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ART. X. — *Some of the features of non-volcanic Igneous Ejections, as illustrated in the four "Rocks" of the New Haven Region, West Rock, Pine Rock, Mill Rock and East Rock*; by JAMES D. DANA. With Plates II to VII.

THE observations on the igneous ejections of the New Haven region here recorded and discussed were mostly completed during the years 1879 and 1880, shortly after the publication (in 1877) of a detailed topographical map of the region by the U. S. Coast and Geodetic Survey, made under the special direction of R. M. Bache. As this map is on the large scale of $\frac{1}{100000}$, or about $6\frac{1}{3}$ inches to the mile, and has 20-foot contour lines, it afforded a very convenient basis for the record of geological facts.

A reduction of a portion of this map to a scale of two miles to the inch, is presented on Plate II.* Excepting the hills in the southwestern corner of the map, its whole area, even that of the New Haven plain, is underlaid by the Jura-Trias Red-sandstone formation. (The excepted hills are part of the border of metamorphic schists that bounds the Jura-Trias region

* This map is a portion of Plate II in the writer's paper on the "Phenomena of the Glacial and Champlain Periods about the mouth of the Connecticut Valley, or the New Haven Region" (This Journal, xxvii, 113, Feb. 1884). The limit of the New Haven plain is marked by a dotted line at the base of the hills, and the contour-lines over it are omitted, the heights instead being given after a special survey. The small nearly circular depressions marked on the map represent "Kettle-holes." The New Haven plain was of river-flood origin and it is presented on the map with the outlines and height unaltered by the gradings for road-making, and by the making of mill-dams; and hence the map is a map of the region of New Haven before 1640, as stated in its title.

on the west.) The map shows the positions of the four trap ridges—more strictly trap-and-sandstone ridges—West Rock, Pine Rock, Mill Rock and East Rock, and gives their heights above mean tide. These rampart-like elevations are now two to three miles from New Haven Bay; but they bear evidence of having been for a time the headlands of a much larger bay.

The ridges are part of the Jura-Trias Mountain-range of the Connecticut Valley. (1) East Rock and West Rock are like the other north-and-south ridges of the range in their form, structure and direction, and West Rock ridge after a course of seventeen miles, dies out just where the higher trap ridges of the Mt. Tom line commence, showing an interlocking with the rest of the system. (2) They consist of Jura-Trias sandstone with an intercalated sheet of trap (as the igneous rock is popularly called). (3) The sheet of trap in the ridges has a rising inclination westward, or a dip eastward, like the associated beds of sandstone, the liquid rock having been extruded from a fissure or fissures situated somewhere to the eastward. (4) As a consequence of these common features, denudation by water and ice has given to the New Haven ridges the features typical of the range,* namely, a steep western front, consisting of sandstone below and the harder trap above, a top of bare trap, and eastern slopes of sandstone, that is of the overlying sandstone.

From such common features the inference as to a common method of origin is natural. Still, as Professor Davis claims, it needs also other support for acceptance.

We note also (4) that these Rocks are situated at the southern extremity of the Jura-Trias Mountain-range; for the Connecticut Valley and its Jura-Trias beds do not extend over Long Island. Instead of this, Long Island pertains to an east-and-west system of mountain-structure. Whether nearness in position to this east-and-west range has occasioned any of the features of the Rocks is an interesting question for consideration.

1. SUMMARY OF THE PRINCIPAL FACTS AND CONCLUSIONS.

The facts.—The facts relate to the sandstone of the New Haven region as well as the trap; for the sandstone was broken through to give exit to the liquid trap, and it broke as such a sandstone would break.

(1) The sandstone, as the rock is comprehensively called, varies from fine-grained to coarse, and beyond this, to a fine

* In the writer's paper on the Geology of the New Haven region of 1869, (Trans. Conn. Acad. Sci., ii. 4. 1870), he observes that "the sandstone mass with its intersecting dikes of trap constituted the block out of which the future New Haven region was to be carved by various denuding agencies."

and coarse conglomerate, even cobble-stone-gravel conglomerate. When fine-grained and shaly it is not a firm laminated rock, but divides or crumbles readily to thin chips. The more massive kinds are usually traversed with fractures; and none has much firmness except where consolidated by heat from the trap-ejections, or the hot vapors produced thereby. Consequently, fissures made though the formation should have great irregularities, from irregular fracturing and the tumbling into them of masses of sandstone and large sections of their walls.

(2) The thickness of the sandstone intersected by the fissures over the center of the New Haven region was at least 3000 feet, as proved by borings at a point half way between the bay and the west end of Mill Rock. Along the West Rock line the depth was probably less, as this ridge is within a mile and a half of the western metamorphic limit of the Connecticut Valley of Triassic time. Beneath the sandstone the fissures came up through underlying crystalline rocks, in which they would probably have great regularity in course, width and continuity.

(3) When the heat from the trap, or the hot vapors generated by it, consolidated the sandstone, it generally made hard, durable rock of the coarser kind, but left the finer beds, alternating with the coarse, fragile and chip-making; and this was so, apparently, because hot vapor penetrates most easily the coarser beds for the cementing work. The heat, through the penetrating vapors, generally discharged more or less completely the color of the beds it consolidated, producing an ash-gray and brownish shade; made in them steam tubes with blanched walls; produced blotches of impure chlorite, or epidote, and crystallizations of hematite and epidote, and less commonly garnet. But the finer beds that alternate with the coarse commonly retain, except perhaps for a few inches, their red color, and even have it deepened to a dark purplish red—as if by the reduction of some of the red coloring matter (oxide of iron) to magnetite. Moreover, the sandstone often loses all the old bedding. These varying effects from the heat have added much to the original irregularities of the beds.

(1) Of the four Rocks, East and West belong to the prevailing north-and-south system, as already stated; the other two, Pine Rock and Mill Rock, to a transverse system.

(2) In East Rock and West Rock the sheet of trap made by outflow from the opened fissure or fissures has a length westward of 100 to 500 yards.

(3) The supply fissure, or its filling, the dike, descends beneath the eastern slope with a large eastward pitch: the angle of pitch in the case of East Rock being about 50° .

(4) In Pine Rock and Mill Rock, the trap is in *dikes*, there being no evidence of any outflow. Yet these dikes have in some of the outlets the great breadth of 150 to 300 or more feet.

(5) The pitch of these dikes is to the northward; and its angle 18° to 40° —both characters of unusual interest.

(6) Although neither East Rock, Mill Rock nor Pine Rock has a length exceeding a mile and a half, each has three or four distinct outlets of trap, separated by intervening sandstone; moreover, there is wide diversity between the Rocks in the form and arrangement of these areas of extruded trap, as the map illustrates.

(7) The trap of the several ridges, according to examinations by E. S. Dana, is true doleryte, free, or nearly so, from chlorite and other evidences of interior alteration, and not at all vesicular.

(8). Columnar fractures give the rock a rudely columnar structure, in which the half-defined columns are four to eight feet in diameter. In the west fronts of the north and south ridges the rude columns have usually an inclination nearly at right angles to the mean dip of the associated sandstone—according thus with the usual rule: perpendicular to the cooling surfaces. But among the columnar fractures, whatever the inclination of the columns, that plane of fracture or joint which is transverse to the sides of the dike or trap-mass and nearly vertical is the most strongly developed, and consequently the trap often cleaves into nearly vertical plates or laminae of great extent, much like a laminated rock. There usually is also a second easy cleavage-direction, nearly at right angles to the former so that rectangular columns sometimes come out with great prominence.

(9). The outflows of trap have a floor either of an inclined layer of the sandstone or of edges of the upturned layers.

The principal conclusions.—(1). The igneous eruptions of the New Haven region took place after the sandstone had been upturned; that is, after the evolution of the Connecticut-valley mountain-range in this part of the valley had made great progress.

(2). None of them were volcanic eruptions, for there was no center of action, no pericentric discharge of volcanic materials.

(3). In the outflows from the fissures (those of East and West Rock) the liquid trap did not escape into the open air and spread over the surface, but entered between layers of the sandstone.

(4). Moreover the flow was not by gravity into spaces that had been previously made, but a forced flow that opened

spaces or chambers for its occupation, the liquid rock thus lifting the overlying sandstone as long as the discharge was continued. By such means the sheets of liquid trap attained, in some cases, a thickness of 300 or more feet. This forcible opening and filling of a chamber in the sandstone by the up-thrust lavas, is a *laccolithic* process, it according with that of the typical laccoliths ably studied out and described by Gilbert.*

(5). The intrusion of the flowing rock between the sandstone layers took place at comparatively shallow depths, where the pressure of the rock was not too great to prevent it.

(6). It was favored, in each case, by the fact that the oblique fissure supplying the lava was inclined in the same direction with the layers of the uplifted sandstone—both inclining westward, the dip being eastward.

(7). The termination of a fissure in several outlets, exemplified in three of the Rocks, was largely due to the great inclination and depth of the fissures opened through the weak upturned and faulted sandstone, and thence to great downfalls of the hanging wall. The same cause led to irregularities in the width and forms of dikes, and influenced the outlines and surface-features of outflows.

(8). The course and dip of supply-fissures was not determined by the foliation or bedding of the schists underneath the sandstone.

2. SPECIAL FACTS FROM THE SEVERAL ROCKS ILLUSTRATING THE ABOVE CONCLUSIONS.

The ridges, Pine Rock and Mill Rock, containing simple dikes are first considered, and then East Rock and West Rock, which include dikes and outflows from them.†

1. PINE ROCK.

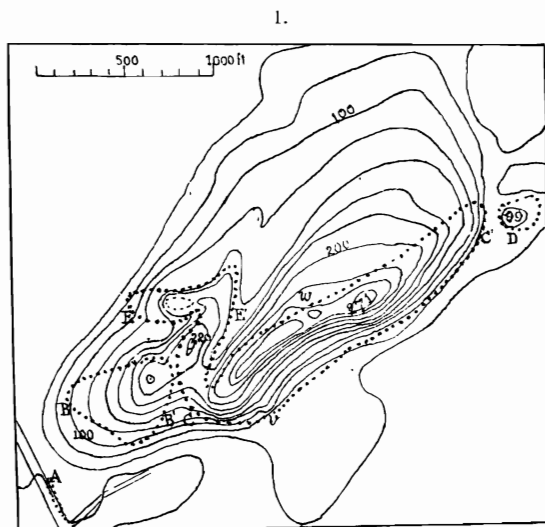
The general form of Pine Rock is shown on Plate II, and still better on the following larger map.‡ It is only three-fourths of a mile long and trends N. 67° E., or east-northeast. This small ridge has three, perhaps four, independent outlets of trap, A, BB', CC' and D. The first, at the west end, is a small dike 15 to 20 feet wide, trending north 20° west, and traceable for 220 feet. It dips eastward 25° , and thus proves

* Geology of the Henry Mountains by G. K. Gilbert, 4to, 1877.

† In justice to Percival, the author of the Report on the Geology of Connecticut of 1842, it should be here stated that there is scarcely an outlet or area of trap mentioned beyond which is not recorded on his map or described in his Report.

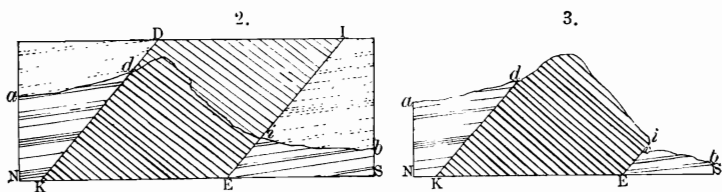
‡ The contour lines on this map, and also those on that of Mill Rock on page 87, are copied from the Bache Coast Survey map.

that it is not an outlier of West Rock, but part of the Pine Rock group. The other three are, more evidently, outlets from one great fissure. The width of the larger mass, CC', is about 300 feet; and it is therefore one of the widest of dikes. The dip of the dike is 50° to 55° northwestward. This inclined



Map of Pine Rock. Heights reckoned from high-tide level. Areas of trap with dotted outline.

position (35° to 40° from a vertical) is given the dike in fig. 2, in which D I K E represents a section of it between its sandstone walls before denudation, and *d i K E*, the same through the



highest point of the Rock as it now is—or was before recent quarrying. The cross-lining gives the direction of the columnar fractures. The other figure, fig. 3, is a section through *v* on the map, where the removal of the sandstone of the southern wall (*v*, in the section) has left a depression called the *Cave*. (The sandstone of these sections is now concealed by the debris, and outside of this by the Terrace formation.)

The southern wall of the dike is the roof of the cave; the rock has the fine texture and fissured surface usual where it cooled in contact with the sandstone. Just above the cave,

4.



Inclined columns of Pine Rock, above the "Cave."

where the exterior is removed, the surface is made up of the ends of rude columns. A profile view of these inclined columns from a point just south is shown in fig. 4.*

At *w*, (see the preceding map) the *north* wall of the inclined dike is uncovered for a height of 50 feet, the sandstone having been carried off by the glacier.†

At the eastern extremity of Pine Rock (near C'), the trap of the north wall may be seen in contact with hard-baked sandstone. In the large quarry just south, the rock exhibits finely the transverse lamination crossing the dike—referred to on page 82. The laminae incline 10° to 15° to the eastward, the dip being 80 to 85° to the westward. The surfaces of the plates are usually yellowish-brown with limonite for scores of feet from the summit, owing to the waters that penetrate from the surface downward and oxydize the iron of the rock; but in the transverse joints or cracks, which are less accessible to the waters, there is usually a coating of stilbite and sometimes

* From a photograph by G. N. Lawson, of the class at Yale of 1890; taken in December, 1890.

† The shaping of the northern slopes of the Pine Rock ridge is a part of the same work of the ice; and the trend of the mass, like that of Sachem's Ridge, (Plate II), indicates the direction of movement of the glacier. The same is true for the northern slopes of Whitney Peak and Indian Head.

of other zeolites, as chabazite, analcite, heulandite.* The dike has a few transverse courses of fracture containing prehnite and occasionally apophyllite, but no longitudinal have been observed.

A sandstone ridge connects A and BB', in which the rock is hard, and has the strike N. 40°–45° E., and the dip 45° S., becoming N. 30° E. and 30° to 35° in dip more to the west. It is mostly a coarse sandstone; but some layers contain stones 4 to 5 inches in diameter.

Origin of the Features of the Rock.

The existence of so many outlets of trap in the small space, and the irregular forms of the areas are unusual facts. BB' is short, broad and blunt, shield-shaped; and CC', is duck-like in shape, the irregular bosses at the northwest end (EE') making the neck and head. These bosses are not in the line of the dike, and must be due to a local catastrophe. In view of the great inclination of the fissure, and its depth of 2000 to 3000 feet in the weak sandstone, a caving in of some part of its northern or hanging wall would be of extreme probability. Such a catastrophe would account for the stoppage of the outflow and the separation thus of BB' and CC'; and such a stoppage of the up-thrust lavas would explain their escape by one or more extemporized outlets, and for the actual position of the apertures on the *north* side of the fissure; and thereby for the making of the bosses. The obstructed lavas of the fissure may also have found exit in the western dike, A.

The trap-mass D is possibly a result of a second smaller catastrophe of like character; but its separation from CC', may be a result of erosion.

Another consequence of the great inclination of the fissure is the exposure of the dike of heavy trap to degradation through the removal of the supporting sandstone on the south side. Such undermining has produced the steepness of the southern front. And sea-shore *waves* or breakers were probably the chief agent—the shores being those of the broad center, or a central arm, of the New Haven Bay.

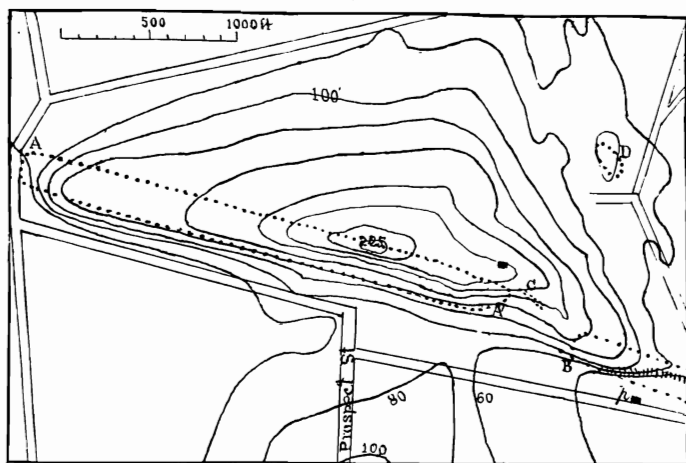
2. MILL ROCK AND THE WHITNEY RIDGE.

Mill Rock is one mile distant from the east end of Pine Rock. Its length to Whitneyville or Mill River, is four-fifths of a mile. This small area, as is seen on Plate II, and better in the following larger map, has four independent outlets of trap—

* The surface of the crust of zeolites is frequently tinged with the red iron oxide—which is a probable indication of heat as high at least as 200° F. during the formation of the minerals.

the western, AA', the eastern, BB'; north of the gap between these, a short narrow dike C, and farther north, the isolated area, D. The width of the first, AA', (as measured at its west end) is 200 feet; of the second, 140 or 150 feet; of the third, 1 to 10 feet; of the fourth, 50 feet, the length being 150. The mass BB' continues to Mill River where the surface of the country declines to tide level. But the trap does not stop here; it crosses the river and extends on eastward, with an increased width, 180 feet, to the summit of Whitney Peak. The Whitney Peak dike belongs therefore to the Mill Rock region, although topographically part of the East Rock area. The trend of the Whitney Peak portion is S. 68° E.; of AA', S. 78° E. The mean course for the whole series to the summit of Whitney Peak is about S. 72° E.

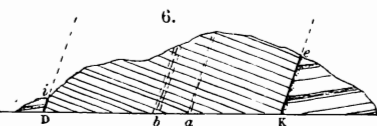
5.



Map of Mill Rock, excepting its eastern extremity. Trap areas with dotted outlines.

The dip or pitch of the main dike is about 72° to the northward, or 18° from the vertical. This inclination and the course of the columnar fractures are well exhibited at the west end of the dike, A, and are represented in figure 6.

Besides the columnar fractures at right angles to the walls, there are also longitudinal fractures in interrupted lines, parallel to the walls. Two are seen at the west end of the Rock and are indicated in the above figure. They are now mineral veins. The more south-



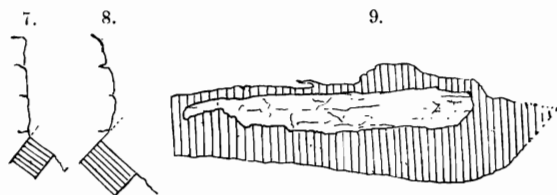
Section of Mill Rock, west end.

ern one, *a*, contains chiefly prehnite, with traces of copper ore, and the trap along its course is solid or little altered. The other is situated about half way between the sides. It contains abundantly the very hydrous mineral laumontite and the trap along it is decomposed; it contains also impure chlorite, and is fragile for a breadth of six to ten inches. A similar laumontite vein, but nearer the north wall of the dike, is seen at Whitneyville, and also in the trap of Whitney Peak.

The junction of the Whitney Peak part of the dike with BB' takes place in the bed of the stream at Whitneyville, and is not now exposed to view owing to the dam and the buildings below it.*

The level of the trap beneath the dam is but a few feet above and below tide level. The height of the Whitney Peak dike increases eastward; first by a sudden rise of 100 feet, and then more gradually in the last 500 yards to 280 feet. Whitney Peak has a bold front to the eastward with sandstone at its base showing a sudden stoppage of the fissure in that direction; and at the same place it widens southward—not by overflow, as the precipitous eastward front and the depth of the trap shows, but through the opening of a transverse fissure. The Rock has a steep wall 70 to 80 feet high, on the north side of the summit for nearly 100 yards; but this is due to the removal of the sandstone by glacier action, exposing the north wall of the trap dike.

The narrow dike C is about 110 feet long. It is situated in the face of a bluff of sandstone; and from the evidences of heat in the hardness of the rock, its mottled and light gray color in places, its steam tubes, and epidote, it is plain that the ejection determined the resisting power of the sandstone against denuding agencies. The following figures represent



two cross sections from the western half, and a map of the last 40 feet of the eastern half. At 65 feet the outflow is divided,

* To the fact of this continuation I have recent testimony from Mr. Eli Whitney, who has superintended the constructions made there during the past forty years. Besides mentioning that the dam was built along the junction of the trap and sandstone, he says that below the dam for some distance, there is trap rock only, no sandstone outcropping there to his knowledge.

The gun factory at Whitneyville was established there by his father, the inventor of the cotton-gin, in 1798, for the manufacture of muskets for the United States Army.

a narrow stream of trap (fig. 9), coming out above a layer of the sandstone 5 to 6 feet thick, the main part of the dike appearing below. This envelope of sandstone by trap continues for 30 feet, when the two parts come together again. The depth at which the side stream goes off from the main dike is not known. The inclination of the dike is mostly 25° to 28° (fig. 7) from a vertical, but at 45 feet from the west end it becomes 40° (fig. 8), and 10 feet beyond this, 30° .

The sandstone of the Mill Rock region is of all degrees of coarseness up to cobble-stone conglomerate; and no distinction is observable between that of the west and east ends.

Origin of the Mill Rock features.

The subdivision of the trap into its four masses may be explained in the same way as that in the Pine Rock area. A downfall of the northern sandstone wall of the fissure, the hanging wall, would account for the separation of AA' and BB'. Further, the obstruction thus occasioned to the great ascending stream—its width 150 to 200 feet—would have forced open passages to the surface for the discharge of the liquid trap, and thus may have been produced the small dike C, situated near the fissure wall, and the remoter mass D. The irregularities of the little dike C, and the situation of both C and D to the north of the line of the dike, accord with this idea of a downfall of a part of the northern wall. The liability to such a catastrophe in a wall made of the rude sandstone 3000 feet or more high, and having a large inclination, was augmented in both Pine Rock and Mill Rock by the tilted position and faulted state of the sandstone. The beds had already received their eastward dip of 15° to 25° , and breaks and faults innumerable that had been made in the adjustment to the new tilted position; it was therefore a tottish structure overhanging a profound abyss. The fact here introduced that the eastward pitch of the sandstone was given it before the ejection of the trap is sustained by facts reported beyond. But an argument for it is afforded here: for if this *eastward* pitch were of subsequent origin, then the Whitney Peak end of the system should be the lowest. Instead of this it is greatly the highest; the ridge slopes westward.

It is possible that the fissures of AA' and BB' were, from the first, independent fissures to a considerable depth; for they are not in precisely the same line. If this were so, the above explanation, while in the chief points right, would require some modification.

As in Pine Rock, so with Mill Rock but to a less degree, the northward pitch of the dike made it easy of degradation

by sea-shore action. Through such means, beyond doubt, the part of it extending from Mill River westward for 300 yards, was reduced to a width above ground of 40 to 50 feet. This narrowing commences just west of the Pumping House of the City Water Works (*p*, fig. 5), and continues without interruption to the river. It is part of the evidence of a greater New Haven Bay at some former time.

Why the range falls gradually to so low a level at Whitneyville, appears to be explained only on the view that less trap here came to the surface. I have elsewhere shown that it cannot be due to glacial removal. Neither is it probable that fluvial or marine waters have produced it. We have to attribute it to some condition existing or produced in the supply-fissures of eastern Mill Rock and Whitney Peak, at the time they were opened.

Besides the dikes of Pine Rock and Mill Rock, there is another transverse dike of special interest which intersects the West Rock ridge just below the margin of Wintergreen Lake, or about one and a quarter miles north of the southern termination of the ridge and four miles from New Haven Bay. It descends the eastern slope of West Rock in an interrupted ridge, forms part of the southern bank of Wintergreen Lake, sinks to the level of the West Rock surface at the summit, but stands out like a buttress along the steep west front of the Rock. From the last feature I have called it for the past twenty years, the "Buttress dike." It extends south-westward through the metamorphic region of the towns of Woodbridge and Orange to the mouth of the Housatonic—as long since mapped and described by Percival. This dike has a pitch northward, amounting to 25° from a vertical in the part of it intersecting West Rock, but in that through the metamorphic rocks it is nearly vertical.* The strike of the inclined columns in the buttress portion is S. $30-32^{\circ}$ E. It is an example of a dike made subsequently to the cooling of another dike, that of West Rock. It has great importance in this connection, since it brings into the Jura-Trias system of mountain-movements a dike intersecting the metamorphic rocks outside of the Connecticut Valley, and one that branches off from the southern or New Haven part of the system.

3. THE EAST ROCK SERIES.

The form of the East Rock area and its position between Mill River and the Quinnipiac, are shown on Plate II. Through

* The rock of the dike is sparsely porphyritic; and the feldspar distributed through it in crystals a fourth to a third of an inch long is anorthite, as shown by G. W. Hawes (this Journal, III, ix, 188, 1875). This character makes it easy to identify the several parts of the dike; it is the only case in which this mineral has thus far been found in the Connecticut Valley trap.

Percival's account of the Buttress dike and its extension southwestward is on page 399 of his Report.

denudation by the sea, rivers and ice, it has lost all of the sandstone formation that may have covered the summit, and for the most part that over its slopes above the 200-foot contour-line. The form of its upper portion is therefore largely that of the trap in its constitution—the hard rock that was most successful in resisting wear. This fact gives special interest to the larger and more detailed topographical map making Plate III, as will appear beyond.*

To the north is Whitney Peak, which has already been described as the eastern extremity of the Mill Rock series. South of this and of a large area of sandstone, are East Rock and Indian Head, one in trap surface, but in fact the result of two independent outflows. To the south of Indian Head is Snake Rock, which also has its large trap mass, but is peculiar in having ridges of hard-baked sandstone that are higher than those of trap. The East Rock areas of trap here referred to are lettered on the map BB', CC'C'', DD'. Besides these there is a more northern one, lettered AA', which lies near the eastern foot of Whitney Peak.

The trap-mass AA'.—This northernmost mass, is about one hundred yards long. At its northern end it is only forty feet distant from the trap of Whitney Peak, and it is a question, therefore, whether it is not a part of the latter dike. But it is separated from it by outcropping sandstone, except where the interval is narrowest, and at this point there was until recently drained, a standing pool of water, a pretty good indication that sandstone exists beneath, since trap is commonly too much fissured to hold water or afford springs. Moreover, the mass AA' has the trend of the East Rock series; and,

* The map of East Rock Park which is the basis of Plate III, was obtained from the Engineer department in New Haven, through the City Engineer, Mr. A. B. Hill. The roads of the Park from the termination of Orange St., around by the north to the summit of East Rock are lettered *F*, and the others *E*. These letters refer to two citizens of New Haven, Henry Farnam and James E. English, who liberally bore the expense of their construction. The topography is in part from the Bache Coast Survey map; but the accuracy of its contour lines was not sufficient for their transfer to the Park map. The heights are reckoned from high tide. The map is indebted to Prof. S. E. Barney, for the determination by leveling of the height of the highest point of East Rock, just south of the monument (358½ feet) and also of other points on its south and east sides, and for that of the junction of the trap and sandstone on the west front near Orange St. bridge (155 feet). The height of the bolt at the Coast Survey Station he found to be 343 feet, and the height of the top of the first step leading to the terrace about the monument, 355 feet. (Prof. Barney's figures are underscored on the map). The circuit road about the summit has a height of 320 to 350 feet: and the nearly parallel road on the east rises from about 216 feet near the quarries south of the summit, to 270 near the junction of the "Farnam drive" and "English drive," and thence declines northward to about 250 where it bends westward. The letters *S* on the map indicate an outcrop of sandstone in the vicinity of junctions with the trap.

In giving the topography of the Rock, the quarry excavations on the south side above a level of 216 feet are not introduced, it seeming best to represent the Rock in its original form. They are separately mapped on the plate.

besides, ledges of trap along the east side appear to indicate that the supply of liquid rock was from the eastward, like that of East Rock. On this view it is the northern mass of the East Rock series.

East Rock proper.—The trap mass BB', or East Rock, curves around from N. 25° E., on the north to N. 75° W. at the southwest extremity. Adding to it the Indian Head mass, it ends in an east-and-west dike, and is a complete crescent in outline. It has a bold columnar front, in which the columns incline about 22° from a vertical—the position, being, as is usual, at right angles to the mean dip of the tilted sandstone. A view of the southwest front of the Rock is presented on Plate IV. Plate V illustrates the character and inclined position of the columns, and shows the contrast in the latter respect with Pine Rock.

The upper 200 feet are of trap. The junction of the columnar trap with the sandstone is exposed to view at several points along the front. One such exposure may be seen when crossing the Orange Street bridge. The view in Plate IV, in which the bridge appears in the foreground, has the exposure half way up the front to the right. The height of the junction plane above mean tide at this place is 155 feet. Another is faintly indicated on the same plate directly below the Refreshment House; the height of the junction is there 150 feet. In other exposures of the junction-plane to the north, the height is less and becomes only 85 feet near the Rock Lane bridge; and it is also less to the south being but 132½ feet at B', the southwest angle of the trap mass. Since the strike of the sandstone of the region is about N. 30° W., the sandstone (or the junction plane) has its greatest height, 155 feet, where the front has this direction; and the bedding of the sandstone in the section for this reason appears to be horizontal. The diminished height to the northward is owing mainly to the exposures being at a lower level on the junction-plane because of the changed direction of the front, it becoming N. 10° E. near Rock Lane bridge. Through this interval the trap retains its thickness of about 200 feet. North of Rock Lane bridge the underlying sandstone is wholly covered by debris, so that the position of the junction-plane is doubtful.

The supply of the trap forming East Rock came up, as the slope of its surface shows, from the eastward; and it continues rising westward to the western and southwestern margin of the summit. The slope from the summit eastward and northward is gradual for about 300 yards, and then it pitches off at an angle of 45° to 50° along the course of one of its dikes.

The position of the dike, and thereby of the supply-fissure, is well exhibited at *bc*. A bare wall of trap, 50 to 55 feet in

height, descends at the angle mentioned. Since the surface there exposed became solidified against the northern sandstone wall of the fissure, the rock is of fine-grained texture and has an irregularly rifted aspect. The foot of the wall is about 200 feet above high tide, and from it the land, underlaid by sandstone, slopes off gently to the eastward. Since the direction of this wall of trap is S. 15° W., or that of the movement of the ice over this region in the Glacial era, the wall escaped the tearing action of the glacier, and so retains its original surface.

Farther south, along a line from *d* to *e*, there is a similarly steep slope, but it is made of displaced blocks of trap. At its base there is a flat, terrace-like surface, which is near 200 feet above tide level. This steep slope appears hence to have been the course of the wall of another part of the supply-fissure. The flat terrace, although nearly 100 feet wide, is without stones over its surface of either trap or sandstone except in its southern portion, and there occur sandstone in fragments along with trap, and an outcrop of sandstone over trap at *S*. This fact and the occurrence of a perennial spring in this southern part (at the point toward which the two paths on the map, Plate III, descend) make it probable that the terrace rests on sandstone, and that this sandstone was that bounding on the east, the supply-fissure above referred to.

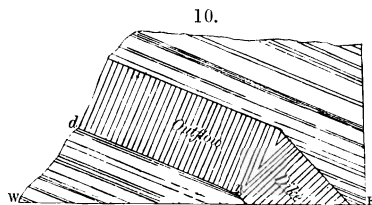
But there is trap again to the east of this terrace, showing that the lower eastern slopes were supplied from a more eastern fissure. Along from *c* to *d*, the trap of the outer fissure appears to have flowed over and coalesced with that of the inner. Again south of *e*, the distinction of the two fissures cannot be made out. But the fact that the supply-fissures, one or both had a large inclination—not far from 45°—is evident from the very steep slope of the surface.

Sections of the dikes of trap are nowhere exposed, and hence we are ignorant of the width of the supply-fissures. Judging from those of Mill Rock and Pine Rock, it may have been 150, 200 or 300 feet; but it was possibly much less.

The Outflows.—In East Rock, the trap which overlies the sandstone along the front, was that of outflows from the fissures westward between layers of the tilted sandstone. The fact that the columns of trap have a position at right angles nearly to the inclined layers of sandstone is believed to be good evidence of this intrusion of the melted trap.

Fig. 10 represents the view that has ordinarily been held with regard to the relative positions of the trap and sandstone. According to it the trap left the dike to flow westward between sandstone layers having a dip of 20° to 25°. A space was opened between the layers of sandstone which the liquid

trap filled. It is plain that this chamber could not have been so opened in advance of the inflow; for the hanging wall of the weak sandstone inclined 65° would have had no support. It is hence evident that the ascending stream of trap, forced

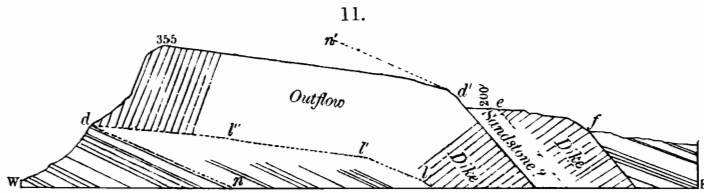


Ideal Section of East Rock before the removal of the sandstone from the summit.

along its course, opened a way between the layers; that a tongue of trap first entered, which would have been partly cooled against the cold rock; but the flow was kept up below this first intruding portion until the trap had all entered, the lifting of the overlying sandstone going on as it needed more space. This lifting would have brought a strain on the sandstone that would have broken the connection between the lifted portion and that either side, to the northward, westward and southwestward. To the question, therefore, how far did the trap flow westward, the conditions reply: to the wall of such a fracture; and it may not have extended many rods beyond the present limit. The sandstone of the western wall has disappeared in the general denudation over the New Haven region, excepting a small part at the southwest angle, where a zigzag path (Z, Plate III) ascends to its top; the height of this sandstone is 185 feet, which is twenty-five feet above the base of the trap where highest to the northward, and fifty feet above that just south at A'. The locality of this sandstone and the zigzag path is seen on the right margin of Plate IV. The sandstone of the northern wall remains to a height of 196 feet at *m*: the sandstone between Whitney Peak and East Rock is what is left of it. The dip of this sandstone at *m*, near the junction, is 30° , in the direction N. 73° E.; and the inclination of the columns of the trap just above is also 30° .

The theoretical section of East Rock in fig. 10 represents correctly the fact of the intrusion of the melted trap between sandstone layers. But since the bottom over which the flow took place is concealed from view, it is not quite certain that the sandstone layer on which the flow began continued to be the floor to its western limit. Moreover, there is a large discrepancy between the pitch of the trap over the summit and that in the section. An actual section of the rock from

east to west (or more exactly E.S.E. to W.S.W. since this is approximately the direction of a transverse diameter) drawn to a scale, fig. 11, throws some light on these points.



Section of East Rock, showing the correct profile.

This section is essentially right in its profile, but more or less doubtful in its interior lines. The height of the upper surface of the outflow where it left the dike at d' is 265 to 270 feet. It was not less than this; for we have this height for the top of the bare, unabraded wall of trap (adding the part of it under the Summer House west of the road). The length of the overflow to the present western front, is, as already stated, about 300 yards. The height of the western brow of trap in the section is 355 feet;* and that of the bottom of the trap in the western front, 155 feet. These are facts; and the divergence here from figure 10 is very great. Further, the mean angle of the trap surface over the summit is 10° instead of 22° , the mean dip of the sandstone. The latter dip is shown in the lines dn ; and if the floor had originally this pitch throughout, the thickness of the trap would have been about 450 feet, this being the distance on the scale of the section between dn and $d'n'$, while actually it is only 200 to 210 feet.

The question arises: How was the lower slope of 10° attained, and how the lessened thickness. Are they a result of wear by glacial or other methods; or was the present slope approximately the original slope of the outflow? A large amount of observation over trap ridges leads me to believe that the loss over East and West Rocks by abrasion has been small, probably not over 50 feet. The glacier, as it was shoved along, might easily have torn off columns from the front, but it would have made little impression on the exposed surfaces. Moreover glacial abrasion would hardly have left the highest points of the summit so near the western edge.

If the outline of the summit approaches that of the original outflow, then— d being the lower limit of the trap on the front—a line drawn from d nearly parallel to the summit plane,

* This is the height 80 feet north of the Summit Refreshment House, just west of the road, this being the highest point over this northern half of the summit area.

would probably represent the position of the bottom of the outflow. The line $d\ l''\ l'\ l$ has been drawn on this view. It supposes that the trap, on leaving the dike, passed between two layers of sandstone from l to l' and that afterward it broke away the layer beneath it and flowed on, either over the edges or surfaces of layers as the conditions favored.

The only spot where a section of the floor or plane of junction of trap and sandstone, is seen, is at A' , the south-south-west corner of the trap-mass, by the road-side. There, for a few yards, the trap *rests on upturned ledges* of sandstone, and not on one continuous layer. The section is too short for any reliable conclusion were it not sustained by facts from West Rock.

The section, fig. 11, also represents the *inner* and *outer* dikes described above, with the intervening (?) sandstone. The doubts with regard to the widths of these dikes and the area of sandstone have already been the subject of remark.

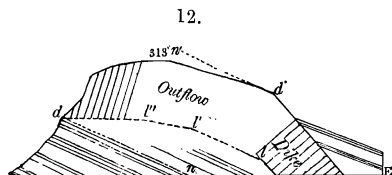
Columns stand out boldly on the steep western front of East Rock. But they have none of the normal forms, for the angle between the most prominent faces frequently approaches a right angle, resulting from a combination of the plane of fracture at right angles to the trap-mass and another transverse. The direction of these planes varies along the course of the Rock on account of the curve in its outlines. At the quarry, on the south side of the summit, at the termination of the zigzag path Z, there is a fine display of broad surfaces in the two directions meeting nearly at a right angle. The courses here are about N. 35° E. and N. 55° W. The surface of one of them for many square yards is covered with rosettes of garnets and scattered minute crystals of magnetite, their faces brilliant in the sunshine. Along the whole western front of the Rock there is a remarkable predominance of planes conforming to its plane through all its changes of direction. This is apparent on Plate IV. and some of the right angles are seen on Plate V.

The upper half of the columnar front (see Plate IV), down to a level of about 220 feet above tide-level, has columns four to eight feet in diameter; below this the size is in general half less; and for the lower twenty feet above the sandstone, they are quite small.

Indian Head.—Indian Head is much like a small edition of East Rock. The length of the outflow is 100 yards; the height 310 feet (313 above mean tide). A section made on the same principle with fig. 11 of East Rock is given in fig. 12.

Indian Head stands quite apart from East Rock. The gap now separating them, where highest, is about 200 feet above high tide, and therefore nearly 160 feet below the top

of East Rock and 110 below that of Indian Head, and probably sandstone intervened for the greater part of this depth; for the two Rocks face one another with steep slopes, as well brought out on the map, Plate III. These continue to be



Section of Indian Head.

steep to the very foot of each, where they approach one another down the eastern slopes. Their bases are here in independent valleys, designated on the map by the letters E and I, separated by a low trap ridge, R, so that East Rock and Indian Head, although the trap extends over the surface of the gap from one to the other, are nowhere united at base. The eastward sloping valley, I, lying at the northeast foot of Indian Head is continued in a westward sloping valley I', at its north-western foot, and the two together define its outline. The low trap ridge R, between E and I, although consisting at surface mostly of blocks of trap, has a solid ledge in its lower part. It probably crosses the gap westward; and the Summer House, near 201 on Plate III, may be on its western part. The valley E, at the southeast foot of East Rock, is perhaps, a result of glacial action; but why there should be two valleys side-by-side if erosion made either, is not explained.

The trap of Indian Head rises from the bottom of the small valley just mentioned apparently in two half-separated streams instead of one even stream; but this feature may be a result of erosion. The eastern outline of the trap (see Plate III) is in a line with the eastern of the East Rock trap, indicating that the supply-fissure corresponded in direction with the outer and not the inner of the East Rock courses of fissures. The two Rocks, although alike in features, are to a large degree independent. Abrasion helped to deepen the gap between them, but more by the removal of sandstone than of trap.

Indian Head is peculiar in having a long eastward projection from the southern end. It is described on a following page.

The mode of origin of the trap-masses of East Rock and Indian Head—by a forced flow of lava, opening through its uplifting action, a chamber in the sandstone for its accommodation—entitles the two to be called *laccoliths*. Through degradation, stripping them of the covering of sandstone, they stand side-by-side—a pair of laccoliths.

Snake Rock.—In Snake Rock, a broad mass of trap measuring about 900 by 450 feet in its two diameters lies encased in sandstone. The greatest height of the trap is but 160 feet, and that of the sandstone west of it over 200 feet. The trap covers the eastern slope of the Rock nearly to its foot, thus showing that the supply-fissure was on that side, as in other parts of the East Rock series, and also indicating by its steepness that the fissure was much inclined. At the south end of the Rock, in the yard behind the north corner of the Bassermann house, at a junction of the trap and sandstone, the dip is about 45° ; and this is direct evidence as to the inclination.

The area of trap of Snake Rock has on the north the width of that of Indian Head; and the mass may hence owe its increased width northward to an outflow. If so, Snake Rock contains a half-emerged laccolith, its summit exposed, but the western wall of sandstone still standing and overtopping the trap. The sandstone shows everywhere the effects of hot vapors in all their varied forms, and before encroachments were made by a brewery there was a fine display of columnar sandstone in the southwestern bluff.

Origin of the breaks in the East Rock series.

The prominent breaks in the East Rock series are that between Indian Head and Snake Rock, and that separating the small northern area, AA', from the main East Rock mass, BB'.

The Indian Head and Snake Rock masses, CC' and DD', approach one another bluntly within a hundred yards, and the area of sandstone between has parallel sides, as the map, Plate III, shows. In view of the steep pitch of the supply-fissure, a catastrophe to the western or overhanging wall is a most probable explanation of the break between them. The checking of so great a stream for a length of 100 yards might be expected to open escape-ways in some direction. The long eastern tail-like projection from Indian Head, C'C'', is the result of outflow along an east-and-west fissure. The pitch of the fissure, as the position of the trap shows, was about 25° to the northward. Its southern front is steep and rocky, the northern, gentle and grass-covered. It may be that this supply fissure was the escape-way then made, and the trap the part of the stream that would have occupied the interval had no such catastrophe occurred.

The relations of the northern trap-mass of the series, AA', to BB' are doubtful. Yet it is probable that the trap of AA' was ejected from the north end of one of the two East Rock fissures, or lines of fissures. The ledge of very hard sandstone which extends southward from near the south end of AA', passes by the east side of the dike-wall *bc*; and it probably derived its position and its excessive consolidation and lost bedding to

a catastrophe that closed the fissure for the interval between them, which is only 200 feet wide, yet left it giving out heat, and generating volumes of hot vapors for the consolidating work.

The East Rock masses of trap may therefore be traced to two ranges of fissures. The western was the probable source of the most northern area, AA, and of the summit portion of that of BB' on East Rock. The eastern, contributed to the lower slopes of East Rock; and also through its continuation southward gave origin to the trap of Indian Head and Snake Rock. But for the accident to the hanging wall of the great fissure, the trap of Indian Head and Snake Rock would have made one continuous mass, and the columnar front of the former might have been continued over part of the present Snake Rock area. The areas of trap in the East Rock series narrow both to the south and the north.

4. WEST ROCK.

The facts and conclusions relating to the West Rock region derive prominent interest from their pertaining to one of the long trap-ranges of the Connecticut Valley region. The area is represented on the accompanying map, Plate VI, from a survey made by the author with chain and hand-level in 1879 and 1880. The 20-foot contour-lines of the steep western and southern fronts of the Rock and the geographical positions are from Bache's Coast Survey map; but the other contour-lines exhibiting the surface features, which required for mapping detailed measurements, are those of the author.*

Features.—(1.) While the general course of the West Rock Range is north-and-south, the western foot of the blunt southern extremity bends round to an eastward course, and ends with north 30° east. The summit of the ridge also curves, in its last 500 yards, around to S. 70° E. or nearly to east-by-west. Its height in this part is 399 to 405 feet above high tide, the geodetic station at the extremity being 399 feet. The eastern foot of the ridge has no corresponding bend.

(2.) The trap of the Rock is a continued mass instead of being divided into several masses through a multiplication of outlets. But it has a large bay of sandstone, of triangular outline, in its southeastern portion, which from its form is called the Triangle. (3.) South of the Triangle there is a prolonged hook-like point making the southeast termination of the trap.

(4.) North of the Triangle commences the trap of the west slope of the mountain. For a distance of 500 feet near the foot, increasing to 800 feet above, the surface of the trap is here elevated sixty to eighty feet or more above the level

* The dotted line on Plate II is the north limit of the map, Plate VI. Heights C to Oa are plane-table results of Prof. H. A. Newton, from Bache's 399 as base.

farther north. Moreover it is raised into rounded ridges, and some of these ridges have a high inclined wall on the south side. The first of these walls adjoins the Triangle and has a height of seventy-five feet, a slope of about 45° and an even flat surface free from marks of abrasion. Another similar wall farther north is thirty feet high. The smaller troughs are mostly one to three yards deep. The angle of slope in the embossed surface between the 300-foot and 100-foot contour-lines is less than 17° ; and in the surface north of it less than 14° . (5.) The long, hook-like point, above referred to, is not a simple ridge of trap, like that from an ordinary fissure, but consists, as seen along its northern side (Plate VI), of a series of rounded ridges which increase in height to the westward, like those of the elevated surface of trap on the other side of the Triangle. Moreover, all these wrinkle-like ridges, concave troughs and oblique walls, have a general parallelism. (6.) The embossed surface north of the Triangle has lost, through glacial abrasion, as a consequence of its elevation above the general level, all of the sandstone once covering it, even to the foot of the mountain, excepting small portions in two of the troughs. Farther north the sandstone remains in some places nearly to the 300-foot contour-line. (7.) The trap of the embossed area that was thus uncovered suffered little from the abrasion; for the rock of the surface has the fineness of grain and other characteristics of the contact rock. This is true also of the trap of the southeast point. Moreover, in many places on this point below 300 feet, the trap contains imbedded fragments of the sandstone which fell into it while it was still liquid. The trap of other parts of West Rock ridge rarely shows evidence of abrasion below a level of 300 feet. On the contrary, above this level it has lost by abrasion the fine-grained, brittle crust-portion, and presents at surface the coarseness of crystalline texture that belongs to the interior of the mass.

(8.) Another very important feature of West Rock is its affording a long east-and-west section through the breadth of a great trap range, exhibiting the contact-plane for several hundred feet of the outflowing trap and the underlying sandstone, as described and figured beyond.

The map, Plate VI, has the walls, troughs, and ridges of the surface shaded, to bring out better these features of the original surface of the trap. The southern front of the Rock has been made by degradation and hence has no shading. The southeastern point owes its straight outline on the south side to the quarrymen and the joints in the trap. The map shows what remained of the point in 1880. There is much less now.

The Supply-fissure.—The inclination and width of the fissures supplying the liquid trap for the West Rock range are

undetermined. Exposures that will afford the facts are most likely to be found along the eastern base of the ridge. At one place where the surface of trap had been uncovered but not abraded, which was seemingly favorable for a safe conclusion, the slope was 25° to 30° , and suggested the angle of 30° for the inclination. But the trap at the place may have been part of the *outflow*, and not that of a dike. Observations along the eastern slope of the range farther north may obtain decisive facts.

The Outflow.—The slopes of the higher parts of the West Rock ridge, the pitch of the columns of the western front, and the resemblance in features of West Rock to East Rock, lead to a like conclusion for the two, that the outflow was laccolithic; in other words, that the liquid rock forced its way between layers of sandstone, and made the chamber it occupied. The present thickness of the mass is nearly 250 feet. The overlying sandstone is to a large extent the weak, chip-making rock of dark red and purplish color already described. It is remarkable that a rock of so feeble coherence could have been lifted in the way mentioned.

The questions suggested by East Rock here come up again: Whether the feeble slope of the surface from the west edge of the summit eastward to the 300-foot contour-line, and the small thickness of the trap, are due to abrasion, or whether the present conditions are nearly those of the original outflow. As the length of the outflow is nearly 500 yards, the mass, if forced up between layers dipping 25° eastward, would have had a much larger amount to lose by abrasion than in the case of East Rock.* Speculation is here set aside by the actual east-and-west section of the Rock which is presented along its southern front, and is shown in part on Plate VII, from a photograph.† It exhibits the trap resting, to the eastward, on

* The thickness does not admit of calculation, because the only datum besides the dip of the sandstone, is the height of the bottom of the trap over the sandstone on the west front (about 200 feet); the height of the outflow where it left the fissure is not ascertainable.

† The fine photograph was taken by M. W. Filley, of the firm of Bundy & Filley, of New Haven. The sandstone has here been exposed to view by the removal of the debris for macadamizing. The irregular line in the plate a third of an inch above the sandstone was the limit of the talus or debris slope; and the line below the sandstone is the profile of the quarry wagon road. Along the part of the section represented, the height of this road is ninety to one hundred feet. If the debris were wholly removed to the bottom of the slope, the height of the sandstone exposed to view would be, where greatest, over 150 feet.

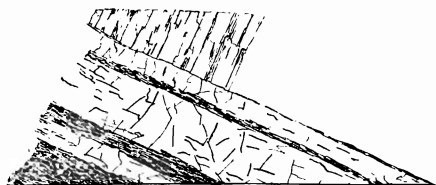
The photograph does great injustice to the view in the diminution of the vertical as compared with the horizontal scale, and also in flattening the angle of dip in the sandstone. 200 feet measured on the quarry road reaches from the eastern point of the sandstone section westward to within twenty-five feet of the line of the deep notch in the columnar front of the Rock (the place where the first section of sandstone ends); but this length applied vertically to the front above the road would make it only 180 feet in height, when in fact this height where greatest is over 300 feet. This error arises partly from the fact that the view was taken from the terrace opposite, which is only sixty feet high, but more from the error in an ordinary lens.

a tilted layer of the sandstone, the dip of which eastward is 25° . We are left to conjecture as regards the eastward and downward continuation of this layer to the supply-fissure (which the further removal of debris might perhaps uncover). But we know that the trap continues up this sloping layer for seventy-five yards from the commencement of the outcrop. It conforms to the theoretical view of an outflow as presented in fig. 10, on page 94.

But on reaching the end of the seventy-five yards, there is a change. The trap beyond rests on the edges of the layers in a series of ledges of the sandstone. Moreover there is but little rise westward along the floor; for a line drawn along the top of the ledges would be almost horizontal, and have therefore near parallelism to the surface of the trap at the summit west of the geodetic station.

The following figure represents the eastern extremity of the sandstone for a height of fourteen feet, together with the

13.



base of the overlying trap. The rock is partly a hard-baked granitic sandstone, and partly the feeble shaly chip-making purplish-red sand-rock. The trap columns above the sandstone have in the lower part an inclination of 20° , approaching thus verticality to the surface of the sandstone; but, higher up the bluff front, there is a gradual change to 5° , which is the prevailing inclination.* The upper layer of the sandstone where uncovered shows a surface without breaks or much unevenness.

A section of the sandstone, with the trap above, for the next seventy-five yards is represented in the following figure. The fact that the trap when melted flowed over the upturned edges is manifest. The chip-making rock constitutes much of the mass, and at its contact with the trap it is scarcely changed in color or texture. The trap is far more finely columnar than that to the east over the single sandstone layer, and probably because moisture reached the trap freely from between the upturned layers. Other sections farther west are of similar

* The angles of inclination here recorded are those presented to an observer in the front view of the rock here described.

character, excepting that the apparent dip is less. They may be followed westward along the quarryman's road for 400 yards, when they begin to pass into the normal sections of the western front, that is, sections in which the lines of bedding are horizontal because they are in the line of strike of the sandstone.

14.



The question here arises : Did the flowing trap, owing to its movement and weight, wear off the layers of sandstone and so make the succession of ledges on which it rests; or did it escape from its confining cover of sandstone into the open air and cover in its flow the exposed ledges of the region. The former is probably the correct view. Had the flow become subaerial there would have been at once a decline westward in the level of its upper surface; for the level would have fallen as soon as the resistance from confinement ceased. There is no evidence of such a decline. From points on the summit close to the western precipice the surface for the first 300 yards has generally a slope eastward of 1 to 4, or 1 to 5, corresponding to a pitch of 14° to 11° . The decline is eastward; not westward. Such a rise westward, even if only 5° , would be an impossibility except in a covered passage-way, that is, in the present case, one having a cover of the sandstone. Other evidence bearing in the same direction is afforded by the position of the columns along the western front, which pitch westward 15° to 20° .

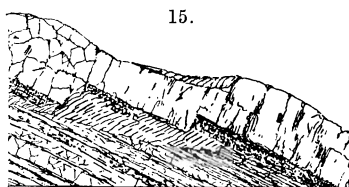
The summit slope eastward of 14° to 11° is less than the dip of the sandstone, and favors the conclusion that the underlying sandstone was in many places torn up by the heavily moving liquid trap, while left in place elsewhere. The floor so made consisted of alternations of wide strips that had the regular dip of the sandstone, with others abraded down to nearly flat and ledgy surfaces; and the former prevailed sufficiently to determine the direction of the contractional

fracture-planes or the columnar structure. A reduction so nearly to horizontality as that shown in the south front of West Rock along with parallelism in the profile of the summit may not be common.

West Rock teaches that the section of East Rock in fig. 11, p. 95, may be no exaggeration. Yet it is more probable that the original condition was intermediate between this position and that indicated in this diagram.

Sections similar to that in the south face of West Rock may be looked for, with some probability of success, among many of the trap-ranges of the Connecticut Valley wherever they terminate in transverse sections. All that is necessary to ascertain the truth is to remove the talus of trap debris.

Three miles east of New Haven (in East Haven) a section was opened in cutting for a carriage-road through the second trap ridge west of Saltonstall Lake; it is but a few rods west of the railroad station. The facts are in all respects similar to those of West Rock, as shown in the annexed figure. The



trap covers a series of ledges of upturned sandstone, and shows no traces of displacement subsequent to its cooling. The sandstone is intersected by extensive nearly vertical fractures, whose surfaces, owing to friction, are scratched and polished; and the larger planes extend up through the sandstone without any appearance of corresponding displacement in the trap. Moreover these polished slickensided surfaces have the white porcellanous coating common in the region; probably made by the grinding of the feldspar of the sandstone in the mutual friction of the walls.*

* At all the East Haven quarries, and in the ledges elsewhere exposed to view, these evidences of displacement and of much friction attending it abound. Fragments as large as the hand, slickensided on both surfaces and over planes of cross-fracture, are common; and so are walls of various inclinations hundreds of square yards in area. The sloping upper surfaces of the sandstone layers laid bare in the quarrying are sometimes polished and scratched in the direction of the dip for many square rods. There is abundant evidence of a vast amount of movement, though movement in a small way, during the progress of the upturning in which the sandstone received its universal eastward dip.

The section represented in fig. 15 has lost much of its original distinctness by the sliding down of debris from above.

The trap of this ridge, at a higher level above the sandstone, is more or less chloritic and in many places amygdaloidal. Part of the amygdules are slender cylinders, two to three inches long and like pipe-stems in size, occurring often in groups—the result probably of the sudden vaporization of particles of liquid carbonic acid.

In the railroad gap through the Saltonstall Ridge, the first west of Saltonstall Lake ("Pond Ridge" of Percival), the sandstone appears to lie in a similar manner unconformably beneath the western extension of the trap. But the section is now too much covered by debris for a satisfactory observation. Two miles east of the Saltonstall ridge in Branford, as described by Mr. E. O. Hovey,* the trap of a short range, the easternmost in this part of the sandstone region and near the gneiss boundary, overlies the *upturned* edges of the sandstone, and there is between the two rocks a layer of sandstone conglomerate containing nodules of trap, which he attributed to the rubbing action of the flowing trap on the sandstone.

These facts, ranging in this part of the Connecticut Valley over the whole breadth of the Jura-Trias formation, from the west side of the New Haven region where the trap is of the compact non-vesicular kind to the dikes of vesicular trap toward and near the eastern gneissic border, have great importance in their bearing on the subject of the other Jura-Trias ridges. The more eastern are placed by Professor Davis among the ridges made of horizontal subaerial flows, ejected before the upturning of the sandstone; and the more western he has regarded as horizontally ejected and subsequently upturned, although admitted to be interstitial intrusions. Neither of these conclusions are sustained by the facts which have been presented.

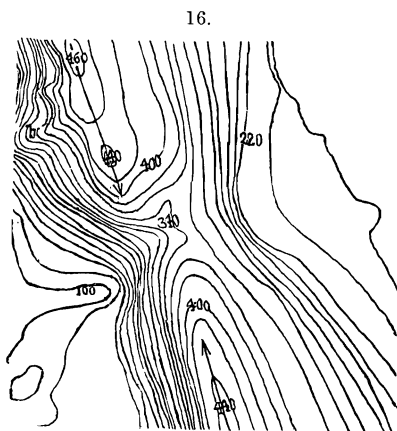
The facts prove further that the era of disturbance or of the upturning of the sandstone was not due in any way to the ejection or heat of the igneous rock. The latter event, although so extensive, was simply incident to the disturbance; the upturning preceded the eruptions.

Effects of Obstructions to the outflow.—Although the trap of West Rock—that is of the southern part of the West Rock ridge—is not divided into several areas, other effects of obstructions may be looked for, since the hanging wall of a large inclined fissure is sure to have its downfalls. The gaps or notches in the ridge indicate incipient division, and may be among the effects from such a cause. They may have been produced also by local narrowings of the fissure through horizontal or oblique movement of its walls, or in other ways; and it is a question whether the results of these two modes of origin can be dis-

* This Journal. vol. xxxviii, p. 361, 1889.

tinguished. The deeper and more abrupt notches we should be disposed to refer to the former cause.

As the Bache map of West Rock ridge indicates by its contour lines, within a mile and a quarter of the south end of West Rock, there are three gaps. Two are included on Plate II. At the first, the height of the ridge falls off sixty feet in the course of 500 yards. The second, situated 300 yards farther north, and called the "Judges' Notch," because near the "Judges' Cave," is similar to the first in depth, but narrows more down the western front. Half a mile farther



Wintergreen Notch.

north is the third, called the "Wintergreen Notch." It is one of the larger gaps in the ridge. Along the summit, both from the north and the south, there is a descent of 100 feet, from a height of 440 feet to 340. Figure 16, from the Bache map, exhibits the facts.* The decline is gradual on the south side, but very rapid northward; in the latter direction the level of 460 feet is reached at the same distance from the center of the gap as 440 on the south. This third gap is

probably one of those caused by obstructions to the outflow, whatever the fact with the others. The stream, in consequence of the obstruction, reached a height at the gap of but 340 feet; but just beyond, the lavas that had been held back, made the abrupt rise in the ridge to 440 and 460 feet. The correctness of this explanation appears to be sustained also by the abruptness of the rise in the slopes east of the gap, as the contour lines in the figure show, and the great breadth of the nearly horizontal area farther east. It will be observed also that the summit of the ridge north of the gap is farther to the west than that on the south. (Arrows are inserted to make this distinct.) It is so because any given amount of trap depends for its height on the distance it flowed westward up the inclined sandstone layers. It may be observed that not only the height,

* The west side of the ridge in this part, as elsewhere, is the precipitous side, bold columnar above. Its upper 200 to 225 feet usually consist of trap, and the part below of sandstone; but the junction-plane at the Notch is concealed by trap debris, so that its actual height is not determinable.

460, but also 440 on the north side is to the west of 440 of the south side; but the height of 440 to the north is probably produced with a less thickness of trap. This notch is 300 yards south of the Buttress dike described on a former page; the position of this dike is shown on the above figure at *b*.

This example will suffice for illustration. Other gaps in the ridge occur farther north, but they are outside of the region here under consideration.

Obstructions to the outflow of lava while it was making its way between the layers of sandstone are also possible through any cause that would prevent the lifting of any portion of the overlying rock. The area of the Triangle has been described as an area of sandstone within the proper limits of the trap range. This sandstone was not lifted like the rest of the overlying stratum. Instead of this, it remained in place for the most part, and hence, forced the liquid rock to pass to one side of it. The lava, mainly took the north side; and so the trap of that side had its surface raised in level above the rock north and became the elevated embossed area already described. The great sloping trap wall making the north side of the Triangle is the wall of an oblique fissure in the sandstone formation. Along this fissure— 45° in inclination,—the sandstone of the south side, or that of the Triangle, lay unmoved or nearly so, while that of the north side was shoved up as the lavas came in below. Other walls, and the small ridges both north and south of the Triangle, are evidences of similar fractures, in parallel directions, with analogous results. The unlifted sandstone was in some way put under a strain that produced the parallel fracturing and movements.

The origin of the southern or western walls of West Rock is sufficiently explained in the remarks on this subject respecting East Rock (page 94).

The southern front of West Rock has a columnar aspect. But in reality no columns stand out with the boldness they have in East Rock. The surface is mostly made up of the cleavage surface or joints that are in its plane; and where there has been quarrying, these joints have great width as well as height.

3. RELATION OF THE EAST-AND-WEST AND NORTH-AND-SOUTH FISSURES, AND THE ORIGIN OF THESE COURSES.

These two courses of fissures are so locked together in the New Haven region that they evidently are results of one system of movements. They occur together in Pine Rock; and West Rock has the general trend of the Pine Rock ridge represented in the embossed area and the southeast point.

Mill Rock ends to the eastward in a south-southwest fissure, transverse to its main course which is apparently parallel to the adjoining part of the East Rock trap. East Rock commences with a nearly north-and-south course, but bends around to east-southeast. Mill Rock and Pine Rock are not necessarily synchronous in eruption with East Rock or West Rock, but they belong to one epoch of disturbance.

The origin of these courses is not fully ascertained. I have long explained the north-by-east trend of West Rock, and of the other ridges of like direction to the north, on the general principle that the mountain-making forces of Eastern America operated over any part of the area, as a general thing in the same direction from Archæan time onward, examples occurring in the Taconic and Jura-Trias elevations of the western half of New England. In accordance with this view the strike of the Jura-Trias should be that of the underlying crystalline rocks. It does not follow that a like dip prevails in the schists beneath. It is true however that the predominant dip in them, and in the Jura-Trias fissures and bedding, is eastward. This last fact seems to favor the suggestion of Professor Davis that the foliation of the underlying schists has determined the courses of fissures in the Jura-Trias area. This suggestion would have support in the fact, were it not that in New Jersey, where the same is true as to the dip of the underlying schists, the Jura-Trias fissures and bedding dip westward.

In the New Haven region, the idea of an accordance between direction of foliation in the schists and of fissures in the Jura-Trias finds no support. The West Rock ridge crosses the line of strike of the metamorphic schists two miles west of it at an angle of 20° . East Rock has an east-of-north course only in its northern extremity, and curves around through nearly half a circle. Pine Rock and Mill Rock cut across any probable course of foliation in underlying schists and do it on lines that differ 50° in trend.

The origin of the east-and-west courses, which commence in the extremity of West Rock and continue to Whitney Peak, four miles, may have its explanation suggested by the remark on page 80. Or, it may be a consequence of the movement attending the production of the north-and-south fissures, and local to the New Haven region. The subject at present is one of conjectures.

On account of the interest of the dynamical question here brought into view, I introduce another illustration of the facts from a transverse ridge only six miles north of Whitney Peak and Mill Rock. It is called Mt. Carmel. The ridge is only one and a half miles long. It is higher than those already

considered, the most elevated point being 736 feet above high tide.* But height means here, not larger accumulation of igneous rock or trap, but, simply, greater emergence above the sea-level; for this increase northward of height runs parallel with a like increase in the height of the metamorphic ridges just west; and it is continued, at a diminished rate, into Massachusetts.

Mt. Carmel has resemblances to Pine Rock. Its mean course is E. N. E.; and a north-and-south trend exists in its western part. But the north-and-south portion in Mt. Carmel is a large feature in the ridge and has direct continuity with the east-northeast portion.

The ridge is divided by a very deep and open gorge, into an eastern and a western section. The gorge is often called the "Neck," and the high summit adjoining it on the west, the "Head" of the "Sleeping Giant"—a name suggested by the form of the ridge as it appears lying on the northern horizon. Both have northern and southern slopes of sandstone, the southern going about half way to the top above its base, and the northern reaching a greater height.

The western section, while high and massive at its eastern extremity, falls off rapidly to the westward, and in half a mile is reduced to a narrow trap ridge not exceeding 100 feet in height above the adjoining country. Through this part within 300 yards, pass Mill River, a north-and-south carriage road (N. 20° W.) without change of grade, and, a few rods farther west a railroad. Along the railroad, and between the carriage road and the river, the course of the trap changes from about north-and-south to N. 10° E.; and as it crosses the river to N. 20° E. Thence it continues on to the summit, widening and increasing rapidly in height and curving still farther eastward.

At the section in the railroad cut, the trap is seen resting on its south wall of sandstone, the wall dipping about 45°—apparently indicating that the dike has this pitch. Between the carriage-road and Mill River, the north side of the trap has in many places a westward dip of the same angle, confirming the conclusion from the railroad section as to the large dip of the fissure. It is thus proved that the western section is a continuous mass of trap of gradually changing course and magnitude; and that it is strictly "transverse" in direction only along its eastern end. It is a dike to the westward and probably so throughout.

The eastern section is made one continuous mass of trap by Percival, and one also with the western portion. It is divided

* According to the leveling of two parties under Mr. Bache.

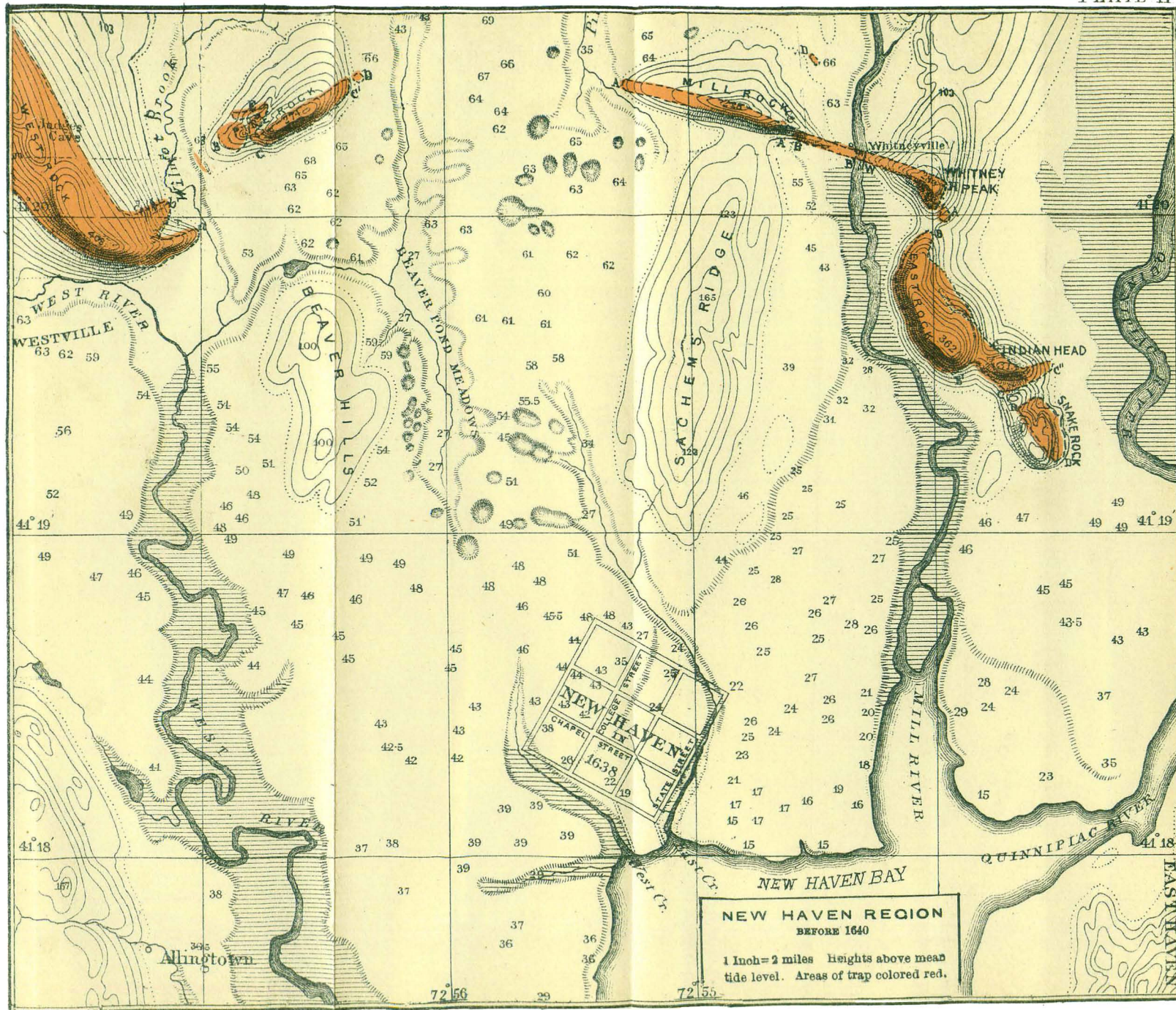
from east to west, as he states, by a valley, and in the valley there is a spring giving out a streamlet which flows northward. There are gaps in both the southern and northern sides, dividing them into a series of elevations. These elevations are indicated on Percival's map, so as to look as if he regarded them as separate dikes; but this is contrary to the description in his Report. I have looked for sandstone in two of the gaps of the south side, east of the "neck," and have found evidence in each that the trap is continuous, and descends in these gaps nearly half way to the base of the mountain. In the east-and-west valley the spring and streamlet are probable evidence that there is sandstone beneath; and on this ground, it may be that there are, in this eastern part of Mt. Carmel, two parallel east-and-west dikes.

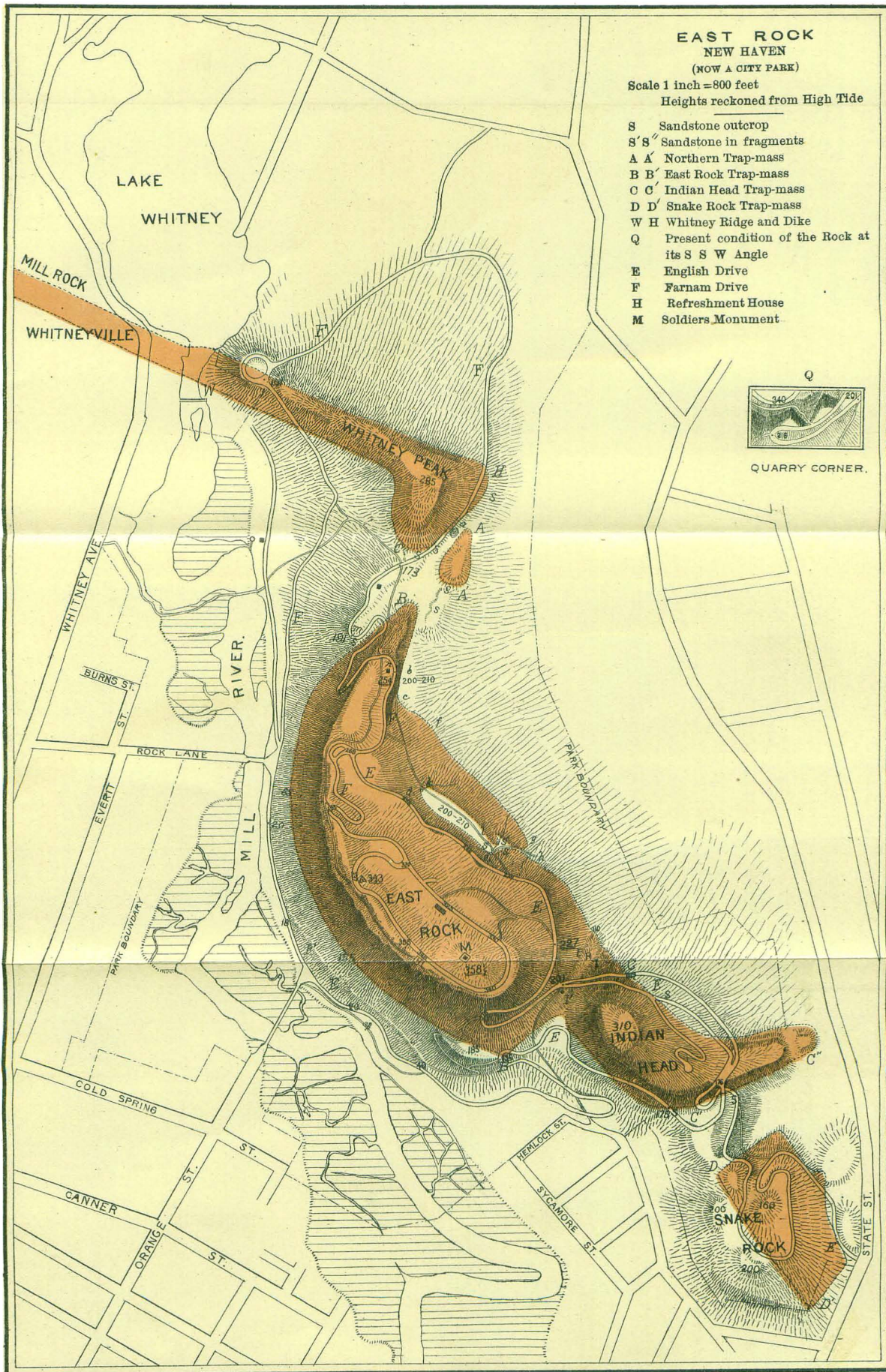
Mt. Carmel appears to be a combination of dikes, without the "buried volcanoes" supposed to exist there by Professor Davis. In the view from the west side of Mill River there are in sight nearly 600 feet in height of massive trap, having no subdivision into sheets or layers, and nothing to suggest the idea of lava-streams in the depths below.

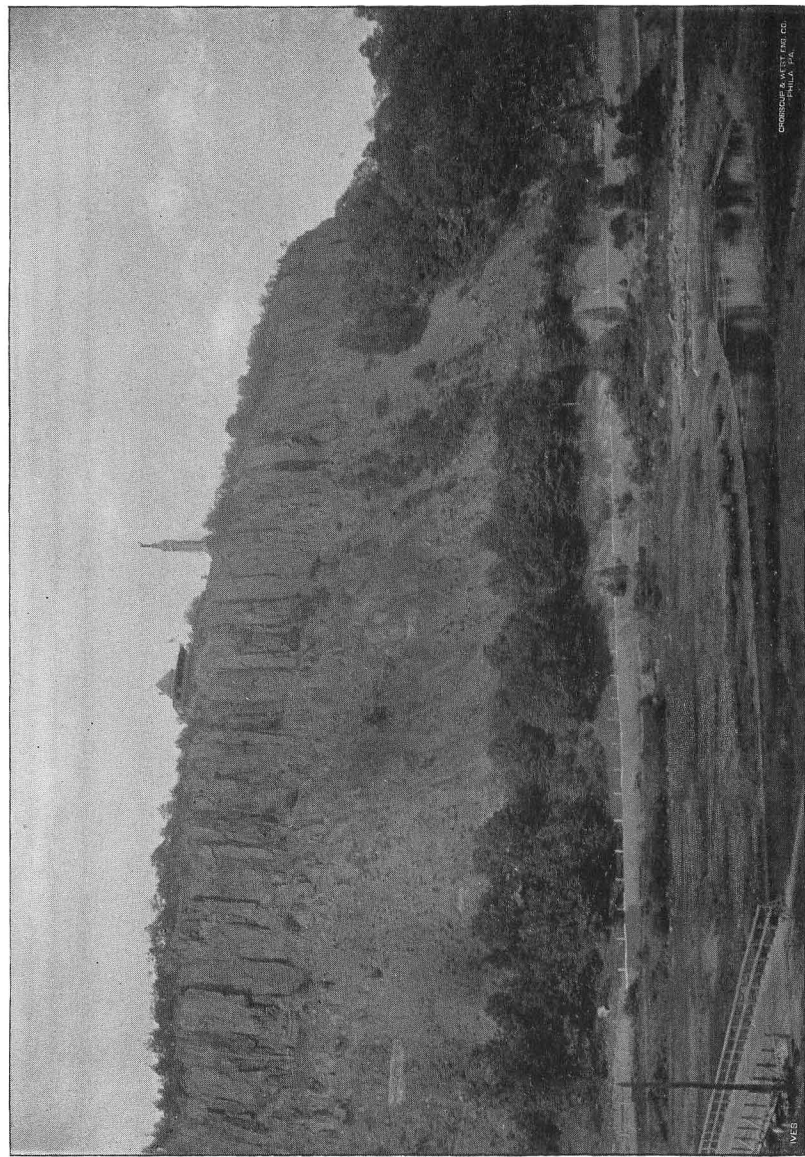
The union in this small ridge of approximately north-and-south and east-and-west courses is further proof of their mutual dependence in the system of movements attending the Jura-Trias mountain-making of the Connecticut Valley. But its origin remains unexplained.

Concluding Remarks.—A review of the principal conclusions in this paper is given in its introductory remarks (page 82), and a recapitulation here is therefore unnecessary.

The reader may have been led to the idea that the author would make the West Rock Ridge typical for other ridges of like features in the Connecticut Valley region, in disagreement with the conclusion of Professor Davis who holds that in the case of most of these ridges, if not of all, the trap was poured out in one, two or more horizontal sheets, separated, and overlaid horizontally, by beds of sandstone, and that the whole was afterward faulted and tilted so as to make the ridges. The author acknowledges that he is inclined to make the conclusions he has reached general. He, however, admits that he has not made the structure of the other ridges of the valley a special study. He believes his observations sufficient, however, to authorize the statement that a more intimate knowledge of the facts is required before any adverse views can be regarded as established.

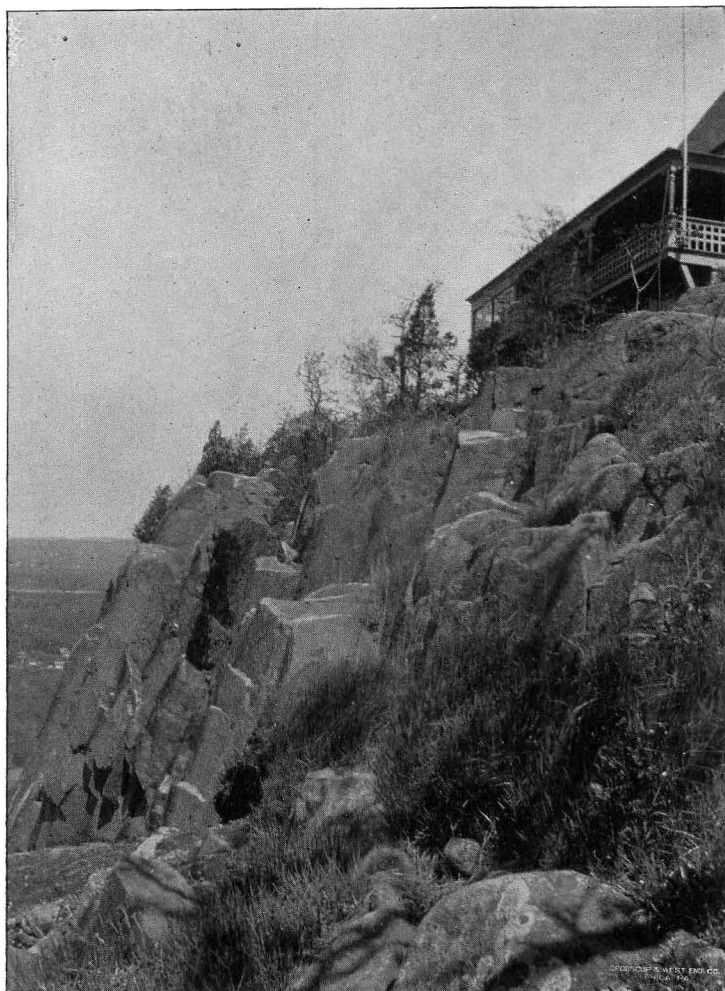




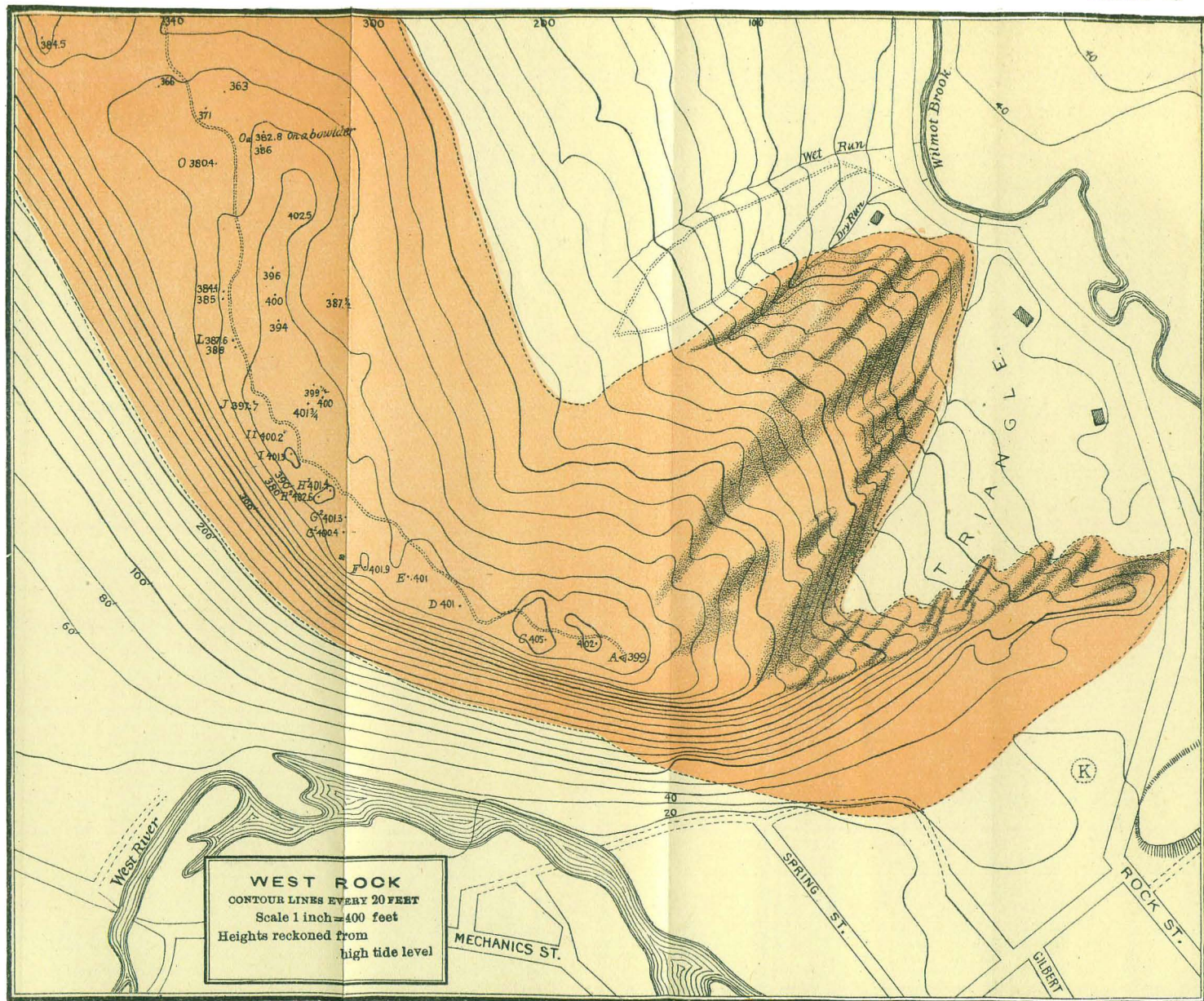


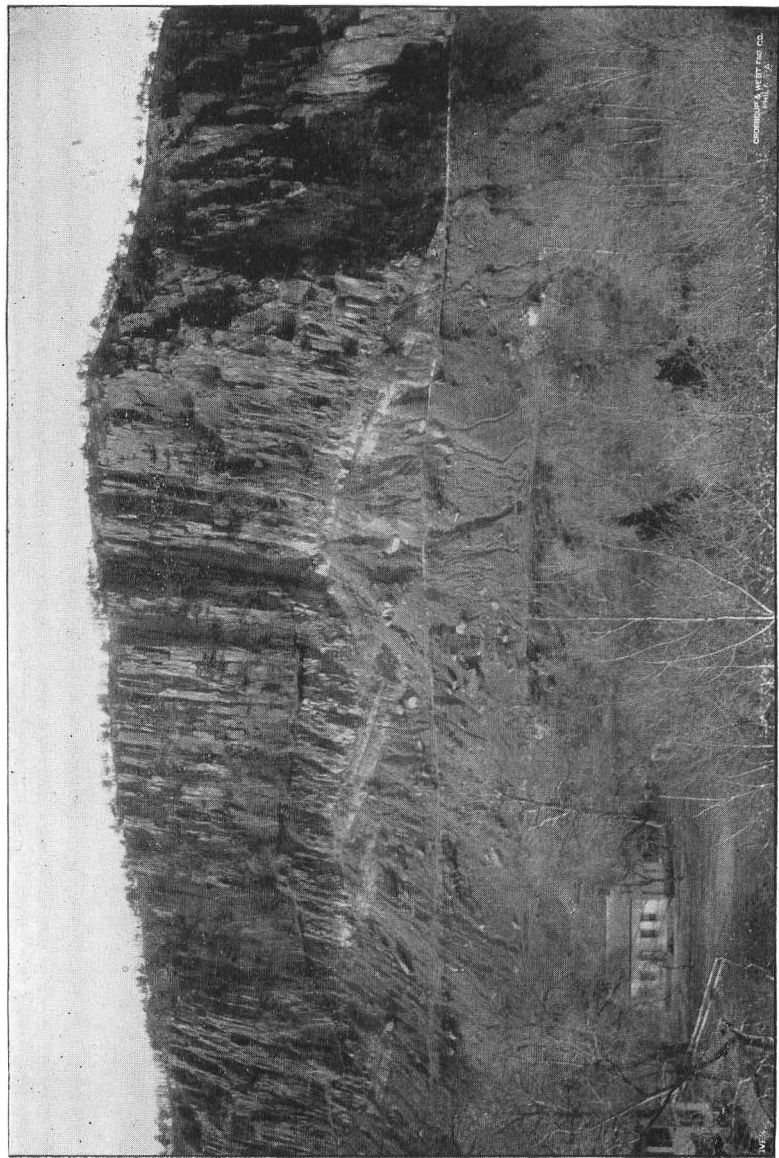
View of East Rock from the southwest, near Orange Street Bridge.

(From a photograph.)



Profile view of columns, East Rock, near the house on the brow of the Rock in Plate IV.
(From a photograph.)





View of the south front of West Rock, showing the trap of the outflow overlying upturned sandstone for a distance of 550 feet.
(From a photograph.)