Art. XXXIX.—*Phenomena of the Glacial and Champlain periods about the mouth of the Connecticut valley—that is, in the New Haven region;* by James D. Dana.

The Glacial phenomena over the New Haven region have many points of special interest, an important part of which arise from the fact that the ice of northern New England which had moved down the Connecticut valley or trough, here left the mainland for a passage through Long Island Sound. The subject includes therefore a discussion of the relations between the part of the glacier to the north and that over the Sound and beyond, and suggests questions as to—

(1) The thickness of the glacier at this southern end of the trough, and the pitch along the trough.

(2) The fact or not of two directions of movement in the ice —a *lower* or *trough stream* south-southwestward, and an *upper stream* southeastward; and, if two, as to their being simultaneous or not.

(3) Any mixing of drift materials from the two streams.

(4) The direction of movement after escaping from the confines of the Connecticut trough and entering the east-and-west trough of the Sound.

(5) Any effects in the New Haven region consequent on a change of direction in the glacier-movement.

The phenomena also of the early Champlain period, when the floods from the dissolving glacier were pouring down the valley and made use of New Haven Bay for the outlet of part of the waters – repeating the drainage conditions that existed long before in Triassic time—have a wide bearing, especially those connected with—

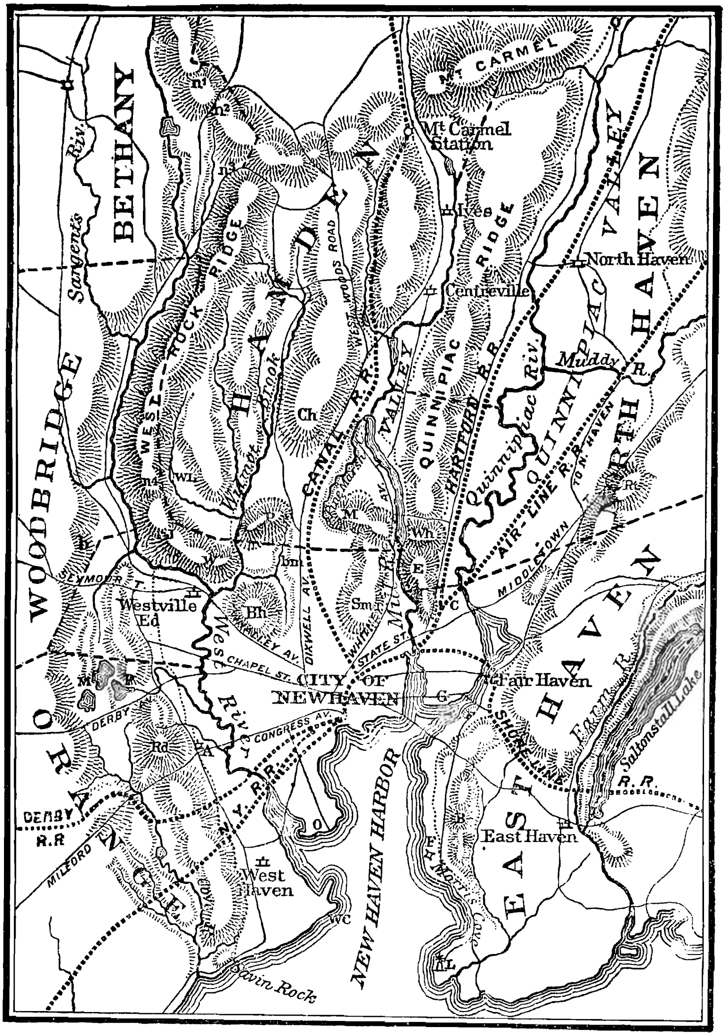
(1) The structure and seaward slope of the New Haven terrace-formation, or the deposits of stratified drift which underlie the broad New Haven plain.

(2) The occurrence, over the flood-made fluvial deposits of the plain, of more than forty isolated basin-shaped cavities called "kettle-holes."

(3) The existence also of two broad north-and-south depressions in the plain, each over a mile long, which look like deserted river channels.

(4) The apparent connection of these depressions and the "kettle-holes" with a former system of drainage, characteristic of the Glacial era.

(5) The existence of a terrace on the bay, testifying to the sea-level during the era of the flood.



MAP OF THE NEW HAVEN REGION. Scale 4-10ths inch = 1 MILE.

Explanations.—A, Allingtown. B, Beacon Hill. Bh. Beaver Hills. Ch, Cherry Hill. E, East Rock range, consisting of East Rock to the north, next south Indian Head, and further south Snake Rock. Ed, Edgewood. F, Fort Hale. *F*, Ferry Point, or Red Rock, on the Quinnipiac. G, Chapel Street. J, Judges Cave, on the West Rock ridge. L, Old Light House. M, Mill Rock. M P, Maltby Park. O, Oyster Point. P, Pine Rock. Rd, Round Hill. Rt, Rabbit or Peter's Rock. Sm, Sachem's ridge. T, Turnpike; also Tomlinson's bridge, across the head of New Haven Bay. V, Whitneyville. W, West Rock, the south end of West Rock ridge. W C, West Cape, or West Haven Point. Wh, Whitney Peak. W L, Wintergreen Lake. *b*, 1200 ton bowlder in Woodbridge. *bm*, Beaver Pond Meadows. *n*1, *n*2, *n*3, *n*4, different notches in the West Rock ridge; *n*1, *n*2, the upper and lower Bethany Notches; *n*3, the Hamden Notch; *n*4, the Wintergreen Notch.

Some of these points were discussed by me in 1870, in a paper on "the Geology of the New Haven Region," published by the Connecticut Academy of Sciences in the second volume of its Transactions. But since that time many new facts have come to light, sustaining some of the conclusions then presented and requiring modifications of others, besides affording fuller illustrations of all the various characteristics of the plain. Further, in the interval which has elapsed, a topographical survey and chart of the region have been made under the auspices of the Coast Survey and the special superintendence of Mr. R. M. Bache, assistant U. S. Coast Survey, laying down the features of the surface with great accuracy, and indicating the level over the whole area by 20-foot contour lines. In my endeavor to secure such a survey, I had especially in view its use as a basis for geological investigations and reports; and it fulfills well the purpose. Moreover, it has brought to view new facts, and given greater precision to our knowledge of topographical details. A review of the subject with the aid of all the additional light obtained is therefore needed.

On the preceding map, the *New Haven region* comprises all of the area south of the trap-and-sandstone range of Mt. Carmel, and east of the range of hills of metamorphic schists which make its western border through the towns of Orange, Woodbridge and Bethany.

The *western* border region has a rather abrupt eastern front, and rises in height from 100 feet above mean-tide level on the south to 650 feet on the north. This western border was the western margin of the deep Connecticut trough and estuary of Triassico-Jurassic time, all the rocks of the region eastward of it being trap and sandstone of that era; and it was the occasion of important results also in the Glacial and Champlain periods. South of Westville it is a *double* ridge—that of a broken-backed anticlinal—a shallow valley of ledges and marshes (one-fourth to three-fourths of a mile wide) separating an eastern and a western range of hills.*

The outline of the flood-made terrace-formation is indicated on the map by a dotted line, at the base of the hills. As is seen, the three principal valleys and former flood-ways of the region—West River, Mill River and the Quinnipiac—open southward into the broad New Haven plain. The Quinnipiac valley is separated from that of Mill River by the Quinnipiac ridge, made of sandstone hills 100 to 250 feet in height, with East Rock ridge, 362 feet in greatest height, at its south end; and Mill River valley from that of West River, by the "West Rock Ridge" of trap (doleryte) 400 to 600 feet in height, together with the various sandstone hills that lie to the east of it.

* The valley is called (from one portion of it at M on the map) Maltby Park valley. See also the map on page 358.

On the eastern margin of the region the hills are of trap and sandstone; the largest of the trap ridges constitutes the western border of Lake Saltonstall.

After this introduction, I will take up, first, the phenomena of the Glacial period, discussing the points in the following order:

1. The fact of a southward (S. by W.) movement in the *lower* ice of the glacier along the Connecticut valley, and the angle of slope of the surface of the ice in the direction of the valley.
2. The fact of a *southeastward* movement (S.S.E. to S.E.) in the *upper* ice.
3. The correlations of the two movements as to time and as to drift depositions.
4. The direction of movement over Long Island Sound.
5. The drift deposits, and the probable effects of the wrenching attending the change of direction which they exhibit.

I. Glacial Phenomena.

1. *The fact of a Connecticut valley movement and the probable surface-slope of the ice in the direction of the valley.*

a. The fact of the valley movement.—The fact of the valley movement I pointed out in 1871,* basing the conclusions on (1) observations in Massachusetts, by Professor Edward Hitchcock, published in the Massachusetts Geological Report (1841), (2) observations in Vermont, from the Vermont Geological Report (1861), made chiefly by Professor C. H. Hitchcock, (3) a map of New Hampshire by the latter, giving the directions of glacial scratches, published in advance of the final Report on the Geology of that State, and (4) on my own investigations. The facts supplied by Professor Edward Hitchcock, the earliest careful investigator of the subject on the continent, were sufficient alone to establish the truth announced; and he recognized it, but made the ice mainly that of icebergs. The same conclusion is presented in the Vermont Report. But in the New Hampshire Report, published in 1878, the movement is made by Professor C. H. Hitchcock a *glacier* movement.

The fact *is proved by the glacial scratches.* All observations from New Haven northward to Windsor in Vermont, 140 miles, give, with rare exceptions, courses between S. and S. 20° W. In the upper part of the valley, north of Windsor to Wells River, 60 miles, both southward and southeastward directions occur.

It *is proved also by the drift transportation.* Of the drift material in the New Haven region, more than 99 per cent, including bowlders innumerable, from one ton to 1200 tons in weight,

* This Journal, II, li, 233.

were derived from the trap and sandstone *of the valley*, that is, were taken up in the valley and transported along the valley. The proof is hence positive that the transporting agent moved down the valley, gathering the stones and earth by the way, and, sooner or later, depositing also by the way. The mean course of the Connecticut valley in Connecticut, from the Massachusetts boundary to New Haven bay, is S. 17° W., and this is about the mean course of the scratches and drift.

b. Directions of the bottom movement over the New Haven region; the large amount of WESTING *along the western border and beyond over Orange and Milford.*

The glacial scratches in the eastern part of the New Haven region, over East Haven, about the various opened quarries, indicate a movement in the direction S. 13° W. The usual trend of the sandstone ridges of East Haven is about the same, showing that they owe their forms to glacier abrasion. Sachem's Ridge (Sm on the map), made into a ridge by the ploughing glacier,* because of the protecting Mill Rock to the north, has a trend of S. 11½° W. In Hamden, farther north, the "Quinnipiac Ridge" (similarly carved out by the glacier because under the lee of Mt. Carmel) has the mean course S. 16° W. The valleys and sandstone ridges west of this ridge have nearly the course of the West Rock ridge to the west of them, or S. 26° W.† Along the western border of the New Haven region, in Orange, the course at the many scratched ledges is S. 26°–38° W., and mostly S. 33° W. But it varies over Maltby Park, (M on map) to S. 45° W. and S. 56° W. owing to local conditions.

The large amount of westing on the western border was pointed out in my paper on the New Haven region of 1870; but I have now the additional fact that the course S. 33° W. occurs to the westward of this border over Orange and Milford, for half a dozen miles from the New Haven region, or nearly to the Housatonic and Naugatuck valleys, showing that the south-westward movement had a wide westward extension. The fact points, I suppose, only to near uniformity of direction in the low and broad valleys and ridges of the surface; and proves that the topography, notwithstanding the fact that the rocks are fragile slates, was of pre-Glacial origin.‡

* Ploughing deeply over the soft sandstone formation, but feebly abrading over the trap.

† An exception as to westing occurs two miles north of Westville in the narrow West River valley, where the course of grooving over the slate rocks is South; an exceptional course evidently due to the form of the surface at the place.

‡ Many variations in the directions of glacial scratches are due simply to the varying slopes in the land-surface underneath. The variations usually found about a knoll are an example on a small scale. Only when the slopes of the land-surface and upper glacier-surface coincide in compass-course, will the scratches have the direction of the glacier-flow. If these surfaces are oblique to one an-

The positions of the great bowlders and of the accumulations of drift correspond as to the amount of westing with the courses of the scratches.

The larger bowlders of trap and sandstone lie in the *western* half of the New Haven region. Further, they are gathered in great numbers, together with thick deposits of till, along the hilly *western border*, and especially the *eastern declivity of the high border*—as if moraine-like in origin. But some bowlders of large size occur on the top and eastern declivity of the West Rock ridge, which is one to two miles east of that western border, and a few are found farther east.

One of the largest of the trap bowlders, called the Judges' Cave, lies on the top of the West Rock ridge (at J, a mile north of Westville), at a height of about 365 feet, where it was probably stranded because 25 feet too low in the ice to clear the top of the ridge. It is now in a few large pieces, probably through the rending action of growing trees, but weighed when entire at least 1000 tons. Just a mile west of the "Judges' Cave" on the Woodbridge declivity, lies a still larger bowlder of trap and entire, its extreme length 42 feet, and estimated weight 1200 tons. The spot where it rests is about 360 feet above the sea-level, and 20 feet below the summit beyond it. But a few rods south lies another of 100 tons, and a few hundred yards to the north there is a group of five great trap bowlders, the largest about 200 tons in weight, that were similarly stranded—a most impressive assemblage. Three-fourths of a mile north *on the same declivity* lies another bowlder of 500 tons. Many more of great size—500 tons to 10 (equivalent to 6000 cubic feet to 120), occur both north and south along this border. Further, very few trap bowlders of large size passed its summit. One, measuring 13×9×5 feet, lies a mile west of it in southern Woodbridge; a group of others, the largest 17×15×5 feet, at the same distance nearly, in northern Woodbridge; and one of 8×5×7 feet in northern Orange, west of Maltby Park. Smaller trap bowlders or stones however, with others of sandstone are widely distributed for three to six miles in that direction; on the south they reach beyond Milford.*

The *course of travel* of some of these great bowlders can be made out quite closely. They were derived either from the

other. the scratches at bottom will have an intermediate direction. which will be determined by (1) the angles of the two slopes, (2) the angle between the dip-directions, and (3) the thickness of the overlying glacier. (The velocity was too small to be included.) Hence, some variations in the direction of scratches in a given region are to be expected rather than perfect uniformity, even where there are no defined troughs or valleys.

*A trap bowlder, measuring 15 × 8 × 6 feet. lies near the Housatonic River above the railroad crossing; but it is probably from a dike that intersects the metamorphic rocks from southern Woodbridge to the mouth of the Housatonic.

West Rock Ridge or from some part of the Mount Tom range* to the north; for the more eastern trap ridges are too far east. They are, for the most part, alike in consisting of *fine-grained much-rifted* trap, the variety that occurs only as the *outside* of the ejected trap-masses where the melted rock was *rapidly cooled* against the sandstone or air. Hence they probably came from the *top* of the ridges, for the sloping eastern side is now usually under sandstone to within 100 feet (in height) of the top, and the western is that of the bold columnar front.

The trap ridges projected upward into the ice abruptly, several hundred feet—the Mt. Tom ridge (or that from Meriden to Mt. Tom in Massachusetts) probably 600 to 900 feet; a most favorable condition for the successful rending and grasping work of the glacier. The Mt. Tom ridge is 996 feet high (Guyot) in South Mountain, Meriden, 985 feet in Talcott Mountain, west of Hartford, and 1214 feet in Mt. Tom. Some of the fallen masses at the base of its bluffs near Meriden are as large as the largest of the bowlders. Moreover, the trap (doleryte) of this western trap range in Connecticut is mostly a hard, durable rock, while that of the more eastern trap range is generally a hydrous or chloritic kind, very decomposable, and having usually only small chips as its fallen masses. This is one reason why large trap bowlders are rare to the eastward.

The "Judges' Cave" certainly came from the Mt. Tom ridge, —either the main ridge or those subordinate to it, and either from the vicinity of Meriden (16 miles distant), or some point farther north. The trap beneath it is very unlike that of the bowlder. If from the Mt. Tom ridge, the direction of travel was between S. 22° W. and S. 12° W.—the latter if from the northern half of the ridge.

The 1200-ton bowlder, near the top of the Woodbridge border, was probably from nearly the same source, the rock being closely the same; and its course was therefore between S. 24° W. and S. 16° W. If the former, it had passed over the West Rock ridge, at a height of at least 500 feet; if the latter, its course was west of this ridge.

Supposing, in the case of each of these bowlders, the height whence taken to have been 900 feet, the former had sunk in the ice before landing 550 feet, and the latter 540 feet. A 500-ton bowlder that must have had the same course with the "Judges' Cave" and may have been its near companion in the ice, continued on *over the West Rock ridge* and now lies S. 21° W. of it, a mile and a half farther south (on the grounds of Mr. Donald G. Mitchell). It is about 120 feet above the sea-level—which indicates a sinking in the ice, after passing the

* The Mount Tom range of trap extends north from Meriden to Mt. Tom in Massachusetts. See map, Plate v, in volume xxiv, of this Journal, June, 1883.

West Rock ridge, of nearly 300 feet, or half the whole amount it experienced before it landed. Two other large bowlders lie near it. It is possible that these, and others of the bowlders, reached terra firma at the final melting, or through crevasses, in which case part of the sinking may have taken place abruptly.

The distribution of bowlders and till along the western border has been stated above to be somewhat moraine-like. But it is largely a consequence of the fact that these hill-slopes, 100 to 400 feet in height above the plain fronting them, faced obliquely the advancing ice, the trend of the border being north and south, and the flow of the ice S. 12°–35° W. Consequently, as above illustrated, the stones and earth that were not high enough in the glacier to pass the summit, were dragged out or dropped. There was also diminished movement and therefore long detention of the ice-conditions against the declivity, and this favored deposition.

c. Probable slope of the upper surface of the ice down the valley.

To understand the conditions at the south end of the great valley it is necessary here to consider the question as to the slope of the ice in the direction of the Connecticut valley on which the southward movement was more or less dependent.

Wells River (a little north of the latitude of the White Mountains), is distant from New Haven about 200 miles, and from the south shore of Long Island, the supposed southern limit of the glacier, 240 miles. The height of the ice-surface about the White Mountains above the sea-level, according to the best observations, including those by Professor C. H. Hitchcock, was at least 6,000 feet and probably 6,500 feet. Assuming the height to have been 6,000 feet and this level to have extended west-by-north (the probable direction of contour lines on the glacier) over the Wells River region, the slope of the ice along the 240 miles would have been about 0·17′, equal to $4\frac{3}{4}$ feet in 1,000, or 25 feet per mile. With the height 6,500 the slope would have been 5 feet in 1,000. Either angle of slope is very small. In the Alps the lowest mean slopes are $2\frac{1}{2}$° to 3°, or $4\frac{1}{2}$ to $5\frac{1}{4}$ feet per 100, a rate ten times greater than the above; but the thickness of the ice there is not over 500 feet. In Greenland, where the conditions were much like those of glaciated North America, the slope observed by Jensen over the Frederickshaab glacier* was 0·49′, or about 75 feet per mile; and that measured by Helland on the glacier in the vicinity of Jakobshavn, 0·26′, or about 45 feet per mile. 45 feet to the mile would make the height of the ice-surface at Wells River over 10,000 feet.†

From such facts it would appear to be a safe conclusion that

* Meddelelser om Grönland 1879, and this Journal, III, xxiii, 363, 1882.

† Even smaller angles of slope are stated to be sufficient to cause motion in

the height of the ice-surface above the sea-level at Wells River and the White Mountains was *at least* 6,000 feet. On this assumption, and supposing the slope of a line on the surface in the direction of the valley equable, and the height at the southern termination on Long Island, 100 feet, the height over the region of Windsor and Mt. Ascutney, in Vermont, would have been about 4,500 feet, and over the New Haven region very nearly 1,000 feet.

It is still a question whether the height of the ice-surface to the northward was due solely to the accumulation of ice and not partly to an increase in the southward slope of the land. Yet, since even an increase in elevation of 500 feet would make little difference in the result, it follows, if the above conclusion as to the amount of slope required for movement in the valley is admitted, that

(1) For *movement down the valley the ice should have had nearly or quite its maximum thickness;* that is, the maximum thickness of the great glacier over that region. Further, that

(2) *Its flow could not have continued after melting had far advanced;* and further, that

(3) *Movement in the valley over lower New England by local glaciers after the disappearance of the general glacier is improbable;* the supposed local glaciers (as the scratches likewise show) were merged in the one great glacier, *and acted locally only through its aid.* Supposing the great glacier to have melted away so as to have reduced the ice over the valley to just the limits of the Connecticut valley, which is nowhere over 1,500 feet deep and generally less than 1,000, it is not at all probable that with this slope (the mean for the valley 3·3 feet a mile, this Journal, xxiii, 190, 1882) the ice could have overcome the various resistances to motion.

2. *The fact of a southeastward movement in the upper ice of the Glacier.*

The evidence as to a southeastward movement in the upper ice is afforded by *glacier scratches outside* of the valley, and by *transported bowlders within it as well as outside.*

a. Glacial scratches over the high plateaus of western and northwestern Connecticut, 800 to 1,500 feet in elevation, have directions between S. 12° E. and S. 45° E.

Greenland, but better measurements and knowledge of conditions are needed before any confident conclusion can be drawn.

In my paper of 1873 (this Journal, III, v, 108), I assume a slope of at least 10 feet a mile, and this gave a height for the glacier of 13,000 feet in the region of the supposed icy plateau on the Canada water-shed. For a reason stated beyond, the surface along the line crossing the St. Lawrence valley may have been level, and the slope confined to the ice above and below it; and that above may have been only just enough to keep the St. Lawrence valley full to the required level.

According to my observations in Connecticut, the direction in eastern Huntington is S. 14°–25° E., and near Lane's Mine in Monroe, S. 12°–13° E., places within 12 miles of the New Haven region; in the towns of Norfolk, Preston and Kent, farther west, S. 18°–20° E.; of Warren, S. 30° E.; of Newtown, S. 32° E., and 2 miles farther west, S. 41° E.; of Sharon, S. 33°–36° E.; of Cornwall, S. 33°–36° E.; and on Mt. Washington and its highest summit, Mt. Everett, in southwestern Massachusetts (the latter, 2,634 feet high), S. 18°–29° E. The direction in Goshen, according to Mr. H. Norton is S. 23° E. and S. 38° E.; in Norfolk, according to Mather, S. 20°–25° E.; and on Mt. Tom, in southwestern Litchfield, according to E. Hitchcock, S. 17°–22° E. Other facts of similar import from eastern New York, Massachusetts, Vermont and New Hampshire, are given in my former paper. The following White Mountain observations, from the New Hampshire Report by Professor C. H. Hitchcock (vol. iii, pp. 177–195), are of later publication.

Mt. Adams, W. side, height 5,500 feet	S. 58° E.
Between Adams and Jefferson, near gap (4,939 ft.)	S. 33° E.
Top of Mt. Washington (6,293 ft.), smoothing and faint markings (at 5,800–6,000 feet, transported stones, p. 204), but striæ obscure	S. 43° E.
200 feet above Lake of the Clouds	S. 30° E.
Lake of the Clouds (5,000 ft.), the intersecting directions	S. 22° E. S. 52° E.
Between Mt. Pleasant and Mt. Franklin (4,400 ft.)	S. 30° E.
Between Mt. Pleasant and Mt. Clinton (4,050 ft.)	S. 30° E.
Near top of Mt. Clinton (4,320 ft.), N. side	S. 47°–52° E.
Mt. Clinton, S. peak	S. 50° E.
South end of Mt. Webster	S. 37° E.
Top of Mt. Webster (4,000 ft.)	S. 30° E.
Top of Mt. Moosilauke (4,811 ft.)	S. 22° E.

The abrasion observations thus far made appear to show that the *mean direction of glacier flow* in western Connecticut and Massachusetts was somewhere between S. 12° E. and S. 38° E., and probably between S. 12° E. and S. 25° E.

b. The evidence from bowlders outside of the Connecticut valley is of the same import.

Percival states that transportation over Litchfield was S.S.E., as indicated by the distribution of limestone blocks from Canaan—which means about S. 20°–25° E. A few of these Canaan limestone bowlders I have found lying now in Orange, within four miles of the New Haven region, indicating transportation for 48 to 50 miles in the direction S. 16° E. They are easily recognized by the tremolite and canaanite (massive white pyroxene) they contain. Bowlders of quartzyte, from the same region, or from Berkshire, just north, are widely distributed. Bowlders of porphyritic gneiss from the north-west are very numerous over Orange and Woodbridge.* It is not necessary to multiply facts of this kind; for it is a matter of common observation over New England that the chief part of the drift came from the northwestward.

c. Bowlders within the area of the wide Connecticut valley prove that the southeastward movement or ice-stream extended over the valley. Those of the unmistakable porphyritic gneiss of the Naugatuck valley, which are scattered so widely over Woodbridge and Orange, occur also in the New Haven region; and one, now three miles east of the western limit of the region is over 20 cubic feet in size. Masses of ordinary gneiss, from the same general source, are numerous for two miles east of the western border, and among them are some of 100 cubic feet and larger; and smaller ones down to a foot in diameter are of occasional occurrence for a distance of at least twelve miles eastward. Quartzyte bowlders, derived, in all probability, from the Canaan or Berkshire region, are more numerous than those of gneiss, evidently because of their greater durability; they are scattered widely, and I have found some, probably from the same source, 15 miles northeast of the city of New Haven.

Similar facts have been observed through other parts of the Connecticut valley. Professor E. Hitchcock states, in his Massachusetts Report (1841, p. 381), that the bowlders of syenyte and granite from the west side of the Connecticut in Massachusetts are found in great numbers on the east slope of the Mt. Tom range, all the way from Mt. Tom to Hartford. To this I add that I have found a syenyte bowlder from the same source 10 miles south of Hartford, and 15 from the western limit of the old Connecticut valley. He says also (p. 605), that bowlders of quartz containing manganese and iron ores in peculiar concretionary forms, derived from Conway *west* of the valley, are abundant about Amherst, southeast of Conway near the *east* border of the valley, and Professor B. K. Emerson, of Amherst, informs me that they occur farther east in Pelham.

Up the valley to Windsor, Vermont, the same courses have been reported by Professor C. H. Hitchcock, who says, in his New Hampshire Report (iii, 263, 1878), that bowlders from Mt. Ascutney (which stands on the west border of the valley and has a height of 3,200 feet), are distributed southward along the valley to Bernardston, over 60 miles, *but also southeastward* across the valley; one, 20 feet long, 27 miles, was carried

* The crystals of feldspar in this porphyritic gneiss are generally 2 inches long and ⅜ inch wide, making the rock easy to identify. It forms part of a band of gneiss to the westward of, and 10 to 20 miles from, New Haven, ranging in a N.N.W. direction from Bridgeport to Prospect, places bearing S. 45° W. and N. 12° W. from New Haven.

S. 10° E., into Surry; another 5 feet long, 35 miles, S. 8° E. into Keene; others, 42 miles, S. 20° E., to the west base of Monadnock; along with which large bowlders, occur many others of smaller size.

It is thus evident that a glacial movement in a direction crossing the valley south-southeastward is as well established as that in the direction of the valley. North of Windsor evidence of both movements occurs, as already stated; southeastward scratches are most common.

3. *Correlations of the two movements as to time and drift-depositions.*

a. The valley movement continued until the general glacier-flow in the region ceased. For the scratches in the direction of the valley are the last that were then made. They are not only scratches, but over the sandstone often deep ploughings; not of occasional occurrence, but universal, every fresh removal of soil from the rock bringing them to light, and showing in Connecticut, as far as observed, no marks of any later transverse movement.

b. The valley movement was cotemporaneous throughout with the general glacier-flow. This follows from the statement on page 349 as to the thickness of the ice and the angle of slope required for a valley movement. It is indeed a necessary consequence of the fact that thickening the ice over a valley to maximum thickness would increasingly facilitate the flow in its direction, notwithstanding any transverse motion in the general ice-mass; and a thinning that would finally leave it a local glacier would enfeeble its motion or stop it altogether.

Consequently valley-movements, with exceptions in a mountain region, were not those characterizing the beginning or end of the Glacial era, but the movements that prevailed through its height. The two went on together, an *upper* general flow over a *lower* valley flow.

c. But *it may be questioned whether the upper flow kept its course unchanged quite across the great valley of the Connecticut in the States of Massachusetts and Connecticut.*

A small narrow valley, especially if steep or gorge-like, would have no valley-flow of ice, owing to friction; and the glacier would readily pass it, impeded only, if at all, by the resistance from shearing. But where the valley was larger, and had its valley flow, the case is different; yet facts that have been collected prove that this resistance was overcome in multitudes of cases over the country. And it was so in the case of the Connecticut valley in Vermont and Massachusetts, the facts above cited as to transported bowlders about the region of Amherst and Massachusetts being evidence. About

Ascutney there appears to have been some southward deflection of the *upper* or *southeastward* stream by the valley flow, for the direction of transport across is in part only 8° east of south; yet the differences of direction observed (p. 351) may have been due to the height on Ascutney from which the bowlders were taken, whether within the range of the lower current, or near the limit of the two, or far above it. About Amherst the evidence from bowlders proves clearly that the upper ice-stream continued quite across the valley. In central and southern Connecticut, the valley has a breadth of 25 miles; and positive proof that the upper current continued across has not yet been found. The distribution of bowlders indicate a flow half way across, and probably farther; but whether the upper ice did not finally in the eastern half lose its own motion and take that of the lower for the remainder of the breadth of the lower stream is yet to be ascertained. Such an event could not have happened unless the valley-flow succeeded, by its rate of discharge, in taking the southeastward slope of the overlying ice out of it, so that the only surface slope along this portion was in the direction of the valley; and were this done, the valley movement would have necessarily become the only one. Even if this were a fact, the slope of the ice-surface *east* of the eastern border of the Connecticut trough would have been southeastward, and so also the course of movement.

d. Great deflections in the courses of the transported bowlders within the valley took place on account of their sinking from the upper or general current into the lower or valley stream. In this way, as happens in the ocean, the lower current became the transporter and distributer of material derived from the upper. It was supplied with stones from the *north*westward and carried them *south*westward.

This fact is abundantly and strikingly illustrated in the distribution of the bowlders of gneiss. In the New Haven region they are far the most numerous, and of largest size, along the *eastern* slope of the West Rock ridge. The map shows that this ridge curves eastward at its southern extremity, making thereby a large deep corral of sickle-like outline facing almost directly the valley ice-movement, whose direction there was S. 16°–26° W. These bowlders of gneiss are most abundant over this portion of the declivity, south of Wintergreen Lake. A few hundred yards south of the lake, one of the bowlders, now in three pieces, has a length of 12 feet.

These bowlders, derived from the high land of northwestern Connecticut, must, beyond question, have passed the summit of the West Rock ridge—where between 400 and 650 feet in height—while in the upper stream of the glacier; for in no other way could they have got to the *east* side of the ridge;

and it is also beyond question that they finally got into the valley current, and were drifted back into the well-arranged corral. Some are now on the summit of the ridge; one of several cubic feet is near the "Judges' Cave;" but the larger part are a third way down the eastern slope and below this level. The gneiss bowlders are mingled with those of trap and sandstone; and nothing shows difference in time of deposition.

This kind of evidence is repeated again along the Mt. Tom ridge. Professor E. Hitchcock states in his Massachusetts Geological Report (p. 381) that bowlders of syenyte and granite, taken from the syenyte band west of the Connecticut in that State, are found in great numbers on the *east* slope of the Mt. Tom range *all the way from Mt. Tom to Hartford* Eight miles farther south, in the village of New Britain (as made known by Mr. James Shepard of that place), a bowlder of zoisite and radiated hornblende (chiefly the former), measuring about 2×2×3 feet, was turned out in grading, which must have come from a locality *west* of the Connecticut valley, in Goshen, Williamsburg or Conway, Mass., Professor Emerson informing me that this region affords just such a zoisite rock, and especially "the first row of high hills as you go up from the Connecticut valley." (Letter of June 16, 1883.) Still farther south (20 miles S. of Hartford) and just *east of a more eastern* trap ridge (6 miles farther east), extending from south of Hartford to Saltonstall Lake, I found, near the Air-Line Railroad, a syenyte bowlder 10 cubic feet in contents, which came from the syenyte band of Hatfield and Whately, Mass. (Emerson), west of the valley;* and near it lies another twice larger, of similar general aspect, but not so certainly identifiable.

Such facts prove that the phenomenon, although so remarkable, was general along the valley. They are instructive also with reference to the distance eastward to which the upper ice-stream extended over the southern part of the Connecticut valley region, though leaving the limit doubtful. They are good evidence that the two currents were moving at the same time.

4. *The direction over Long Island Sound.*

For twenty miles to the eastward and westward of New Haven bay the Sound has a mean width of 16 miles. Yet the greatest depth opposite New Haven bay is at present only 140 feet. Adding the height of the adjoining hills on its sides, the southern side of the trough has a height of 300 to 400 feet and the northern, of more than twice this amount.

*I submitted a fragment of the bowlder to Professor Emerson, of Amherst, and he writes that it is from the "syenite" band of Hatfield and Whately (Hitchcock's geological map), it agreeing precisely with it, containing much triclinic feldspar and small square crystals of orthite."

Since the Connecticut valley trough is not continued over the bottom of Long Island Sound, or through Long Island, the valley ice, as it moved out over the area of the Sound, left behind it those confining limits which had determined its southward course; and it is a question of interest whether it found new confining limits, or not, in the sides of the Sound trough.

The trend of the Sound is N. 75° E. Now this trend is transverse to the course of the *upper* or southeastward ice-stream of the glacier, the direction of this current having been, as above shown, S. 15°–25° E.

The mean direction was between these limits quite to the borders of the Sound; for on the Sound, 8 miles east of New Haven, near Stoney Creek, glacial scratches, covering large surfaces of gneiss and granite, have the direction S. 20° to 24° E.; others, 10 to 12 miles west of New Haven, in Stratford (near the N. Y. & N. H. railroad), S. 21° to 32° E.; and 18 miles west, near Bridgeport, S. 13° to 17° E.

Further, the bowlders of Long Island show that this was approximately the direction of flow over the Sound. Trap and sandstone bowlders were carried in great quantities from Connecticut to the island, and the most abundant deposits are situated on the parts lying S. 10°–20° E. from the New Haven region where alone the Triassic borders the Sound. On the north shore of the island, between Baiting Hollow and Northville, a region bearing S. 10° E. from New Haven, the bowlders of trap are very numerous; and the sandstone fragments at one place on the shore hills are in so great quantities that they seemed at first to indicate the existence near by of an outcrop of the Triassic.

Mather mentions the same fact in his New York Geological Report, remarking, on page 170, that from Roanoke Point for three or four miles east (points between Baiting Hollow and Northville) "a large proportion of the bowlders and pebbles are of red sandstone and trap rocks, like those of New Haven and that vicinity. In some places these rocks form one-third of the mass of bowlders, blocks and pebbles." He also states (p. 171) that a mile west of Wading River (4 miles west of Baiting Hollow) "a block of fine-grained limestone containing serpentine was found; it was precisely similar to the New Haven verd antique marble." It was probably from the Milford verd antique quarry, six miles southwest of the New Haven quarry, where the rock is more largely limestone than at the latter; in which case the mean direction of travel was S. 25° E.; if from the New Haven quarry, it was S. 13° E.

On one of the hills in the interior of the island, southwest of Riverhead, near Osborn or Bald Hill, bearing S. 15° E. from

New Haven, lie several large bowlders of trap, and one of red sandstone, along with others of gneiss. One of the trap bowlders contains over 200 cubic feet. Farther east, trap and sandstone bowlders are in rapidly decreasing numbers; and the same is true of the region to the westward.*

If then, as we have shown, the flow of the mass of the great glacier was at right angles to the Sound valley, it would have tended to move the ice of the Sound against and over Long Island, and not at all in the direction of the Sound, N. 75° E. To have had an eastward movement in the direction of the Sound the surface of the Sound-ice should have had a rising slope westward, and this is opposed by the facts already stated.† It is certain, therefore, that the view that the Sound valley was excavated by the glacier is not tenable. Further, the *lower* ice-stream, or that of the Connecticut valley, struck the ice of the Sound in the direction S. 13°–25° W., which would have helped a westward flow rather than an eastward.

All the facts thus point to the conclusion that the great glacier passed, with essentialy unchanged course as far as the upper ice is concerned, from Connecticut across the Sound and the island beyond. At the same time, the existence, though sparingly, of small masses of trap on Long Island for a few miles west of the meridian of New Haven, appears to show that this valley-stream moved south-southwestward not only over the towns next west of the New Haven region but at times also nearly across the Sound before losing wholly its own direction.

5. *Effects probably consequent on the change of course in the lower, or valley, ice-current manifested in the drift depositions.*

The following are the principal facts as to the deposition of the till:

(1) The till of the New Haven region is most abundant along the eastern declivity of the western border, east of the

* Trap bowlders occur sparingly on the eastern part of Long Island, and a few reached even Block Island. Sandstone fragments have the same range but are far fewer, because less durable. Block Island is nearly east of New Haven, but S. 20° E. from the Triassic of central Massachusetts. To the westward, some bowlders of trap are found about Port Jefferson. and rarely sandstone fragments. One chloritic bowlder, probably from two to ten miles west of New Haven, lying on the shore, measured 25 x 20 x 15 feet. Port Jefferson is south of southeastern Milford (Connecticut), and as Milford and other towns north of it. on the western border of the Triassic region, received numerous bowlders of the kind by the lower glacier current, the transportation to points so far west on Long Island is not surprising. (*Western* Long Island received its trap and sandstone bowlders, as was long since announced, from New Jersey and southern New York.)

† The movement of the great glacier, over southern Connecticut. in a direction *at right angles* to the Sound-ice implies that there was an equable slope in the surface of the glacier toward the Sound, and hence that the ice-surface over the Sound was nearly uniform from west to east, although the eastern end is half a degree farther north than the western.

Maltby Park valley (the central north-and-south depression of this border), where the depth is generally from 10 to 20 feet.

(2) The Maltby Park valley has, in general, little till over it, the surface being largely one of bare ledges and intervening marshy areas.

(3) But at one place in the eastern half of this valley (*Rd*, on the map, p. 342) *the till has a depth of more than* 107 *feet; and this piling up of till made there the isolated Round Hill* (as it is called), and gave it a height of 304 feet above mean tide, while the hills of the western border just east and southeast are only 140 to 200 feet high. Moreover these hills, and the surface along the road south of Round Hill, have not enough till to conceal the jagged rocks.

(4) The broadly rounded hills of southern Orange within three miles of the Sound, 200 to 280 feet in height, are deeply covered with till—the depth in some parts 40 feet or more.* Farther from the Sound, the till is usually of less depth, and rock-exposures are not uncommon.

The unusual amount of till and bowlders against the eastern declivity of the western border has already received explanation (p. 348).

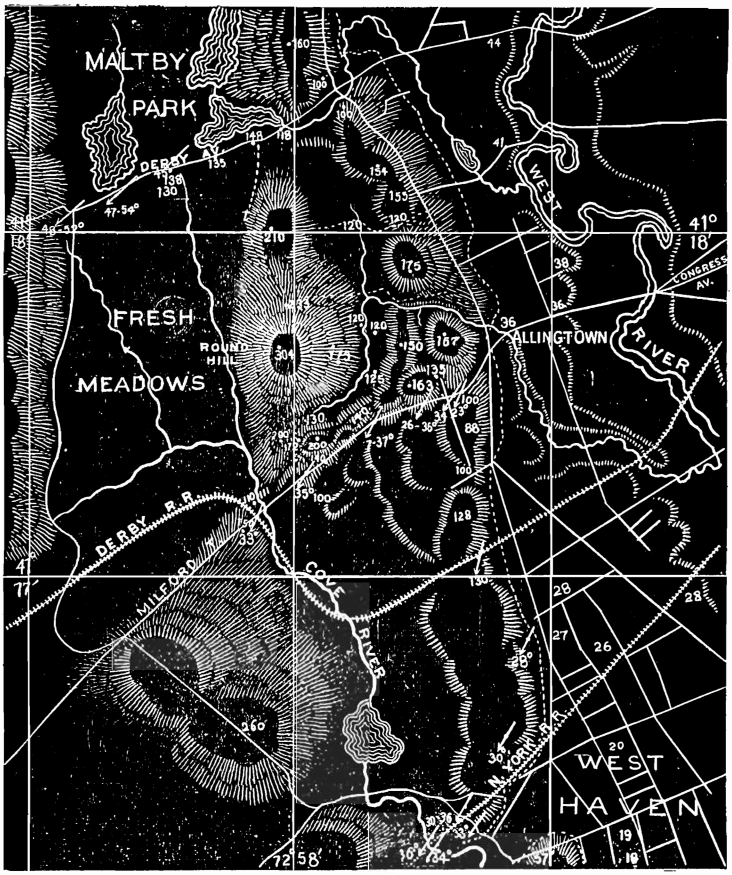
The existence of bare ledges and little till over the Maltby Park valley is evidently a consequence of denudation; the region was swept by deep waters from the melting glacier—part going southward, directly to the Sound, with a pitch of 30 feet a mile for the four miles, and the rest northward into the valley of West River north of Westville.

The third feature mentioned is of less obvious explanation. Round Hill stands prominently in view from all directions. This isolated feature, its form, and the height of the surrounding region are shown on the following map. The great depth of the till at the summit had seemed probable from the fact that, unlike the other hills, it has no outcropping rocks over the upper third of its height; but it was *proved* by an excavation for a well made under the orders of Mr. R. M. Burwell, the owner of the place. The well was carried down 107 feet through the firmest of stoney and somewhat clayey till before water was obtained, and even at that point rock had not been reached. The highest outcrop of rock on the sides of Round Hill is at 174 feet above mean tide.

Another remarkable feature of the region is a deep trench on the southeast and east sides of the hill, only 118 to 130 feet above sea-level, something like the trench around a fortified acropolis.

* On Shingle Hill, a little to the southwest of the region included in the map. an excavation for a well passed through 40 feet of till; on other hills, several wells go down 20 to 35 feet.

Round Hill is elongated northward—N. 8° W.; and half a mile off in that direction the height is 210 feet, and the depth



Map of Round Hill and vicinity, on the western border of the New Haven region.

of *till* is at least 21 feet, as found in a well-digging. It is also lengthened in the direction S. 10° W.; and only here is the slope an even one—a fact represented in the map above.* The hill thus covers and fills the eastern half of this part of the Maltby Park valley. At its western foot flows Cove River, the stream of the valley. Across this stream, another rise immediately begins, that of one of the deeply till-covered hills of southern Orange; so that the Maltby Park valley is here filled

* It has the constitution, as the description shows, of the "lenticular hills" of Professor Edward Hitchcock. But the quality *lenticular* is not an essential feature of such till-made hills, though common, as it is, and for a like reason, of many of the rocky ledges of the same region.

also over its western half, and consequently its breadth in this part is reduced to about 40 yards—although three-fourths of a mile wide just north. It is evident from the features of the region, moreover, that the depositions of till to the westward are essentially a continuation of those of Round Hill; that the valley was here to a considerable extent obstructed by the depositions; and that part of the flood waters from the melting glacier, besides making a lake above, flowed westward and joined the river-course next west, that of Indian River, the extensive flat meadows of Cove River north of the obstruction being elongated in that direction.

With reference to the origin of Round Hill, we note that the direction in which it is elongated is most nearly that of the *lower*, or valley, ice-current; and if we regard the more southwestern depositions as its continuation, the direction becomes S. 10°–15° west, which is yet nearer the course of that current, though still differing by 15 to 20 degrees. The actual direction of the ice-movement around it is registered at many places in glacial scratches. The courses are indicated on the map by arrows. They average S. 33° W. to the south and southeast of the hill, while to the north, the directions S. 45°–56° W. occur.

It is plain, from these facts, that the making of the solitary hill cannot be accounted for on the supposition of an eddy in the flow of the ice. The uniformity in the course of the scratches shows that there was no eddying.

The position upon the western border, where there were large drift depositions, and must have been, as already suggested (p. 348), the frequent opening of crevasses, may have had something to do with its formation. But no *line* of crevasses would have made so local a deposit.

Another point with regard to its position is its nearnesss to the Sound—the distance about three miles; and in this fact and the preceding, in connection with the character of the ice-movement, we have apparently the only data for an explanation. Over the Sound and its borders, the lower or valley ice-stream became warped around into the course of the general glacier-mass. This forced bending must have produced its greatest crevassing effects over the southwestern part of the valley region, within the plane of contact between the upper glacier stream and the lower—a plane that rose from the surface of the Sound at a small angle; and these effects would have been at a maximum in the part of the glacier where this plane intersected the north-and-south crevassed course of the western border. The existence is therefore probable of a knot of profound crevasses on this border region, at some point of greatest pressure, not far from the Sound; and, if a fact, a stream of water, or river, from the upper surface of the glacier may have here plunged down—like some rivers in glacial Greenland—causing a local deposition of the stones and earth that were in the ice, and thus have located and formed the till-made hill.

If the change of course were due only to the slope of the upper surface of the ice *at the place* it might have gone forward quietly. But if partly due to pressure from the northward along the valley there would have been the resistance and wrenching supposed.

The plunging waters would account also for the size and position of the half-encircling valley, cut in the schists about Round Hill; for this valley's being mostly free from drift; and for the trench which is its continuation eastward to the New Haven plain; for this was the way of discharge of the descending waters.

But the stream of water descending a crevasse could deposit only the drift encountered in its course on and through the ice; and wherefore then so high a pile in Round Hill? And why were 19-20ths of the drift in the hill the contributions of the valley or lower glacier current?

The height is evidence of long-continued deposition.

The valley source of the material proves that the drift of the glacier was mostly confined to the lower ice.

The mixture along with the trap and sandstone of some porphyritic gneiss, quartzyte, etc., from the northwestward, and the increased amount of the same in the western part of the hill, shows that the upper ice-stream was supplying material at the same time with the lower, though in much smaller amount.

The height of the hill, in connection with the nature of the material, indicates, further, that the lower, or valley, ice-stream had a depth in that region of at least 300 feet.

Round Hill is an example of a "kame." It is probable that the Andover kames were located by *crevasses* in the glacier that overlaid the region when the material was deposited.

Other facts bearing possibly on the origin of Round Hill will be presented in the following part of this paper—On the Terrace (or Champlain) formation of the New Haven region, its deserted valleys and its "kettle-holes."

Conclusions deduced in the preceding pages.

1. Two movements existed in the glacier-ice—a lower along the valley, an upper crossing it obliquely.
2. The two movements were simultaneous.
3. The upper ice kept its motion over the southward-flowing valley-ice quite across the Connecticut valley in Massachusetts, and across ten miles at least of its breadth in the southern half of Connecticut.

4. The lower or valley ice-stream was most rapid when the general glacier was of maximum thickness.

5. The glacial flow probably ceased when the melting was half completed, except in the mountain regions and some special localities elsewhere of limited extent; in which case, the disappearance of the general glacier did not end in leaving one or more long local glaciers in the lower half of the Connecticut valley.

6. Both the upper and lower ice-streams transported drift-material. The material from the upper that sunk into the lower stream was carried by it south-southwestward and deposited with the drift of the latter, and often against the eastward slopes of obstructing ridges.

7. The lower ice-stream lost its own direction of flow on reaching Long Island Sound, and took that of the general glacier mass across the Sound and Long Island.

8. The obstruction to flow in the western border of the New Haven region was the cause of crevasses and much drift deposition; and between this action and the warping around of the valley ice near and over the Sound, causing intersecting crevasses, the high local till-deposit of Round Hill was produced.