount Paul, (*d*) south of Morristown, and (*e*) south of Pompton Lake.

The calcareous conglomerate is in appearance almost the exact counterpart of the famous "Potomac marble" quarried at Point of Rocks, Maryland.[1] The limestone pebbles are usually bluish or gray, sometimes reddish, set in a red mud matrix, so that the rock has a variegated appearance. The average diameter of the larger constituents is six or eight inches, but bowlders five feet in diameter have been seen, and at a quarry two and a half miles northeast of Suffern, N. Y., bowlders twelve feet in diameter are reported to occur. The larger fragments are generally rounded, but the majority of the smaller are sharp-cornered or at most subangular. Compared with the pebbles in the quartzite conglomerate, the limestone pebbles are but little worn, a fact of some significance in connection with the origin and source of the materials, since with equal transportation the softer limestones must have been most worn. In many localities this conglomerate is so pure a limestone that it is quarried and burnt for lime for local use.

Three small areas of this conglomerate occur northwest of Pittstown between hills of the quartzite conglomerate. A much larger area lies along the border northwest of White House. In New York state it occurs (*a*) two to three miles northeast of Suffern, (*b*) near Ladentown, and (*c*) south of Stony Point.

[1] Geological Survey of Maryland, Vol. II, pp. 187–193.

Not uncommonly the most careful search failed to reveal a single gneissic or granitic pebble in the border conglomerates, even although the adjoining rocks were of this character. But east of Boonton a conglomerate composed chiefly of crystalline pebbles extends for two or three miles along the border.

*Relations of these conglomerates to the older rocks.*—The relations of these conglomerates to the older rocks along the border are significant. In some cases the calcareous conglomerates adjoin small areas of Paleozoic limestone, from which the materials may have been and probably were derived. In other cases, and *this is true of the largest areas*, the calcareous conglomerates abut against the gneissic rocks, and for much of the distance it is certain that no limestone occurs between the gneiss and conglomerate, at least not at the surface horizon. Crystalline pebbles, however, are comparatively rare in the conglomerate. Substantially the same conditions prevail in the case of the quartzite conglomerate. For the most part it adjoins the gneiss, but gneissic pebbles in it are rare. The known areas of quartzite along the border are small, and in general not near the massive conglomerate beds. Lithologically, moreover, they are unlike the bulk of the quartzite pebbles.

It is evident that along the greater part of this border the beds of the Newark series were not derived from the older rocks which now immediately adjoin them. Shore currents doubtless transported more or less material somewhat widely, and yet they do not afford us the complete explanation for these facts. The northwestern border is for the most part marked by faults. Here the dissimilarity of constitution is the most marked. Where the border is not faulted and the newer rocks rest undisturbed upon the eroded edges of the older beds, they are composed of fragments derived from them plus a small contribution by shore currents. Allowance can be made for the work of the currents, but the widespread dissimilarity of constitution is due chiefly to the faulting which has occurred. The waves of the sea in which the Newark beds were deposited did not on the northwest border in general beat against the rocks which now adjoin this area.

The relation of the conglomerates to the shales is also significant. They do not form a single horizon which may be used in interpreting the structure. Instead, they grade either into argillaceous shales, or black argillites, or arkose sandstones. Time and again the pebbly layers were seen to appear in the shales and to increase in thickness and numbers until they became massive conglomerates. This is true both of the calcareous and quartzite conglomerates, and probably also for the gneiss conglomerate, but owing to the glacial deposits its relation to the shales could not be determined.

*The trap rocks.*—The trap rocks of the Newark beds in New Jersey and New York have been described more or less in detail by several geologists,[1] and it has been demonstrated that overflow sheets, intrusive sills, plugs, and dikes occur. Owing to its superior hardness, the trap rock has better resisted erosion than the sedimentary beds, and consequently forms more or less well-marked elevations. In the case of narrow dikes, the elevation is slight and readily overlooked, but the greater masses form hills or ridges rising not infrequently 300, 400, or even 500 feet above their surroundings. The structural relations of the trap masses are among the most interesting questions connected with the Newark series, but only general conclusions can be given here.[2] The most important of the overflow sheets are the three concentric ridges forming the Watchung Mountains, Fig. 3. These sheets are to all appearances strictly conformable, both to the underlying and to the overlying shales. Nowhere is there any indication that the trap breaks across the sandstone or shale layers. Wherever the basal contact is exposed, and exposures several hundred feet in extent are known, the trap is seen to follow exactly the bedding plane of the shales.

Moreover, the extensive metamorphism of the associated sedimentary beds, a marked feature in the case of all the intru-

[1] Chiefly Cook, Russell, Davis, Darton, Iddings, Kümmel.

[2] Detailed descriptions are given by N. H. Darton, U. S. Geological Survey, Bulletin No. 67, and by the author in the Annual Report of the State Geologist of New Jersey for 1897, pp. 58–100.

sive sheets, is entirely absent. Locally, the shale is slightly altered for a few inches beneath the trap, but even this is not always the case. When this is compared with the intense alteration which has affected the shales beneath the Palisades, an intrusive sill, for a distance of over 100 feet, the difference between the sheets is emphasized.

Upper contacts have not been observed in many cases, but the upper surface of these sheets is frequently vesicular, amygdaloidal, and scoriaceous. Locally, a thin layer of waterworn trap particles, intermixed with red mud occurs between the vesicular trap and the unaltered typical red shales, or the vesicles are filled with the red mud. The overlying shales conform to the slightly irregular, ropy surface of the trap. In frequent exposures the rolling-flow structure, named by the Hawaiian Islanders *Pa-hoe-hoe*, is visible. Nowhere have any tongues of lava been found extending from the main sheet into the neighboring shales.

In texture there is a marked difference between the overflow sheets and the intrusive sills. Not only is the trap vesicular and even scoriaceous at many points on the upper surface, but it is uniformly of much finer grain than that of the Palisades and similar ridges. Microscopic examination of fragments from the upper surface shows that volcanic glass occurs to some extent. The conclusions drawn from the texture are that these masses cooled much more rapidly than did the Palisade trap. Locally, vesicular and scoriaceous layers occur next to the under-shales, beneath dense, fine-grained trap. Generally in such localities the rolling-flow structure is clearly marked. The inference from these facts is that as the lava flowed onward the partially cooled vesicular slag-like and broken upper surface was rolled over to the under side of the flow, or in other cases, after a clinker-strewn crust had formed on the top and front of the sheet, the molten lava broke forth from within and flowed over and around the scoriaceous fragments, and on hardening bound them firmly together. Occasionally the red shale rises into the base of the trap, as if the great pressure and flowing motion of the molten lava had forced upward the soft mud on the sea bottom, or as if the steam generated by the intense heat had made the wet mud to froth up between the trap clinkers. There can be no doubt as to the extrusive origin of these sheets.

The crescent-shaped ridges near Morristown, north of White House (near Germantown) and southwest of Flemington (near Sand Brook), are also overflow sheets.

*Intrusive sills.*—The Palisades of the Hudson, the Rocky Hill sheet north of Princeton, the Sourland Mountain sheet near Lambertville, and Cushetunk Mountain near White House, are the largest and most prominent of the intrusive sheets. Their position, size, and the shape of their outcrop are indicated on the accompanying maps. In addition to these, which are demonstrably sills or sheets, there are more irregularly shaped masses northwest of Pennington, near Stockton, and at Point Pleasant (west of Stockton), (Fig. 2), the precise relations of which to the inclosing beds are not clearly revealed. They are beyond all doubt intrusive masses, but it is questionable whether they are strictly sheets. In the absence of positive knowledge as to their relations with the sedimentary beds, I prefer to speak of them simply as intrusive masses.

The evidence of the intrusive origin of all these masses, sills and others, is as follows. Dikes radiate from the upper part of the sills and penetrate the overlying shales for distances up to seven miles, as measured on the surface. The sills are locally unconformable to the inclosing strata, although in general they extend for long distances parallel to their strike. The Sourland Mountain sill makes two sharp bends, by which it changes its horizon several hundred feet. The Rocky Hill sheet crosses the shales obliquely for a total of several thousand feet, and about twenty-five localities are known along the Hudson River where the Palisade sheet can be seen to cut across the shales and sandstones. In New Jersey the Palisade sheet follows closely the strike of the shales, although frequently changing its horizon a few feet. In New York, however, north of Nyack, the trend of the shales would carry it beneath the Hudson River, were it not that it ascends by irregular steps to higher horizons. West of Haverstraw it trends nearly at right angles to the strata, and is more like a dike than an intrusive sheet. A small area near Ladentown, which may be the western extension of the Palisades, presents some characteristics of an overflow sheet, indicating that possibly the trap here reached the surface. The adjacent sediments have often been greatly metamorphosed. So intense has been this alteration that at distances, often of 100 feet the rocks are as completely "baked" as those immediately adjoining the trap. Measured along the surface, traces of metamorphism are frequently found one foot from the nearest trap outcrop. The complete absence of scoriaceous rock, of amygdules, of the vesicular, or the rolling-flow structure, is negative evidence of their intrusive origin which must not be neglected. Moreover, masses of shale and sandstone have been imbedded in the trap near both the under and upper surfaces, and the trap itself shows evidence in its texture of having cooled more slowly (and therefore presumably at greater depths) than the overflow sheets.

*Plugs*.—Round Mountain, a circular mass of trap, south of Cushetunk Mountain, suggests by its shape, that it is an irruptive plug or stock, but in the absence of positive evidence as to its relations to the surrounding metamorphosed shales, no final statement is warranted.

*Dikes*.—The positions of the principal dikes are represented on the accompanying maps. A few others are known, but are too small to show on a map of this scale. Locally the adjoining shales are slightly metamorphosed.

*The age of the trap rock*.—The overflow sheets are contemporaneous with the beds between which they lie, *i. e.*, the upper third of the Brunswick shales.

The intrusive masses extend, for the most part, well up into the Brunswick shales, and are therefore younger than these. Moreover, so far as the evidence goes, they antedate the disturbances which closed the deposition of the Newark beds. There are good reasons for believing that many, perhaps all, of the intrusive masses are younger than the extrusive sheets, although the evidence is not conclusive. From *a priori* considerations it may be suggested that the lava formed intrusive sheets after the formation became so thick that it could not readily rise to the surface; whereas, earlier in Newark time the lava was able to break through the thinner beds and overflow.

*Metamorphosed shales.*—The chief effect of the trap on the shales is the contact metamorphism which has been produced by the larger intrusive masses. The most marked macroscopical changes are (*a*) a greater or less induration, (*b*) change in color —red shales in general becoming purple and then a blue-black. streaked with gray or green near the trap, and (*c*) the development of secondary minerals, commonly epidote and tourmaline. The rock often has a banded or mottled appearance, due to the formation of lime-silicate hornfels. Of these three changes the third is the most significant. Mere induration or change of color does not necessarily signify "baking," but when all three occur together, and only in layers in close proximity to certain trap sheets, proved to be intrusive by their structural relations, the changes can be safely ascribed to the igneous rock. Many of the altered shales on weathering become a pale blue or ashy gray color, a tinge never taken by other layers.

Detailed microscopic study of the altered shales has been made by Messrs. Andreæ and Osann[1] from specimens collected at the base of the Palisades at Hoboken and Jersey City. Their results, which were published in Germany, are inaccessible to many readers in this country, and are therefore here briefly summarized. They group the metamorphosed rocks into four classes:

1. Normal slate hornfels, not distinguishable from hornfels formed by contact with intrusives which cooled at great depth.

2. Hornfels containing numerous tourmaline crystals.

[1] Tiefencontact an den intrusiven Diabasen von New Jersey. Separat-abdruck aus den Verhandlungen des Naturhist.-Med. Vereins. zu Heidelberg. *N. T. V.*, Bd. 1. Heft.

3. Metamorphosed arkose sandstone, distinguished by the formation of a fibrous green hornblende.

4. Lime-silicate hornfels (kalksilikat hornfelse).

The two first groups differ only in the presence or absence of tourmaline. They are very dense rocks, with a splinter-like cleavage and abound in biotite. Traces of the original stratification are preserved in the alternation of layers containing varying amounts of mica. The tourmaline always appears as a secondary mineral, in well-bounded black prisms up to three millimeters in length and one in width. They are without definite arrangement, the longitudinal axis being oblique to the stratification plane as frequently as it is parallel to it. Each of the tourmaline crystals is surrounded by a bright halo about half a millimeter in width, caused by the absence of biotite. This may be accounted for on the assumption that the iron and magnesia were consumed in the formation of the tourmaline. The biotite crystals have their tabular planes arranged parallel to the stratification planes.

Feldspar is the chief constituent of the tourmaline-bearing hornfels, and quartz is entirely wanting—a fact which indicates that the original sediment was very deficient in silica, but abounded in clayey materials.

From such rocks, presenting clearly a crystalline structure, a transition may be found to very dense masses in which, even when highly magnified, no constituent parts, save biotite, can be recognized.

The lime-silicate hornfels is bright gray to green-gray in color, dense and hard, and discloses, under the microscope, an irregular aggregate of very small grains, with strong double refraction, whose nature can be determined only from the larger grains. The minerals common to rocks of this variety occur; a colorless pyroxene, closely related to diopside; green hornblende; colorless tremolite in fibrous and radiating aggregates; garnet; vesuvian; epidote; while feldspar occurs commonly in diminished quantity. This rock frequently exhibits an alternation of bright and dark layers, in the former of which diopside usually prevails; in the latter green hornblende and biotite.

Solitary grains and crystals of titanite occur and frequent masses of calcite were observed. The lime-silicate hornfels effervesces with acid. Their occurrence here indicates a deep-seated origin for the Palisade sill.

The association of the slate hornfels and the lime-silicate hornfels is extremely interesting. The former makes up the main mass of the altered beds. The lime-silicate hornfels forms in most cases small layers in the slate hornfels, the thickness of the former often being no greater than that of a sheet of paper. These layers are parallel to each other and to the original stratification of the shales. Frequently they form small elliptical masses, joining each other like a string of pearls in the stratification plane. From this it is but a step to rocks in which the lime-silicate hornfels form only roundish eyes and knots in the hard, black slate, the "incipient segregation," which gives the rock a mottled appearance. In still other cases the lime-silicate hornfels traverses the darker hornfels in veins and bands at various angles to the stratification. Before metamorphism these were probably veins of calcite, which, together with the surrounding shales were altered on the intrusion of the trap.

In all these various relations the boundaries of these two rocks, of such different chemical composition, are sharply marked, both to the naked eye and microscopically. This is strong evidence that during the metamorphism these rocks were not molten, but that the changes occurred in solid, or at most, very slightly plastic beds. The authors conclude that the beds were originally argillaceous shales, locally strongly calcareous and traversed by veins of calcite and interbedded with layers of arkose sandstone. They find in the contact phenomena strong evidence that the trap was intrusive and cooled at great depths.

Metamorphosed shale, in every respect identical with these rocks, so far as macroscopical examination can determine, occurs along the Rocky Hill ridge, and is well shown along the canal near Rocky Hill village. Epidote and tourmaline-bearing shales occur on both sides of the Sourland Mountain trap, and are well exposed at Lambertville, where many of the features noted by Andreæ and Osann can be seen. Fragments of altered shale can be found on the surface near the other intrusive trap masses, but there are no extensive exposures of the rock in place. Along the Palisade ridge the metamorphism is less pronounced near its northern end in New York, and not infrequently beds in close proximity to the trap here show no signs of alteration. Apparently, as the molten rock approached the surface, its effect upon the adjacent beds was diminished.

## STRUCTURE

*Folds.*— The general structure is that of a faulted monocline the beds of which trend N. 20° to 50° E., and dip 10° to 15° to the northwestward. As a result of this, the layers to the northwest, save where faulting has occurred, are above, and therefore younger than the layers on the southeastern side. When examined more in detail, the structure is seen to depart locally from a monocline. Several broad, gentle flexures occur, in addition to a few sharply marked folds in the vicinity of the intrusive traps and greater fault lines. A good example of the former is seen in the shales of the Hunterdon plateau, where the beds are so inclined that their outcropping edges describe a great curve, parallel on the east, and southeast to the escarpment of the plateau. The structure is a shallow syncline, whose axis is inclined northwestward. Low folds occur in the valley of the Raritan, particularly in the region north of Somerville. From New Brunswick to Bound Brook the dip is quite uniformly to the northwestward, averaging ten degrees, but further to the west the monocline is interrupted by gentle flexures and swells which are difficult to trace because of the absence of individuality in the layers. The broad outcrop of the Brunswick shales in the Raritan valley is due in large part to these low folds.

More definite folds, all synclines, occur (*a*) near the Sand Brook trap sheet, southwest of Flemington, (*b*) the New Germantown trap sheet, and (*c*) the Watchung traps, whose great crescentic curves are due to the synclinal structure of the inclosing shales. Several examples of sharp folds occur near Glenmore, southwest of Hopewell, and not far from the end of Rocky Hill. Other instances were noted near the faults.

In the area shown in Fig. 2, the Stockton and Lockatong beds are the more constant in dip and strike, so that the monoclinal structure is most marked in these belts. The Brunswick shales are characterized by shallow folds, some of them covering an area of several square miles. These, combined with a fortunate arrangement of faults, have greatly increased the area of red shale outcrop, and so permitted the formation of the broad, rolling lowland, so characteristic of the greater part of the Newark system.

Within the area shown in Fig. 3, the extrusive trap sheets are excellent guides in interpreting the structure, once their conformity to the shales has been completely demonstrated. The curved outline of the Watchung Mountains is due to a gentle synclinal fold, the westward side of which has been cut off by a fault along the highland border of the formation. The highest beds of the Newark series are those along the axis of this syncline. Between the Watchung Mountains and the Hudson River the monoclinal structure prevails. This is also true of the Newark beds of the New York area.

*Faults.*— About seventy-five faults are known to occur, and two of them, the Flemington and Hopewell faults, are of great magnitude and extent, causing a repetition of all three divisions of the Newark beds and involving dislocations equivalent to a vertical movement of one half the entire thickness of the series, perhaps 6000 or 7000 feet. Faults of such magnitude must extend downward beyond the limits of the Newark rocks, and involve the foundations on which they rest. Proofs of the faulting are found (*a*) in the repetition of the strata, (*b*) crushed and contorted strata, slicken-sided surfaces or overthrown dips at every exposure along or near the fault line, (*c*) diversity of structure on opposite sides of the fractures, (*d*) contrasts in the topography, and (*e*) the termination of ridges at the line of disturbance.

The northwestern border is formed in part by a series of faults. Elsewhere the Newark beds rest upon the eroded edges of the older rocks. The faulted border is comparatively straight; the normal border is somewhat crooked. Along the former the shales dip in various directions in respect to the older rocks; along the latter they follow the trend of the contact and dip away from the older beds. In the one case Newark beds of very different horizons adjoin the border; in the latter they are basal beds. Along the faulted portion the Newark beds were not derived from the immediately adjoining older rocks; along the normal contact material from the adjacent old formations has entered largely into the newer beds.

The trap ridges, notably the Palisades and the first and second of the Watchung ridges, are cut by a number of faults which cross them obliquely. Second Mountain, moreover, is cut by a curving fault which follows the ridge for many miles, producing a double crest and revealing a strip of shale in the valley between. The throws of the faults rarely exceed 200 feet, save in the case of this longitudinal fracture where it is probably 700 feet or over. Owing to the monotonously uniform character of so many of the sedimentary beds, all estimates of the amount of throw are generally unreliable. Faulting is more frequent in the Brunswick and Stockton beds than in the Lockatong group, but the total number observed in all three subdivisions is hardly more than that found in the trap areas. There is good reason for believing that many faults which traverse the sedimentary beds have not been discovered, and perhaps never will be, with the present methods of geological research. With but few exceptions, all the known faults are reverse faults.

*The thickness of the sedimentary beds.*—In my earlier papers the following estimate of the maximum thickness of these beds was made.

| | |
|---|---|
| Stockton, - - - - | 4,700 feet. |
| Lockatong, - - - - | 3,600 " |
| Brunswick, - - - - | 12,000 " |
| | 20,300 " |

At that time it was felt that not all these estimates were equally reliable. Six sections were made across the Lockatong beds with the following results: Across the belt on the Hunterdon plateau, 3540 feet, 3450 feet, 3500 feet; across the Sourland Mountain area, 3600 feet, 3650, 3660 feet. The sweeping curve of this belt in the Hunterdon area, its uniform width, and the possibility of tracing certain subordinate but well-marked layers continuously along the strike preclude the idea that any great part of its apparent thickness is due to repetition by faulting. Furthermore, the fact that the beds on the Sourland plateau agree in thickness so closely with the same beds on the Hunterdon plateau is further reason for believing that the figures here given represent very closely the actual thickness. To suppose otherwise is to assume that these two separate areas are each traversed by faults, whose throw, by a remarkable coincidence, is almost exactly the same, but of which no traces have been discovered by areal work of the most detailed character.

The thickness of the Lockatong beds, near Ewingville and Princeton, seems to be only half of that in the other two regions, *i. e.*, 1700 to 1800 feet. The same relative thinness was observed in the Stockton beds, near Trenton, as compared with those further north. The explanation of this may lie in the fact that the beds of the former belt are nearer the old shore line than the others. Stratified deposits have the form of an unsymmetrical lens which thins out very rapidly shoreward and very gradually seaward. It is to be expected, therefore, that the thickness of this belt, which is nearest the old shore, would be somewhat less than that of the others. The weight of evidence indicates that in the deeper parts of the estuary the Lockatong beds were 3500 or 3600 feet thick.

The estimates for the Stockton and Brunswick beds are more uncertain. In favor of the estimates given above these facts may be urged. West of Ringoes the Brunswick shales form a syncline whose axis plunges northwest. Between 6000 and 7000 feet of shales are involved in this fold. It is improbable that a fault could follow the curving strike so as to repeat the beds the same amount on both sides of the fold. Furthermore, a narrow trap dike was traced uninterruptedly from the back of Sourland Mountain, near Rocktown, to Copper Hill, a distance of five miles. The dike crosses the strike at an angle of forty-five degrees, and the thickness of the shales thus traversed is between 6000 and 7000 feet. There are reasons for believing that the trap was intruded before the tilting and faulting. If these reasons are valid the continuity of the dike is proof that the shales traversed by it are not cut by faults along the strike Since such great thicknesses prevail in these beds, which are only a part of the whole, there is some reason for believing that the entire thickness of the Brunswick shales is near 12,000 feet.

On the other hand the disparity in the number of known faults in the trap areas and in the sandstone and shale areas indicates that there are probably more faults in the sedimentary beds than have been discovered. The apparent thickness of the Palisades and the two Watchung ridges is from one half to one third greater than the actual thickness, the increase being due to the faults. If the same proportions hold for the Stockton and Brunswick shales the figures given above will be somewhat reduced. The revised estimate, therefore, is as follows:

| | | | | |
|---|---|---|---|---|
| Stockton, - - - | 2,300 | to | 3,100 | feet. |
| Lockatong, - - - | 3,500 | " | 3,600 | " |
| Brunswick, - - - | 6,000 | " | 8,000 | " |
| | 11,800 | " | 14,700 | " |

There is so much uncertainty connected with all measurements where there are so many unknown elements that these estimates may be far from correct. It certainly can be claimed for them, however, that they rest upon a much larger basis of fact than many previous figures.

*Of the trap sheets.*—The thicknesses of the various trap sheets are not included in the above estimates.

The Palisades at Jersey City Heights have at least a thickness of 364 feet (well-boring), with a total thickness, including the amount removed by erosion, of 700 to 800 feet, according to estimates made from the angle of dip and the width of outcrop. At Fort Lee a well penetrated the trap for 875 feet before reaching the underlying metamorphosed shale and the total thickness here is about 950 feet.

In New York the thickness varies considerably, judging by the width of outcrop. A thickness of considerably over 700 feet is known to occur north of Nyack, whereas north of Rockland Lake it probably does not exceed 300 feet.

The thickness of First Mountain at Paterson is estimated to be 600 to 675 feet; at Orange Valley about 670 feet; at Scotch Plains about 680 feet, and at Chimney Rock about 580 feet.

With the exception of the thickness at Scotch Plains these figures agree closely with those obtained for First Mountain by Darton along the same sections. At Scotch Plains the outcrop is narrower than elsewhere, but the dip of the inclosing shales is steeper and his estimate of 450 feet is probably too low.

The thickness of Second Mountain is apparently somewhat greater than that of First Mountain, but owing to the faults which traverse it, estimates are liable to error. Darton's figures range from 600 to 850 feet. My own estimates, based on the width of outcrop and the dip, range from 840 feet to 990 feet. At Caldwell the well at the Mount St. Dominic Academy penetrated the trap for nearly 800 feet, but some addition must be made for what has been removed from the crest of the ridge by erosion.

At Millington the thickness of the Long Hill trap sheet is about 300 feet. At Pompton a well drilled at the Norton house is reported to have passed through but seventy feet of trap before reaching sandstone. Hook Mountain, east of White Hall, has an apparent thickness of 400 feet or more.

The New Vernon trap-sheet has a thickness of about 250 feet, measured at the gorge near Green Village.

The outcrop of the New Germantown sheet is comparatively narrow, but the dip is steep and the thickness is estimated to be at least 400 feet.

The same thing is true of the Sand Brook sheet, the thickness of which is apparently not less than 425 feet.

Too little is known of the relations of the Sourland Mountain, Pennington Mountain, Bald Pate, and Rocky Hill traps to the inclosing shales to venture estimates of their thickness.

*Deposition.*— Most geologists hold the view that the Newark beds are estuarine deposits. Some, however, prefer to consider them lacustrine, believing that the scarcity of fossil remains renders improbable the supposition that the sea had free access to the basin. The fauna and flora preserved for us are meager, and do not settle the question decisively, the forms being such as might have existed either in an estuary or a salt lake. On the other hand, the distribution of the material implies well-marked currents such as the tides would produce in an estuary. For myself I prefer to believe that at the beginning of Newark time a broad, shallow estuary extended across the northern part of what is now New Jersey and into New York state. Whether the estuary was wider than the present area of the beds is impossible to say. Subsequent erosion has diminished their areal extent, whereas faulting, particularly in the western part of New Jersey, has increased it. Which of these factors has been the more effective is uncertain. Probably along the Delaware River section the gain by faulting has exceeded the loss in width by erosion. In the north this may not be the case.

The estuary was bordered on the northwest and southeast by areas of granite, gneiss, and schist, probably pre-Cambrian in age, with narrow belts of Paleozoic quartzite, limestone, and shale. The latter rocks formed in part the floor of the estuary, the foundation on which the Newark deposits were made. This is shown by the "island" of limestone and quartzite brought to the surface in Pennsylvania by the Flemington fault. For long periods previous to the formation of the estuary and the deposition of the Newark shales, the older rocks on which they now rest had been a land area and were deeply eroded. The proof of this is found in the absence from this region of all the later members of the Paleozoic series.

The constitution of the arkose sandstones near Trenton and beneath the Palisades shows that the sediment was derived chiefly from older crystallines on the southeast, but scattered limestone and sandstones pebbles derived from the southwest show that the currents had a northward trend along the southeastern border. Along the northwestern border, where it is not marked by faults, the material was evidently derived from the adjacent rocks on the northwest.

The constitution of the Newark beds points to the conclusion that in pre-Newark times the old land surface was deeply covered with residuary material, the product of long-continued subaërial decomposition. On the crystalline areas it was chiefly quartz and feldspar or kaolin. The limestone was buried beneath a mantle of clay. In both cases the residuary products had been formed chiefly by chemical agencies. The sandstone and quartzite rocks were less affected by chemical changes and relatively more by mechanical agencies. Their surface was, therefore, covered by subangular fragments, due chiefly to the rending action of frost and expansion and contraction with changes of temperature. The almost complete absence of gneissic pebbles with the presence of quartz, feldspar and partially disintegrated ferro-magnesian minerals in the conglomerates, sandstone or shales proves that the crystalline rocks must have been deeply covered with a mantle of residuary material, so that streams, although they had velocity enough to carry pebbles two or three inches in diameter, did not corrade the bed rock, but worked in the residuary material.

The bulk of the Newark beds is so great as to indicate that these residuary products must have been very thick. Their accumulation was aided by gentle slopes, hindered by steep declivities. Previous to the formation of the Newark beds the neighboring land surface seems to have been one of low relief, with gentle slopes, across which transportation was reduced to a minimum. In other words, the land surface was approaching the peneplain stage.[1] Had the land been high and the slopes

[1] Practically the same conclusion has been reached by Professor Davis in regard

steep the accumulation of these residuary materials in a thick mantle would seem to have been improbable. But the size of the materials handled by the streams during the Newark time indicates a velocity inconsistent with streams on a peneplain. It would seem, therefore, that with the beginning of the Newark deposition the land regained something of its former elevation. The rivers were able to carry from the crystalline areas pebbles of quartz or feldspar several inches in diameter and to handle quartzite cobbles ranging up to a foot in size.

The massive border conglomerates are probably not composed entirely of stream-transported material. Limestone bowlders poorly rounded and measuring four feet in diameter have been seen, and some twelve feet in diameter are reported to occur in the calcareous conglomerates. All the coarser border conglomerates were probably accumulated by the waves which beat against limestone and quartzite ledges. The scarcity of gneissic conglomerates indicates that the shores were not chiefly gneissic, as would be the case today were the Newark area to be submerged, but of limestone and quartzite. The faults along the northwest border have, for the most part, cut out these rocks, and brought the Newark beds against the crystallines.

That the sandstones and shales were accumulated in shallow water, is shown by the ripple marks, mud cracks, raindrop imprints, and footprints of reptiles and other vertebrates, which occur at all horizons. At no time apparently was the water of the estuary so deep that the outgoing tide did not expose broad areas of sand or mud. It follows from this that there must have been a progressive subsidence of the estuary during the deposition of these beds, since their thickness is to be measured by thousands of feet. The subsidence went on *pari passu* with the deposition of the sediments, since the shallow-water conditions prevailed continually. The progressive elevation of the adjoining land areas, shown by the material carried by the rivers, was

to the surface on which the Newark beds in Connecticut were deposited. His argument, however, was along an entirely different line of reasoning, being based upon the present topography.

complementary to this subsidence of the trough. If the subsidence were greater along one side of the trough than the other, the central axis must have shifted toward the side of greater depression, and the shore line on that side must have encroached upon the land. If this occurred to any marked degree during the later stages of sedimentation, the shore conglomerates of that time might rest upon the older rocks and so be basal conglomerates. At the same time they would be the correlatives of the topmost shales found further from shore. In this sense they would be the upper members of the series. This may have been the case locally along the northwestern border, and at the northern end of the estuary near Stony Point, but the evidence is far from conclusive on that point.

*The lava flows.*— Before the completion of the Newark sedimentation the quiet course of deposition was interrupted by great flows of lava. Whether the lava issued from a single vent or group of vents, or from a fissure is unknown. Certain it is, however, that the molten lava flowed over the soft mud in the bottom of the estuary. Locally the mud was forced up into cracks in the under side of the lava, or was thrown into low billows by the enormous pressure of the overflowing mass. The molten rock issuing forth into the water generated an enormous amount of steam, causing the mud to froth up and mingle with the scoriaceous lava. So, too, the more liquid lava flowed around and over the cooled and broken masses of clinkers, forming the ropy structure and the commingling of dense trap and breccia-like scoriæ sometimes seen in the Watchung trap sheets. Locally, perhaps somewhat generally, the lava flows were so thick as to rise above the sea level. In these cases the scoriaceous surface was readily eroded: the waterworn trap fragments were commingled with the red mud brought into the estuary by the rivers, and a layer of trap conglomerate or sandstone was formed. Such was the origin of the conglomerate in the back of the first Watchung sheet near Feltville. In other localities the vesicles on the upper surface of the lava were filled with the red mud as the lava flow was buried beneath the succeeding sediments. The three

Watchung trap sheets give us evidence of at least three periods of eruption separated by long intervals of quiet, during which the deposition of the shales went on as regularly as before. The intrusive sheets were probably formed after the overflow sheets but this has not been conclusively demonstrated. Since both the intrusive masses (save perhaps some dikes) and the extrusive sheets are cut by the faults, the volcanic phenomena preceded the faulting.

Professor Davis[1] has suggested that the disturbing force which ended the deposition, was probably "a long enduring and slow acting horizontal compression, exerted in an east and west, or southeast and northwest direction; and that the explanation of the tilted and faulted structure is to be found in the writhing and rising of the inclined layers of underlying gneiss and schist, as they were subjected to this horizontal compression." The foundation on which the Newark sediments rest would thus be faulted and canted, and "the overlying beds, unable to support themselves unbroken on this uneven foundation, settle down upon it as best they may." This explanation, offered to meet the conditions of the Newark beds of Connecticut, is fully applicable in its general features to the New York and New Jersey area.

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LEWIS INSTITUTE,
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[1]DAVIS, U. S. Geological Survey. Seventh Annual Report, pp. 481–490.