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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

# TACONIC PHYSIOGRAPHY

BY

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# ILLUSTRATIONS.

## LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
*Washington, D. C., February 20, 1904.*

Sir: I submit herewith the manuscript of a report entitled "Taconic Physiography," by T. Nelson Dale, and recommend that it be published as a bulletin of the Survey. The report embodies the results of long and careful study of the relations between land forms and lithologic character and structure of the underlying rocks.

Very respectfully,
C. W. Hayes,
*Geologist in Charge of Geology.*

Hon. Charles D. Walcott,
*Director United States Geological Survey.*

# TACONIC PHYSIOGRAPHY.

By T. Nelson Dale.

## INTRODUCTION.

The Taconic and Green Mountain ranges often pass together under the general name of the Green Mountains, although they are topographically and geologically distinct. The Taconic Range lies west of the Green Mountain Range, beginning near the Rutland-Addison County line in the northern half of Vermont and extending south-southwesterly about 200 miles to the Hudson in Dutchess County, N. Y.

The part of the Taconic Range here considered is embraced between latitudes 42° 13′ 30″ and 43° 50′, extending from a point west of the village of Great Barrington, in Berkshire County, Mass., to the northern end of the range, a half mile south of the Rutland and Addison County line in Vermont, a distance of about 113 miles. The accompanying relief and rock map (Pl. I), however, includes some adjacent territory, extending from longitude 73° to 73° 45′ in its southern half and to 73° 30′ in its northern half, and from latitude 42° 13′ 30″ to 44°, covering in all about 3,644 square miles situated in the counties of Berkshire, Mass., of Columbia, Rensselaer, Washington, and Essex, N. Y., and of Bennington, Rutland, and Addison, Vt.

Of this area the rock surface of about 3,075 square miles has been carefully studied during the last nineteen years by the writer, with the assistance of W. H. Hobbs in 1886 and 1887, L. M. Prindle from 1893 to 1897, Florence Bascom in 1895, F. H. Moffit from 1895 to 1902, and N. C. Dale in 1903. That study has made clear some facts relating to rock material and rock structure which throw light on the chief factors in the production of the present surface features, and the writer purposes here to set forth these facts and relations. Some rock boundaries and areas along the flank of the Green Mountain Range in Massachusetts, taken from the contributions of Wolff and Hobbs to Monograph XXIII and to the Taconic folio, and some along the west shore of Lake Champlain from Kemp's contribution to the

Mettawee folio, have been included in the map. It is also proposed, as far as the facts clearly warrant, to apply to the elucidation of these features modern theories as to the formation of base-levels and the origin of river courses, but this will be done briefly. While this paper has to do with the principal causes of the Taconic landscape, glacial deposits are not within its scope. In order to make the paper of more general interest, the needless use of technical terms has been avoided and brevity has been aimed at.

## LITERATURE.

Except in Tarr's general physiography,[a] the region has not yet been treated in the way here purposed; but scattered through the many papers on its geology are careful descriptions of its surface features, traced with some precision to their causes, and in several geographical papers its outlines are given or theories are advanced to account for them. In order both to show the character of these various contributions and to enable the reader to survey the present state of knowledge of the physiography of this region, all this material will be epitomized in chronological order. Its perusal, if made in connection with the map (Pl. I), can hardly fail to be of interest.

This résumé may well be prefaced with Samuel Williams's delineation of the mountains of Vermont, written over a century ago:[b]

> Through the whole tract of country which lies between the west side of Connecticut River and the east side of Hudson River and Lake Champlain there is one continued range of mountains. These mountains begin in the Province of Canada. From thence they extend through the States of Vermont, Massachusetts, and Connecticut, and terminate within a few miles of the seacoast. Their general direction is from NNE. to SSW., and their extent is through a tract of country not less than 400 miles in length. They are one continuous range or collection of mountains, appearing as if they were piled one upon another. They are generally from 10 to 15 miles in width, are much intersected with valleys, abound with springs and streams of water, and are everywhere covered with woods. From the perpetual verdure which they exhibit, they are called the Green Mountains, and with great propriety their name has been assigned to the State.

In Chapter III he described erosion by rivers, the formation of potholes and of ponds, of river terraces and intervales. He suggested a basis for estimating the age of river terraces and observed that fossil shells and buried tree branches indicated that the surface of Lake Champlain was formerly 40 to 50 feet higher and several miles wider than it had been since its discovery by Samuel Champlain in 1608.

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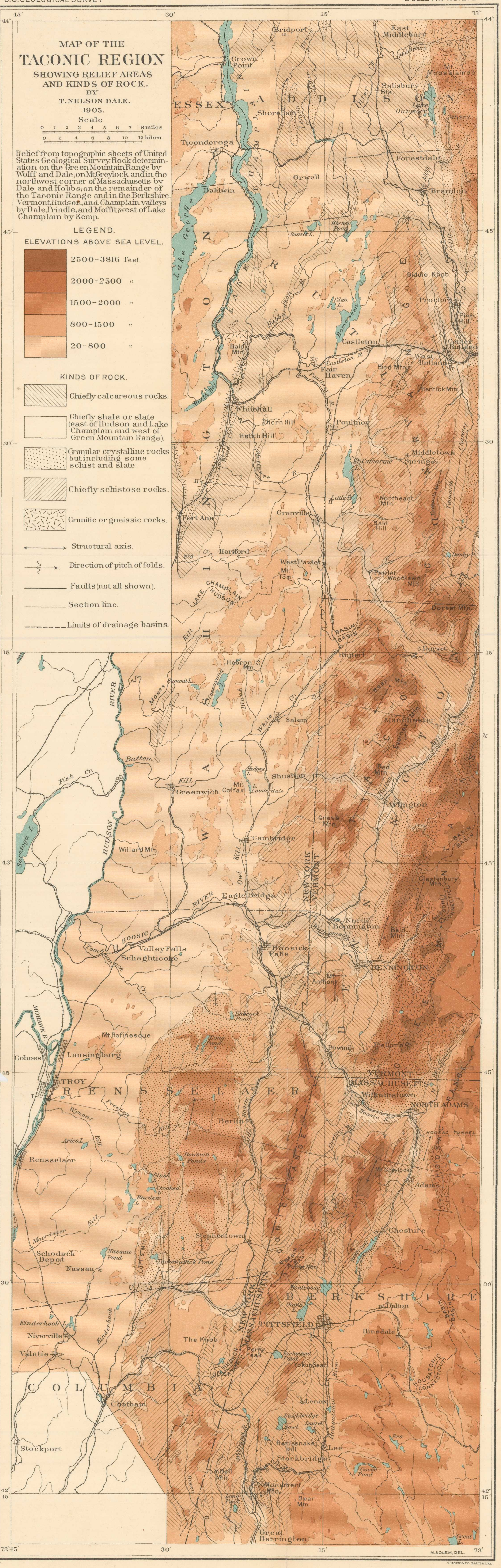
[a] Tarr, Ralph S., Physical geography of New York State: Bull. Am. Geog. Soc., vol. 28, 1896, pp. 104, 105, 118; vol. 29, 1897, pp. 26–31; vol. 30, 1898, pp. 401–406. Reprinted as a volume, New York, 1902, pp. 52–57.

[b] Williams, Samuel, The Natural and Civil History of Vermont; Chapter II, Mountains; Chapter III, Rivers and Lakes; published according to act of Congress; Walpole, N. H., 1794.


MAP OF THE
TACONIC REGION
SHOWING RELIEF AREAS AND KINDS OF ROCK.
BY
T. NELSON DALE.
1905.
Scale
0 1 2 3 4 5 6 7 8 miles
0 2 4 6 8 10 12 kilom.
Relief from topographic sheets of United States Geological Survey. Rock determination on the Green Mountain Range by Wolff and Dale; on Mt. Greylock and in the northwest corner of Massachusetts by Dale and Hobbs; on the remainder of the Taconic Range and in the Berkshire, Vermont, Hudson, and Champlain valleys by Dale, Prindle, and Moffit, west of Lake Champlain by Kemp.
LEGEND.
ELEVATIONS ABOVE SEA LEVEL.
2500-3816 feet.
2000-2500 "
1500-2000 "
800-1500 "
20-800 "
KINDS OF ROCK.
Chiefly calcareous rocks.
Chiefly shale or slate (east of Hudson and Lake Champlain and west of Green Mountain Range).
Granular crystalline rocks but including some schist and slate.
Chiefly schistose rocks.
Granitic or gneissic rocks.
Structural axis.
Direction of pitch of folds.
Faults (not all shown).
Section line.
Limits of drainage basins.
ESSEX
ADDISON
RUTLAND
WASHINGTON
BENNINGTON
RENSSELAER
BERKSHIRE
COLUMBIA
Ticonderoga
Crown Point
Bridport
Shoreham
Orwell
Middlebury
Salisbury
Forestdale
Brandon
Proctor
Castleton
Fair Haven
Whitehall
Poultney
Granville
Fort Ann
Hartford
Rutland
Dorset Mtn.
Rupert
Salem
Manchester
Arlington
Shushan
Greenwich
Cambridge
Eagle Bridge
Hoosick Falls
Bennington
North Bennington
Valley Falls
Schaghticoke
Lansingburg
Cohoes
Troy
Rensselaer
Berlin
Williamstown
North Adams
Adams
Mt. Greylock
Cheshire
Stephentown
Pittsfield
Dalton
Hinsdale
Lenox
Stockbridge
Lee
Great Barrington
Nassau
Schodack Depot
Kinderhook
Niverville
Valatie
Chatham
Stockport
NEW YORK
VERMONT
MASSACHUSETTS
HOOSAC TUNNEL
M. SOLEM, DEL.
A. HOEN & CO. BALTIMORE.

In 1813 Horatio G. Spafford, in a description of Rensselaer County, N. Y., referring evidently to its eastern part, wrote of—

tracts of wet uplands covered with a luxuriant growth of lofty white pine, variously intermixed with hemlock, maple, ash, cherry, beech, and birch, forming a most singular admixture of evergreen and deciduous trees.[a]

In 1821 Timothy Dwight referred to Saddle Mountain (Greylock) in Massachusetts as—

a spur from the range of Taghkannuck connected with it by the hills of New Ashford. From the Green Mountain Range it is entirely separated by the valley and river of Hoosac.[b]

In 1829 Chester Dewey made a distinction between the Green Mountain Range, the Taconic Range, and a spur of the latter, which, beginning west of Pittsfield, ends near South Williamstown and seems to commence again in Vermont. He wrote of insulated hills in the Housatonic Valley, but the Greylock mass he regarded as a part of the Green Mountain Range.[c]

In 1841 Edward Hitchcock, in his "Scenographical Geology of Massachusetts," described the more picturesque features of Berkshire County.[d]

In 1846 Ebenezer Emmons published a sketch of the Taconic Range as seen from the Helderberg Range in New York.[e]

In 1847 C. B. Adams discussed the stoss and lee sides of ledges and mountains.[f]

In 1849–50 Asa Fitch gave this description of the physiography of Washington County, N. Y.:

Between the main range of the Green Mountains and the Hudson River are three parallel ranges of mountains and hills, viz:

1. The Taconic Range, which runs along the east line of this county immediately upon the Vermont side of that line. * * * It is singular that this chain of mountains which are mere outliers of the Green Mountain Range, here shoots up into higher peaks than any points in the main range opposite to them. * * * Though beyond the boundary of the county, these mountains constitute a most prominent and interesting feature in its scenery, looming up, as they do, in majestic grandeur, all along its eastern horizon. And as winter approaches, their summits, capped with snow a fortnight or more before it invades the low country to the west of them, are beacons which prompt every laggard husbandman to hurry in with his last load of potatoes and his last shock of corn.

2. The Petersborough Range, best marked in Rensselaer County, but running also through this county, by Oak Hill, the Jackson Hills, the Pine Hills in

[a] Spafford, Horatio Gates, Gazetteer of the State of New York, Albany, 1813, p. 96.

[b] Dwight, Timothy, Travels in New England and New York; vol. 2, Journey to Vergennes, letter 2, p. 389; New Haven, 1821.

[c] A general view of Berkshire County, Pittsfield, Mass., 1829.

[d] Hitchcock, Edward, Final Report on the Geology of Massachusetts, vol. 1, pt. 2, pp. 229–240, 253–256; Amherst and Northampton, 1841.

[e] Emmons, Ebenezer, Agriculture of New York; Part V of Natural History of New York, Pl. V; Albany, 1846.

[f] Third Annual Report of Vermont, pp. 21, 22.

Hebron, and Rogers Hill in Granville, whence it passes into Vermont. The valley between this and the Taconic Range, which includes the flats and plains about the villages of Cambridge, Salem, and Granville, it may safely be affirmed, is one of the finest agricultural districts in our country. * * *

3. The Bald Mountain Range, which is more regularly and conspicuously marked in this county than is the preceding, extends by way of Baker's, Willard's * * * Bald Mountain * * * to the pinnacle near north Granville, Hatch's Hill, and onward into Vermont. The country between this and the preceding range is elevated and undulated, without any flats or plains * * *.[a]

Dana's studies in Berkshire County were published at intervals. In 1873, referring to the north-south trend of the depression in Mount Greylock called the Hopper, he suggested that it probably corresponds in position to an anticline.[b] In 1877 he expressed the opinion that when in the Taconic region the schist belts are broadest they are not simple but complex synclinals, and that the limestone of the valleys was brought to the surface by anticlinals.[c] In another paper of the same year he added that when the schist rises into high peaks the syncline is broad and relatively shallow. The broad synclines like Mount Everett and Greylock are compound.[d] In 1879 Dana explained:

Limestone being a brittle rock, the region of flexures, whatever the thickness of the overlying mass, would have been profoundly fractured, especially in anticlinals; and being also a soft rock, it would have been easily carried away by denuding agencies. The limestone belts are the chief courses, as Percival pointed out, of all the greater valleys and streams of the limestone region; and in these valleys, as I have found, the underdipping side of limestone is generally the bold, precipitous side, owing to the undermining which it has occasioned. This is so generally true that vertical fronts in these metamorphic regions * * * are pretty sure evidence of outcropping limestone below.[e]

In 1887 he wrote:

The prominent topographical feature of middle and western Berkshire is its intersection in a generally north–south direction by flat-bottomed valleys, lying deep between and sometimes encircling high ridges, while eastern Berkshire is part of an elevated plateau—the plateau of the Green Mountains.[f]

Dana's last reference to the physiography of the region was in the same year:

The deep gaps or open valleys that cross the [Taconic] range are deep openings through the Taconic schists, and hence the outcrop of the limestone through or nearly through the gaps.

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[a] Fitch, Asa, A historical, topographical, and agricultural survey of the county of Washington: Documents of the Assembly of the State of New York, vol. 7, No. 175, Albany, 1850, p. 936.

[b] Dana, James D., Am. Jour. Sci., 3d ser., vol. 6, 1873, p. 273.

[c] Ibid., vol. 13, 1877, p. 347.

[d] Ibid., vol. 14, pp. 261–264.

[e] Ibid., vol. 13, 1879, p. 387.

[f] Berkshire Geology. Read before the Berkshire Historical and Scientific Society, March 12, 1886. Republished by that society in the Berkshire Book, vol. 1, Pittsfield, Mass., 1892.

He also called attention to abrupt east-west shifts in the course of the ranges—the first near North Adams, where the Green Mountain Range advances 4 to 5 miles westward; the second near Bennington, where the quartzite and limestone along the foot of the Green Mountains recede a mile or more eastward; the third at Bear Mountain, in Stockbridge and Lee, where the older gneisses advance 3 miles westward, deflecting the Housatonic River and the rail and carriage roads. He attributed these advances and recesses of the range to bays in the Archean land mass. He also called attention to the sudden turn in the trend of the schist hills between Lenox and Great Barrington from north-northeast in Mount Osceola to north-northwest in Monument Mountain, and also to the absence of schist hills on the great limestone plain about Pittsfield.[a]

In 1891 W. M. Davis defined "Cretaceous peneplain" as the product of the denudation in Jurassic and Cretaceous time of the combined crystalline and Triassic area of Massachusetts, Connecticut, New Jersey, etc. This peneplain was uplifted toward the close of the Cretaceous to the extent of "1,000 feet in Massachusetts east of the Connecticut Valley, of 1,200 to 1,400 or 1,500 feet in the western or Berkshire plateau, of somewhat more where the plateau is cut by the Hudson gorge, of somewhat less in the northern highlands of New Jersey, and thence decreasing southwestward into Pennsylvania; and this uplifted peneplain was eroded in Tertiary time. He thought it probable that the altitude of the Berkshire Valley (800 to 1,000 feet) is to be explained by its imperfect reduction to base-level in the Tertiary cycle, more particularly by—

the absence of any large master river to drain it; second, by the belts of hard rocks that its streams, the Housatonic and the Hoosic, must cross on their way to the sea, and possibly, third, by a shift of drainage. * * * The plateau between the Connecticut and the Berkshire valleys is drained almost entirely by branches of the Connecticut, the divide being close along the western margin of the plateau; it is quite possible that in the Cretaceous cycle these branch streams drained the Berkshire limestone area as well, and that the present outlets of the valley are the result of headward cutting of formerly external streams; if this be true, it is quite natural that the valley should not yet be excavated to the same depth as the Connecticut lowlands.[b]

In 1892 B. K. Emerson gave the following order of physical events for western Massachusetts: (*a*) folding; (*b*) base-leveling, perhaps to old sea level of Cretaceous; (*c*) elevation of about 2,000 feet; (*d*) erosion of gorges.[c]

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[a] Am. Jour. Sci., 3d ser., vol. 33, 1887, pp. 273–276.

[b] Davis, W. M., The geological dates of origin of certain topographic forms on the Atlantic slope of the United States: Bull. Geol. Soc. America, vol. 2, 1891, pp. 545, 568, 580.

[c] Outlines of the geology of the Green Mountain region in Massachusetts: Geologic Atlas U. S., "Hawley sheet," U. S. Geol. Survey, 1892 (a preliminary folio, not included in the regular series).

In 1894 Raphael Pumpelly described the Green Mountains in Massachusetts as consisting of three principal structural elements: "The Green Mountains (Hoosac Mountain); the Taconic Range, lying several miles to the west; and, between these, the great valley;" but he followed Dana in distinguishing "between a central or axial ridge, flanked by an eastern belt extending to the Connecticut, and a western belt extending to the Hudson." The Green Mountain Range is anticlinal and its steep western flank is due to a lofty brow of quartzite. The valley has a floor of crystalline limestone with overlying island-like ridges of folded schist, sometimes anticlinal but usually synclinal, left by erosion. This limestone valley, which really extends from Vermont to Alabama, is marked by the fertility of its soil, and its limonite ores have long formed the basis of important industries. "The Greylock basin of sediment was guarded on the north by the large mass of granitoid gneiss of Clarksburg Mountain and on the south by the great body of pre-Cambrian rocks which are now masked by the Dalton and Windsor quartzite."[a]

John E. Wolff, in the same work, called attention to the relation of topography to structure on Hoosac Mountain. He found that the long crest of the mountain coincides with the axis of a northerly pitching anticlinal fold of the central core of gneiss, and that its profile with gentle slopes and southern-facing bluffs is determined by the northerly pitch of the anticline. The east-west trend of the valleys in the southern part of the mountain is due to an east-west strike in the sedimentary gneisses.

In the same volume the writer of the present paper found that the varied surface features of Mount Greylock are due to the interaction of three causes:

First, the mineralogical character of the rock, presenting minerals more or less easily disintegrated by physical or chemical agencies. Second, the internal structure and position of the strata, forming elevations and depressions in the mass and determining the surface relations of the different kinds of rock. Third, erosion, Glacial, as well as pre-Glacial and post-Glacial, bringing physical and chemical agencies to bear upon those irregularities in the form and composition of the surface. * * * The physically and chemically more resistant schists form the more elevated portions, also the steeper and more rugged and wooded slopes, while the broad, cultivated valleys * * * and the more gently undulating portions of the mountain generally correspond to limestone areas. [The upper limestone and calcareous schists constitute the high benches of arable land, as well as the Notch, which is also anticlinal in structure, and the incision between Rounds Rock and Saddle Ball. Professor Dana's surmise as to the origin of the north-south part of the Hopper is found to be essentially correct. The east-west part of the Hopper and other similar incisions are attributed to erosion operating across the folds. The saddle form of the central crest, as seen from the north-northwest, is due to the opposite pitch of the

[a] Pumpelly, Raphael, Wolff, J. E., and Dale, T. N., Geology of the Green Mountains in Massachusetts: Mon. U. S. Geol. Survey, vol. 23, 1894, pp. 5, 6, 21.

ends of the central trough of the synclinorium. The gentle northerly slope of the surface of Rounds Rock and the similar southerly slope of the top of the Bald Mountain spur, as seen from Potter Mountain on the southwest, are probably due to the trough structure of the entire mass. The cliff of Rounds Rock is attributed to glacial action upon an east-west system of joints associated with the pitch. Generally the schist sends out tongues corresponding to synclines into the lower limestone area. There are also reentering angles of limestone in the schist area corresponding to anticlines. There are also isolated schist areas, generally lenticular in form, corresponding to more or less open synclines, and also isolated limestone areas, corresponding to compressed anticlines, projecting through the overlying schists and exposed by this erosion.]

In a paper on the Rensselaer Plateau, published also in 1894, the writer called attention to the existence of three topographic belts between the eastern foot of Hoosac Mountain and the Hudson: (1) That of the Berkshire Hills, consisting of parallel synclinal schist hill ranges and anticlinal limestone valleys trending north-northeast, the former with deep transverse, branching hollows on both sides; this extends from the Hoosac Mountain to the valley of the Little Hoosic. (2) That of the plateau, with little incised edges and nearly level surface, rising from 700 to 1,200 feet above the valley and from 1,400 to 2,000 feet above sea level and dotted over with ponds and swamps, its features being probably due to its more massive rocks, its NNW.-SSE. trough structure, and to base-leveling; this plateau was once thickly timbered (the uplands referred to by Spafford, p. 11), but its deforestation has left a rocky region thickly strewn with bowlders, in places poorly supplied with water, in others badly drained, and with little good soil, offering in these respects a marked contrast to the fertility of the Hudson Valley and the Berkshire and Berlin valleys; the Berkshire Hills, however, are better watered and drained, and their rocks afford more soil than those of the plateau. (3) That of the Hudson Valley, with its low hillocks extending $7\frac{1}{2}$ miles east of the Hudson and largely due to its more erodible shales.[a]

In 1894 the writer described the anticlinal ridge extending from Dorset Mountain to Pine Hill in Proctor, Vt. The bold east–west face of Dorset Mountain and its elevation of 1,650 feet above Danby Hill north of it are shown to be due to transverse faulting and erosion, a mass of limestone and schist, about a half mile thick, having been removed from the quartzite between the two hills.[b]

In 1895 Davis wrote:

During the period of most energetic deformation, New England must have had as thoroughly a mountainous form as it still has a mountainous structure. Indeed, the most probable conclusion that can be reached regarding the ancient topography of the region raises its peaks to truly alpine heights. * * * New

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[a] The Rensselaer grit plateau in New York: Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, pp. 297–299, 335–336, figs. 18, 19, 34, 35.

[b] Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 531, 543, 545, 546, pls. lxvi, lxx.

England is a worn-out mountain range. * * * the divide between Connecticut and Champlain drainage in Vermont appears to lie on the northern extension of the western upland of Massachusetts; and the peaks of the Green Mountains are presumably monadnocks, like Greylock and Mount Everett farther south. * * * the evidence leading to the belief in the uplift of the old peneplain is found entirely in the form of the region itself.[a]

He also pointed out that the evidence from the present altitude of fossiliferous rocks is inconclusive, because it does not show whether that altitude was the result of original deformation or of later uplift.[b]

In 1896–98 Tarr published his physical geography of the Taconic province and the Hudson River, in which he states:

Before the dawn of the Paleozoic time mountains existed in New England and New Jersey, as well as in the States south of here. The sea which bathed the Adirondacks also beat against the foot of these more eastern mountains. * * * Remains of these mountains are still left in various parts of New England, where they form mountains of true Adirondack type. By their long-continued denudation, sedimentary deposits were furnished to the interior sea, and during the Cambrian and Lower Silurian periods the waste of this mountainous land and of the Adirondacks was strewn over the sea bottom, partly within the boundaries of the State of New York. * * * The close of the Lower Silurian was marked by a regrowth of these eastern mountains; but the new rock-folding involved a part of the old sea bed, and * * * at the same time caused a new development of mighty mountain ranges in western New England * * * and eastern New York. Folds of great complexity and faults of marked extent raised the ocean sediment into lofty mountains. * * * Denudation has etched these complexly altered and folded strata, and since they were originally deposited as sheets of sediment, though now greatly changed, the folding has placed them in such a position that, like the Appalachians, they have been carved into ridges. But the complexity of the rock structure and position is greater than in the Appalachians, and hence the ridges are not long and continuous, but short and choppy, with many intermediate peaks. This is the typical Berkshire type. There is a mixture of the sedimentary and crystalline habit; hence, in general, the mountains extend in ridges that run parallel to the lines of folding (generally about north and south in New England and New Jersey); but we can not follow the ridges for any considerable distance. The difference between Appalachian and Berkshire types of mountains is quite like the difference between the well-developed ocean swell and the deep, wind-broken waves of the billowy sea.[c]

In 1899 the writer described the general physical features of about 700 square miles of Washington County, N. Y., and of Rutland and Bennington counties, Vt., from latitude 43° to 43° 45′ and from the Taconic Range about 10 miles westward. The north-northwest trend of that range north of the Castleton cut was attributed to a change in the strike. The irregular surface forms west of the range were attributed to the unequal operation of erosion on materials of such unequal hardness as quartzite, limestone, slate, and shale, and to

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[a] Davis, W. M., The physical geography of southern New England: National Geog. Mon. of Nat. Geog. Soc. No. 9, vol. 1, 1895, pp. 279, 283, 284.

[b] Op. cit., p. 294.

[c] Tarr, Ralph S., The physical geography of New York State: Bull. Am. Geog. Soc., vol. 29, 1897, pp. 26–29.

a series of miniature anticlinoria and synclinoria, often with pitching axes and generally with a north-northeast trend, and also, in part, to irregular accumulations of drift. An exceptional case of differential erosion was observed in Poultney, where a basic dike forms the bottom of a small canyon, 50 to 100 feet deep, cut in slate. The hard dike rock has been eroded more rapidly than the softer slate.[a]

In 1900 the writer described a small pyramidal mass of conglomerate lying on the more erodible schists of the Taconic Range in Castleton, Vt., and called Bird Mountain. Its form was attributed to its synclinal structure, relative hardness, vertical jointing, and erosion. In the same paper a schist cliff on Mount Herrick, in Ira, Vt., was noted, in which erosion could be seen at work undermining a forest.[b]

In 1902 the writer described some contacts between the pre-Cambrian and Cambrian on the Green Mountain Range, in which the strike of the pre-Cambrian gneisses indicated that the original trend of the pre-Cambrian folds, and consequently of the pre-Cambrian topography, may have been at right angles to that of the present range.[c]

In the same year H. F. Cleland described the recent denudation of the steep east face of Mount Greylock.[d]

The works listed below contain the most important expositions of the general physiographic principles involved in the following discussion.

*Works containing expositions of general physiographic principles.*

DANA (J. D.). On denudation in the Pacific. [and] On the degradation of the rocks of New South Wales and formation of valleys. [Extracts from report on geology for Wilkes U. S. Explor. Exp. Philadelphia, 1849.]
In Am. Jour. Sci., 2d ser., vol. 9, pp. 48–62, 289–294. New Haven, 1850.

LESLEY (J. P.). Topography as a science.
In Manual of coal and its topography, illustrated by original drawings, chiefly of facts in the geology of the Appalachian region of the United States of North America, pp. 121–187. Philadelphia, 1856.

ROGERS (H. D.). Orography and scenery; features of erosion in anticlinal belts; features of erosion in synclinal belts; features of local erosion; additional illustrations.
In Geology of Pennsylvania, vol. 1, pp. 4–39; vol. 2 (pt. 2), pp. 921–941, 1023–1024. Philadelphia, 1858.

[a] The slate belt of eastern New York and western Vermont: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, pp. 175, 222, 297, pls. xii, xiii.

[b] A study of Bird Mountain, Vermont: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 15, 16, 19, 23.

[c] Structural details in the Green Mountain region and in eastern New York (second paper): Bull. U. S. Geol. Survey No. 195, 1902, p. 20.

[d] The landslides of Mount Greylock and Briggsville, Massachusetts: Jour. Geol., vol. 10, 1902, pp. 513–517.

POWELL (J. W.). On the physical features of the valley of the Colorado.
In Exploration of the Colorado River of the West and its tributaries, explored in 1869, 1870, 1871, and 1872, under the direction of the Secretary of the Smithsonian Institution, pp. 149–214. Washington, 1875.

GILBERT (G. K.). Land sculpture.
In Report on the geology of the Henry Mountains, pp. 99–150. Washington, 1877.

DUTTON (C. E.). Tertiary history of the Grand Canyon district.
In Monograph U. S. Geol. Survey, vol. 2. With atlas. Washington, 1882.

LÖWL (F.). Über Thalbildung. Prague, 1884.

RICHTHOFEN (F. von). Einflüsse auf die Erosion welche in der Lagerung und Beschaffenheit des Gesteins beruhen; die tektonische Thäler; Sculpturthäler; Faltungsgebirge; Abraisionsgebirge.
In Führer für Forschungsreisende, pp. 158–177, 639–645, 645–651, 660–669, 669–670. Berlin, 1886. Second edition, 1901.

NOË (G. de la) and MARGERIE (E. de). Des causes déterminant le tracé des cours d'eau.
In Les formes du terrain, pp. 113–178. Paris, 1888. Service géographique de l'armée.

PENCK (A.). Die Thäler; die Thallandschaften; die Faltungsgebirge.
In Morphologie der Erdoberfläche, pt. 2, pp. 58–141, 142–203, 370–408. Stuttgart, 1894.

Readers unfamiliar with the subject of physiography are referred to the following elementary works:

*Elementary works on physiography.*

MERRILL (G. P.). The principles of rock weathering.
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## LAND FORM.

In the northwestern part of the area represented on the map (Pl. I), at an elevation of 101 feet above sea level, lies the southern end of Lake Champlain, and 32 miles south-southwest of it is a portion of the Hudson which, between the mouth of the Batten Kill and Troy, falls from the 100-foot to below the 20-foot level. The highest points in the area are Mounts Greylock, 3,505 feet; Glastenbury, on the Green Mountain Range, 3,764 feet; Equinox, 3,816 feet, and Dorset, 3,804 feet. The map shows the forms of the surface in white and four tints, corresponding to elevations below 800, between 800 and 1,500, 1,500 and 2,000, 2,000 and 2,500, and 2,500 and 3,816 feet.

*Green Mountain Range.*—That portion of the Green Mountain Range which extends northward from the southeast corner of the area about 70 miles is marked by an embayment 30 miles long. This begins at Stockbridge and ends at North Adams, and is divided 10 miles south of North Adams by a westwardly projecting spur. The range has short but deep incisions in Manchester and Sunderland, and also two prominent northeasterly valleys—the valley of the Walloomsac, near Bennington, and that of the North Branch of the Hoosic, near North Adams. The slightly undulating surface of the range is above 2,000 feet, with broad areas above 2,500 and but short narrow ridges or isolated summits above 3,000. Its steep western flank lies entirely between the 800-foot and 2,000-foot levels. Beginning near latitude 43° 45′, this range reappears west of longitude 73° for a length of nearly 20 miles. Its base here descends to the 600-foot level and its frontal part attains an elevation of 2,659 feet in Mount Moosalamoo. It has three transverse incisions.

*Taconic Range.*—A few miles west of the Green Mountain Range a series of long crests and irregularly ramifying masses rises above the 1,500-foot level. At 2,000 feet they become still narrower and more irregular, with a few summits above 2,500 feet. These masses constitute the Taconic Range. This range has a somewhat serpentine course; in Great Barrington and Stockbridge it is north-northwest; thence to Dorset it is pretty uniformly north-northeast; from Dorset to the Castleton cut it is about north, and beyond that point its course is again north-northwest; west of Pittsfield it sends off a northeasterly spur, which, turning northward, ends 5 miles south of Williamstown. The Greylock mass appears to belong properly to a series of hills—Mount Osceola, West Stockbridge Mountain, and Tom Ball—which lies east of and parallel to the main range. In the northern part of Bennington County the range is about 10 miles wide; west of Adams the distance across the range and its spur is 12 miles, while at the north it dwindles to 4 or 5 miles, and finally tapers out altogether near the Addison County line. A marked feature of this range is that the transverse hollows on its western side are usually longer than those on its eastern.

*Transverse valleys.*—There are five main transverse valleys: (1) The valley of the Hoosic, extending down to the 800-foot level, with a northwest-southeast course, diagonal to the general trend of the Taconic Range, but with a parallel crest west of it; a little south of the Vermont-Massachusetts line this valley turns and runs eastward for 4 miles, separating the Greylock mass from the outjutting portion of the Green Mountain Range north of it. (2) The valley of the Mettawee, in Pawlet, Rupert, and Dorset, running northwest-southeast like the Hoosic, but reaching the 800-foot level for only half of its course. (3) The wide valley of the Walloomsac in Bennington and Hoosick. (4) That of the Batten Kill in Arlington.

(5) That of the Castleton River in Castleton and West Rutland. The last three have east-west courses and reach the 800-foot level.

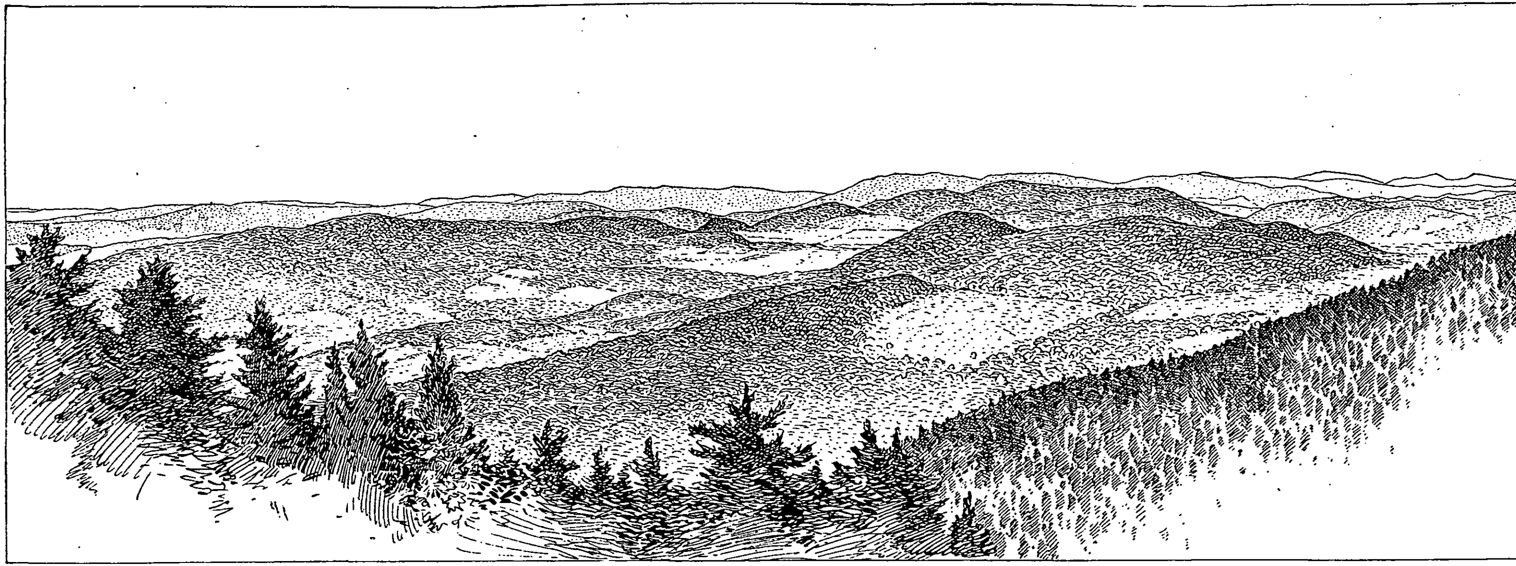
The Taconic Range is so deeply and widely cut by the Hoosic and Walloomsac valleys that the upland has been brought below the 1,500-foot and 2,000-foot zone, and only Mount Anthony rises above them. There are also minor transverse valleys, like that in Canaan, N. Y., used by the railroad, and that of the Kinderhook in Hancock and Stephentown, neither of which has reached the 800-foot level, and an incipient one in Poultney and Middletown, of which only the western part is at 800 feet.

*Longitudinal valleys.*—North of the Taconic Range, in Addison County, a gentle rise to an elevation of 500 feet separates the valley of Lake Champlain from the Vermont Valley. The Vermont Valley, which north of Dorset Mountain separates the two ranges, is divided into two longitudinal valleys by a series of hills rising above 1,500 feet and even reaching 2,000 feet (Danby Hill, Clark Mountain). This series is continued farther north in Boardman Hill (1,313 feet) and Pine Hill (1,445 feet). The map shows only a portion of the eastern valley. Its narrowest part is east of Dorset Mountain, where the Green Mountain Range rises very steeply to the 3,000-foot level. At West Rutland the Taconic Range itself is subdivided lengthwise, and a third valley intervenes, which, however, dies out in Pittsford. South of Dorset Mountain the Vermont Valley is regular until within a few miles of the Massachusetts line, where it may be said to be shut off by a mass which joins the base of Mount Anthony to the Green Mountain Range. The lowest point in the crest of this mass is at Pownal Center, at the 986-foot level.

In northwestern Massachusetts the Vermont Valley may be said either to have receded 6 miles eastward, following the embayment in the Green Mountain Range, or else, following the Taconic Range proper, to end near South Williamstown or in the Hancock Valley. There are structural reasons for the latter view.

West of the Green Mountain embayment there are four longitudinal valleys—the valley along the foot of Hoosac Mountain, that which separates the Greylock mass from the Taconic spur, the Hancock Valley between the spur and the main range, and that between the Taconic Range and the Rensselaer Plateau. South of the Pittsfield Plain the topography is again complex; there are three longitudinal valleys, which near the Connecticut line become merged in the Housatonic Valley.

*Rensselaer Plateau.*—Between latitude 42° 30′ and 42° 50′ and west of the Taconic Range is a very irregularly bounded upland, about 80 square miles in area, above the 1,500-foot level, with a small eminence on its eastern side rising above 2,000 feet. It is separated from the Taconic Range by the Little Hoosic and Kinderhook



VIEW OF THE TACONIC AND GREEN MOUNTAIN RANGES FROM MOUNT HERRICK IN IRA, VT.

Illustrating the complex topography of the Taconic Range compared to that of the Green Mountain Range. From a photograph looking S. 35° E. and S. The distant range in left half is the Green Mountain Range. The cliff is White Rocks in Wallingford. The bold mass in distance, at right of center, with a notch in its crest, is Dorset Mountain. The rest belongs to the Taconic Range.

Valley. The western part of this area is about 35 miles due south of the mass between Lake George and Lake Champlain. These 80 square miles, however, are only the eastern half of a plateau which is marked by steep slopes on the west, north, and south, and ranges from between 1,400 and 1,200 feet down to the 800-foot level. The general surface of this plateau has thus a westerly inclination.

*Hudson-Champlain valley.*—The region west of the Taconic Range at the north, and of the plateau at the south, is mostly a broad expanse of minor undulations and hillocks below the 800-foot level and frequently with a north-northeast trend. In about the center is a double or treble series of more or less detached hills and hill masses, ranging from nearly 800 to nearly 1,500 feet, with a like trend. The western series includes Mount Rafinesque in Brunswick, Mount Willard in Easton, Mount Rascal in Argyle, two hills in Hartford, the Pinnacle in Granville, and Hatch Hill in Whitehall. The eastern series includes the Cobble in Cambridge, Mount Colfax in Jackson, Hebron Mountain, Pine Hill and Mount Tom in Hebron, an unnamed elevation near Granville, and Thorn Hill in Hampton.

## THE TACONIC LANDSCAPE.

There is one feature in a landscape which neither a contour map nor a relief map adequately represents—that is, the horizontal aspect, the familiar aspect of the face of the earth. There are several points in the region from which impressive and instructive general views of the Taconic landscape can be had. One of these is Killington Peak (4,241 feet), in the Green Mountain Range, 8 miles east of Rutland, which commands the Green Mountain Range north and south of it, and also overlooks the Taconic Range. Another point is Snake Mountain (1,271 feet), in Addison County, Vt., which, lying beyond the northern extremity of the Taconic Range, commands a view across the entire Lake Champlain basin, from the Green Mountains to the Adirondacks, as well as of the northern part of the Taconic Range. Rattlesnake Point, on Mount Moosalamoo, in the Green Mountain Range, in the town of Salisbury, in the northern part of the area mapped, also commands a view of the entire Lake Champlain basin.

Other favorable view-points are Dorset and Equinox mountains (after their summits shall have been cleared); Mount Greylock; the granite knoll northeast of Renfrew, on Hoosac Mountain; Bald Mountain, in Bennington; West Mountain, in Shaftsbury; the highest point in the road crossing the Green Mountain offset from Pownal to Stamford, Vt.; Mount Rafinesque, in Brunswick; and Mount Colfax, in Jackson, N. Y.

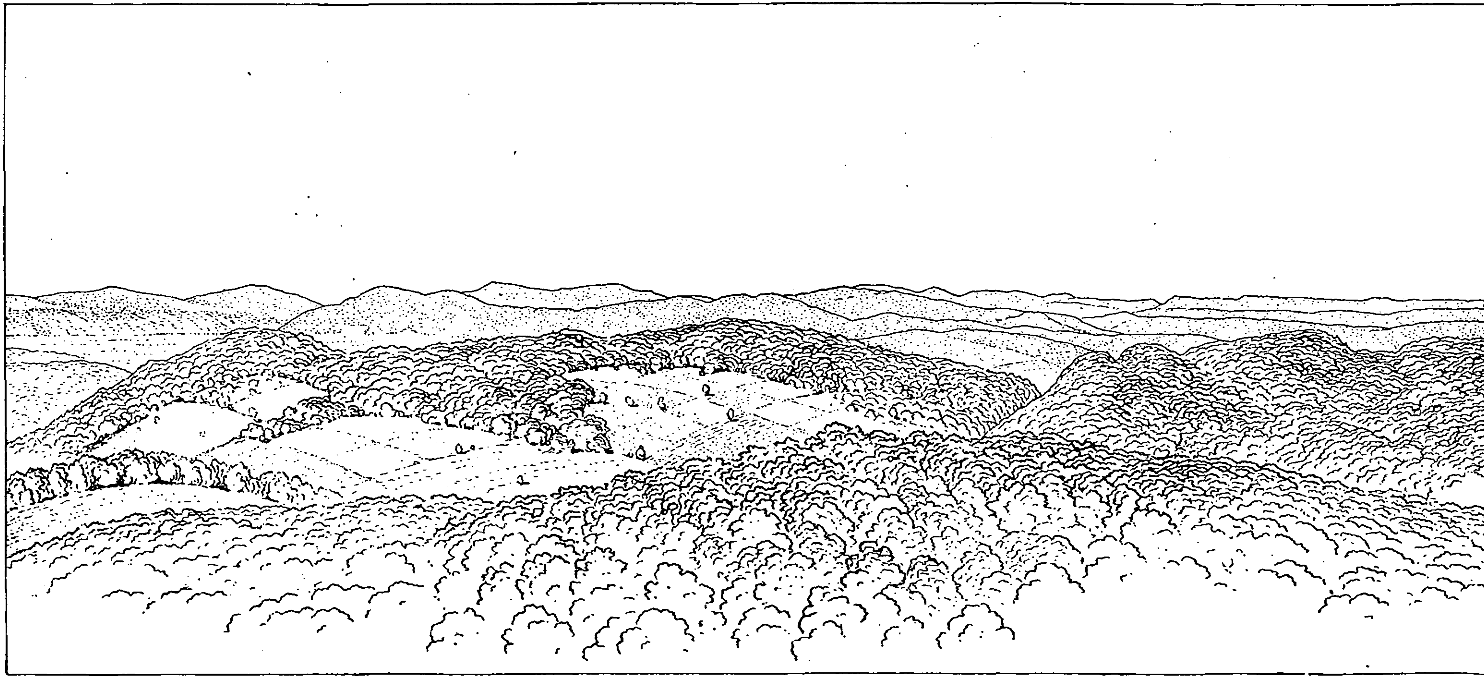
Among published views these may be examined: Mon. U. S. Geol. Survey, vol. 23, pls. xiii, xv, and fig. 30; Thirteenth Ann. Rept. U. S.

Geol. Survey, pt. 2, figs. 18, 19; Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, pl. lxvi.

Some of the characteristics of the Taconic landscape may be seen in accompanying illustrations, viz: Pl. II, taken from Mount Herrick, in the northern part of the area represented on the map and looking toward the southern horizon, shows the bold western face of the Green Mountain Range, the somewhat uniform outline of its surface and the contrasting variety of the Taconic Range with its longitudinal and transverse hollows, and the conspicuous east-west ridge of Dorset Mountain. Pl. III, taken from a point in the Taconic Range in about the center of the area and also looking southward, shows another part of the Green Mountain Range, a broad stretch of the Taconic Range, and the nearly level surface of the Rensselaer Plateau. Pl. IV, taken from a point southeast of Mount Equinox on the edge of the Green Mountain Range and looking northward, shows both ranges separated by the narrower part of the Vermont Valley. Pl. XIV, p. 48, taken from Mount Moosalamoo, looking southward, shows the western flank of the Green Mountain Range and the northern part of the Taconic Range.

The hill forms of the Taconic region, as thus seen, consist generally of long, narrow ridges with crests either gently sagging toward the center or else made up of short undulations with occasional roundish shoulders or dome-like masses and obtuse-angled summits, sometimes with saddles or lateral benches, and ending either in somewhat steep concave or convex slopes or in very gentle declivities. These ridges are sometimes short or roughly pyramidal in outline or send out irregular spurs with amphitheater-like hollows between them. There are also plateau-like masses with a few prominences having long, gentle slopes. The steeper slopes throughout are inclined from 30° to 40°, exceptionally attaining 50°. But few cliffs occur, and these do not exceed 1,000 feet, and usually are not 500 feet in height. They face roughly either east or west or else north or south.

*The lakes.*—There are 78 natural lakes or ponds within the area represented on the map, not including a few small ones on the Green Mountain Range. Twenty-five of these are on the plateau of Rensselaer County and range from $1\frac{1}{10}$ miles down to one-fourth of a mile in length. Twenty-one are in the Taconic Range and the Berkshire and Vermont valleys. The largest of these, Lake Dunmore, at the foot of the Green Mountain Range in Addison County, is $3\frac{1}{2}$ miles long. Lake Onota, near Pittsfield, Mass., is about 2 miles long. The remaining 31 are in the Hudson-Champlain valley, and include Lake Bomoseen, $5\frac{1}{2}$ miles long, and Lake St. Catharine, $4\frac{1}{2}$ miles long, both at the western foot of the Taconic Range. Three-fourths of a mile east of Lake Dunmore and on the Green Mountain Range lies



VIEW OF THE TACONIC AND GREEN MOUNTAIN RANGES FROM TWO TOPS.

Illustrating the contrast between the topography of the Taconic Range and that of the Rensselaer Plateau. Sketch from Two Tops in White Creek, Washington County, N. Y., looking southeast and southwest. In distance at left, the Green Mountains with the Vermont Valley; then Mount Anthony of the Taconic Range; at right of it, in distance, Mount Greylock; at extreme right, the plateau of Rensselaer County. The rest belongs to the Taconic Range.

Silver Lake, about three-fourths of a mile long. (See Pls. XIII and XIV, pp. 46, 48.)

## TOPOGRAPHIC TYPES.

Three well-defined local topographic types stand out from a survey of the Taconic landscape.

*Plateau type.*—This includes the Green Mountain Range, with its gently undulating or roundish surfaces, having few and usually not rugged elevations, its flank deeply incised; also the Rensselaer Plateau, which is a miniature westerly inclined peneplain, about 175 square miles in area, with very few and slight elevations and some broad, shallow valleys. Its edge is slightly incised.

*Taconic type.*—This consists of alternating ridges and valleys. The ridges are cut by transverse and diagonal valleys and are sometimes intricately dissected or else reduced to isolated lenticular masses.

*Hudson-Champlain type.*—This is less marked in character, consisting of minor, irregular elevations and depressions, and yet with a series of isolated hills reaching to nearly 700 feet above its general surface.

## ROCK MATERIAL.

This description and this analysis of the land forms are here naturally followed by a description of the rock material which constitutes or underlies these forms. The map, Pl. I, is not properly a geological map, for it does not show the geological formations, but the distribution of the rock areas with reference to their principal chemical and physical characteristics without reference to age, and it may therefore be termed a rock map.

The map differentiates the following areas: Those underlain by rocks, mainly granular and crystalline (quartzite, metamorphic conglomerate, metamorphic grit or graywacke, and gneiss); those underlain by rocks mainly schistose (sericite-quartz-chlorite-schist); those underlain by the less metamorphic slate or by unaltered shale and grit; and those underlain by calcareous rocks (limestone, dolomite, and marble). It was not practicable to separate slate from shale nor to outline the very small areas of limestone or quartzite or grit occurring within the schist, slate, and shale. The granular rocks also include some interbedded schist and slate. The western boundary of the schist marks approximately the transition from greater metamorphism on the east to less on the west. The area (on the map without rock pattern) west of that boundary and east of the Hudson and Lake Champlain consists almost entirely of slates, shales, and grits, the slates lying usually east of the shales, although in some cases their areas are interlaced. The area of undesignated material along the eastern edge of the map on the Green Mountain Range is complex in composition and arrangement, embracing gneisses, schist, quartzite, etc. Its special consideration is not within the province of this paper, and this applies also to the areas west of Lake Champlain. As Glacial and post-Glacial deposits are ignored, the map represents approximately the rock surface as modified by all post-Ordovician erosion. While the region is all glaciated, the divergence between the actual rock contours and those of the overlying till, terrace gravels, and clay beds is inconsiderable and is confined almost entirely to areas below the 1,500-foot level.

These rocks, viewed as to the degree or mode of their erodibility, may be grouped under four designations and the areas underlain by them apportioned, respectively, as follows:

*Harder rocks.*—Harder rocks (granular, crystalline rocks, and gneisses) constitute the westwardly outjutting masses of the Green Mountain Range and the Rensselaer Plateau, the mass south of Lake Champlain along Wood Creek, the Bird Mountain mass in the Taconic Range in Rutland County, a small area in Columbia and Rensselaer counties, N. Y., besides several minor quartzite areas—Monument Mountain, Rattlesnake Hill, and Stone Hill in Berkshire County, one east of Bennington and several on the intermediate range north of Dorset Mountain and some east of Lake Champlain in Addison County.

*Rocks of intermediate hardness* (*schists*).—These constitute the Taconic Range and its spurs and the masses north and south of Pittsfield, and flank the Green Mountain Range at several points in Massachusetts.

*Soluble rocks.*—Soluble rocks (limestone, dolomite, and marble) underlie the Vermont and Berkshire valleys, the minor valleys within the Taconic Range, several strips along Lake Champlain, and small areas in Argyle, Greenwich, and Hoosick. These rocks of the Champlain and Vermont valleys form an almost, if not quite, continuous area about the north end of the Taconic Range. There are also isolated areas in the Taconic Range in Pawlet, Pownal, and on and about the Greylock mass, and on the Green Mountain Range in Addison and Rutland counties.

*Rocks disintegrated chiefly by physical processes* (*shales, unaltered grits, and slates*).—These underlie the region between the Taconic Range and the Hudson, and between that range and the Lake Champlain limestone area, in places bordering the lake, also between the Rensselaer Plateau and the Hudson. For a number of miles north and south of the plateau the slates advance several miles eastward and the shales also north of it.

*Relation of rock material to surface form.*—It will be noticed that the harder rocks (Group I) are associated with the plateau type and only exceptionally constitute minor hills (Bird Mountain, Stone

VIEW OF THE VERMONT VALLEY.

Illustrating the erosion of both the schist range and the quartzite range. Looking N. 30° E. down Lye B ook Hollow from "The Burning" on the Green Mountain Range, $3\frac{1}{8}$ miles south-southeast of Manchester, with the Green Mountain Range on the right and the Taconic Range on the left. The nearer mass in the Taconic Range is Green Peak, the distant one is Dorset Mountain. In foreground, shattered ledge of Cambrian quartzite, the large block at left being about 4 by 15 feet in size.

Hill, Rattlesnake Hill in Stockbridge, etc.) or ridges (Pine Hill). Although the ravines of the Green Mountain Range penetrate its mantling quartzite, neither that range nor the Rensselaer Plateau is so intricately dissected as the schist masses of Group II. The soluble rocks (Group III) are confined almost entirely to the valleys, but on Green Peak and Mount Equinox the limestone reaches above the 2,000-foot level, and the schist capping has in both mountains been partially removed. Exceptionally, on the Green Mountain Range, near the Addison and Rutland County line, a dolomite, which forms the base of the great limestone formation of the Vermont Valley, covers several square miles and forms a mountain 2,547 feet in height.

The region of Group IV, to the west, generally ranges between the 200- and 800-foot levels. As the series of hills stretching along it for over 50 miles consists largely of the same material as the region itself, the origin of these hills must be attributed to their structure rather than to their material.

This classification of rocks in reference to their erodibility and the relations traced between them and the topography suggest a discussion of the question as to what in each case was the controlling factor in the development of the topography. It should be borne in mind that the problem is not a simple one, for the rocks of each group often have associated with them other rocks of greater or less erodibility. Thus both the slate and the schist include some beds of quartzite, and the quartzite some beds of schist. Limestone and dolomite are not equally soluble, and both are frequently quartzose or micaceous. In the next place, where a rock purely typical of one or another of these four groups does occur, its behavior under erosion may be greatly modified by peculiar physical properties. Thus a cliff of thick-bedded, vitreous quartzite traversed by several systems of joints is more easily disintegrated by frost than a thin-bedded, less vitreous, and less jointed one, and might prove even more erodible than a cliff of mica-schist. The determinant here is the vitreousness of the rock, for to it the much jointing is due, the stress in both cases having been assumed as equal.[a] This is also well illustrated by the case of differential erosion cited on page 17. The controlling factor in the erodibility of the two rocks was the peculiar physical constitution of the eruptive, probably its vitreousness, which caused it to scale in large conchoidal pieces, so that erosion made much more headway on the hard rock than it did on the soft one. Otherwise the dense crystalline mass of feldspar, hornblende, augite, and magnetite of the camptonite would have resisted erosion much more effectually than the microscopically matted sericite of the finely cleft slate. The

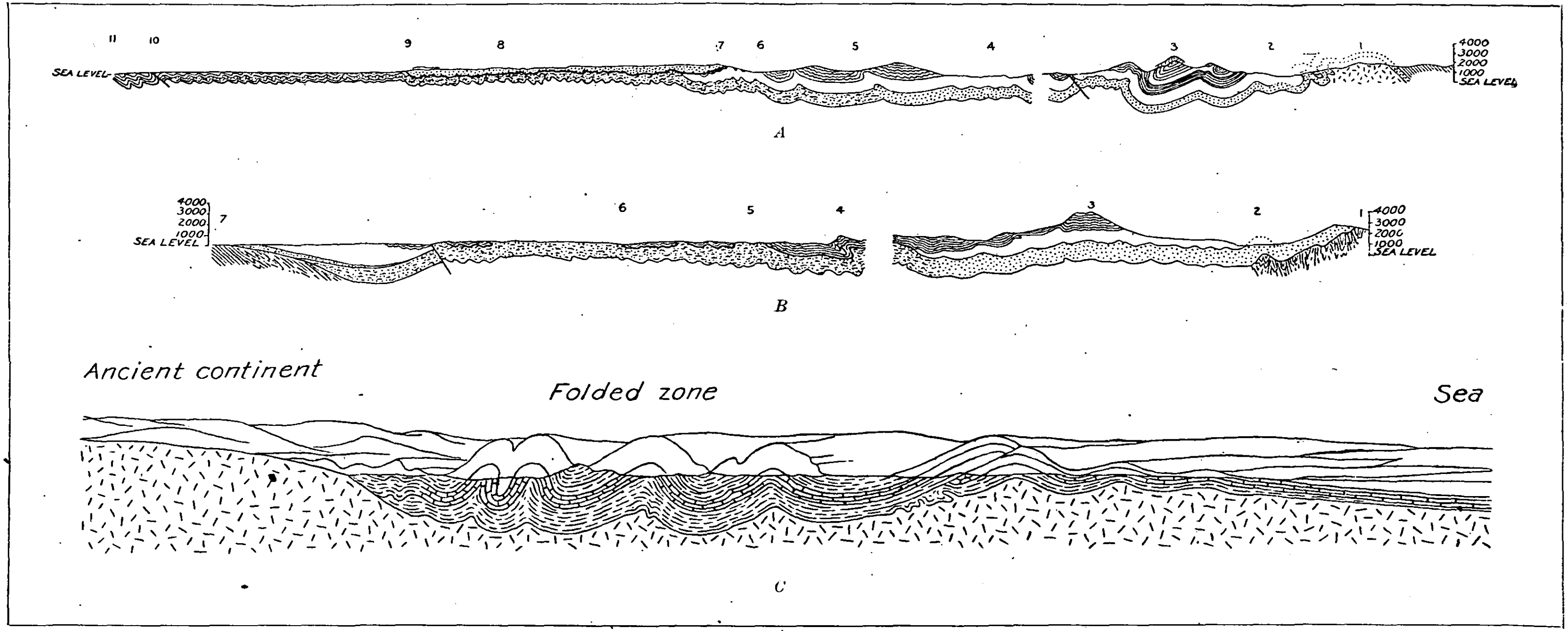
[a] Not only the stress, but also its rapidity of application and the load, are assumed to be equal, for, given sufficient time under sufficient load, stress would have caused the folding of both rocks.

erodibility of any given rock is also largely determined by its position and structure. All that can be claimed, therefore, for this classification of the rocks of this region in reference to their erodibility is that it holds true only in the most general way and for large areas where there is likely to be more or less compensation between the various other factors, and it must be admitted that in such areas there would be exceptional localities where the determining factor was some other than the one made prominent in the definition of the group. The classification corresponds, however, to nature. There are such areas, consisting mainly of gneiss, of schist, of limestone, and of shale and slate, upon which erosion has operated differently in degree or in method. Erosion may have proceeded by physical processes almost as rapidly in a region of shale as by chemical ones in a region of limestone.

## ROCK STRUCTURE.

Having discussed the land form and its constituent rock material, the structure of that material—that is, the rock structure—should next be considered.

*General structural characteristics.*—The general structural characteristics of the region may be briefly summarized thus: All the rocks, including generally the underlying gneisses, lie in a succession of major and minor folds, corresponding approximately to the trend of the ranges. These structural characteristics are shown in two sections, Pl. V, *A* and *B* (lines I and II on the map, Pl. I). Section *A* crosses the recess in the Green Mountain Range, the Taconic Range, the Rensselaer Plateau, and the lowland along the Hudson. Section *B* begins 36 miles north of *A*, on the Green Mountain Range, in Manchester, crosses the Vermont Valley and the Taconic Range, but is resumed 16 miles farther north in Wells, and ends in the lowland south of Lake Champlain. These sections, of course, represent interpretations of structural observations. They bring out the anticlinorial character of the Green Mountain Range, the synclinorial structure of the Taconic Range, of its spurs and outliers, and of the Rensselaer Plateau, the complex structure of the Hoosic Valley west of the Green Mountain Range, and the synclinal structure of the Vermont Valley. They also show that in the Taconic region the valleys are generally limestone and the hills schist, and they show the horizontal transition assumed by geologists from the harder rocks of Group I to the slates and shales of Group IV at the west. The folds vary in character from close to open, erect to inclined, east or west. Careful studies of large areas show that these folds are not always continuous, but merge here and there, and that their axes are frequently inclined north or south. One of the very few points in which the inclination




CROSS SECTIONS AND RESTORATION.

*A*. Cross section along line I of map (Pl. I), Hoosac Mountain to Troy, N. Y. From Monograph U. S. Geological Survey, vol. 23, Thirteenth Annual Report U. S. Geological Survey, and later observations, showing the relations of the granitic, granular, calcareous, schistose, and shaly rocks. 1, Hoosac Mountain; 2, Hoosic Valley; 3, Mount Greylock with Ragged Mountain on east and Mount Prospect on west; 4, South Williamstown Valley; 5, Taconic Range; 6, valley of the Little Hoosic; 7-8, Rensselaer grit plateau; 9-10, Cambrian shales of Hudson Valley; 10, Ordovician shale; 11, the Hudson at Troy. The beds without symbols are limestone, dolomite, and marble. The granular beds pass westward into slaty and granular and these into shales and grits, west of plateau.

*B*. Cross section along line II of map (Pl. I), from the Green Mountain Range in Manchester across the Taconic Range, and continued from that range in Wells, Vt., to Wood Creek near Fort Ann, N. Y. From observations by Dale, Moffit, Prindle, and Miss Bascom, showing the relations of the gneissic, granular, calcareous, schistose, and slaty rocks. 1, Green Mountain Range, with gneiss and quartzite; 2, anticline west of Lye Brook syncline; 3, Mount Equinox; 4, Pond Mountain (in Wells); 5, granular rocks of the east, passed partly into slate; 6, Middle Granville; 7, gneiss at Wood Creek north of Fort Ann.

*C*. Restoration of an uneroded Appalachian surface. (From Bailey Willis, Mechanics of Appalachian Structure: Thirteenth Annual Report U. S. Geological Survey, Pl. XLVII.) *B* and *C* are drawn looking north but this looking south.

of the axes shows itself in surface features is seen in Pl. VI, *A*. The quartzite of the Green Mountain Range south of the Vermont-Massachusetts line and between North Adams and Williamstown is in minor westerly dipping folds, which pitch south to pass under the limestone of the Hoosic Valley. This pitch has much to do with the length of the isolated schist and limestone areas. By comparing Section *A* with the map it will be observed that the eastern syncline of Greylock is in line with the synclinal Stamford Valley, while the rest of that syclinorium is in line with the complex anticline of the Green Mountain Range, the western side of which is represented in Pl. VI, *A*. Mount Equinox, in Manchester, although a part of the Taconic synclinorium, is a gentle anticline, and the westerly facing schist cliff of Pond Mountain in Wells is the western limb of an anticline overturned to the west (Pl. V, *B*.)[a]

In the slate and shale region west of the Taconic Range the folds are frequently close and small. Some of the hill masses there seem to be anticlines of the underlying older formation (e. g., the one in Hebron); others are synclines of the overlying one (e. g., Hatch Hill in Whitehall, Mount Colfax in Jackson, and Mount Rafinesque in Brunswick).

The courses of the axes of the major folds in the Taconic Range where well determined are indicated on the map by long arrows. At the south, in Monument Mountain, the direction is north-northwest; in the Greylock mass, north-northeast; in Mount Anthony, north; Mount Equinox, north-northeast; Bird Mountain, almost northeast; but from West Rutland on it is again north-northwest, as in Monument Mountain, 100 miles south. The structural axis of the Green Mountain Range is shown at several points. Exceptionally the axes diverge for short distances from the course of the ranges. This is due either to transverse folding (e. g., Hoosac Mountain and Mount Anthony) or to the exposure by denudation of folds due to a crustal movement prior to the last one which affected the region (e. g., the north end of the Taconic Range).[b]

The cause of the divergence in the axis of the Green Mountain gneiss east of Bennington is not determined.[c]

*Secondary structures.*—Secondary structures affect the entire region. A slip cleavage, dipping almost uniformly east, marks the schist of the Taconic Range, and the slaty cleavage which characterizes a large part of the belt west has a like direction of inclination.

[a] See Miss F. Bascom's section in Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 197.

[b] See Am. Jour. Sci., 4th ser., vol. 17, 1904, p. 185, pl. xi.

[c] See Bull. U. S. Geol. Survey No. 195, 1902, p. 18.

The joints of this region may be grouped as follows, the groups being named approximately in the order of their prevalence:

Strike joints striking N. 20° W.–N. 30° E.
Dip joints striking N. 65° W.–N. 90° W.
Dip joints striking N. 60° E.–N. 80° E.
Diagonal joints striking N. 35° W.–N. 55° W.

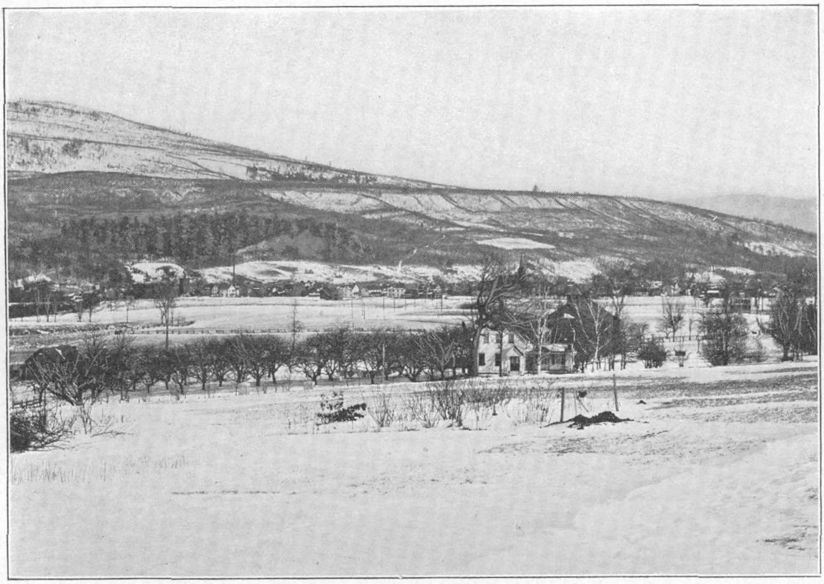
## GENERAL RELATION OF STRUCTURE AND MATERIAL TO FORM.

The general relation of structure and material to form can now be examined. In the Green Mountain area a gently undulating surface replaces, at least on Hoosac Mountain (Pl. V, *A*), the overturned anticlinal structure. In the Dome, in Pownal, on the same range, the structure of which was carefully worked out by the writer in 1897, the overturn is still sharper, yet the form is that of a rather symmetrical oblong dome of gentle slopes and the material is quartzite and gneiss. In neither case has form been determined by structure. The dolomite area on this range east-southeast of Brandon appears to consist of a central anticline with a syncline on either side, but its roundish summits rising above the adjacent but underlying quartzite and schist reflect neither its structure nor the greater solubility of its material. On the other hand, as will be shown beyond, there is the most intimate relation between structure, material, and form in the 5-mile strip of dolomite east of Lake Dunmore.

In the Rensselaer Plateau a typical " peneplain " replaces a corrugated trough-like synclinorium.

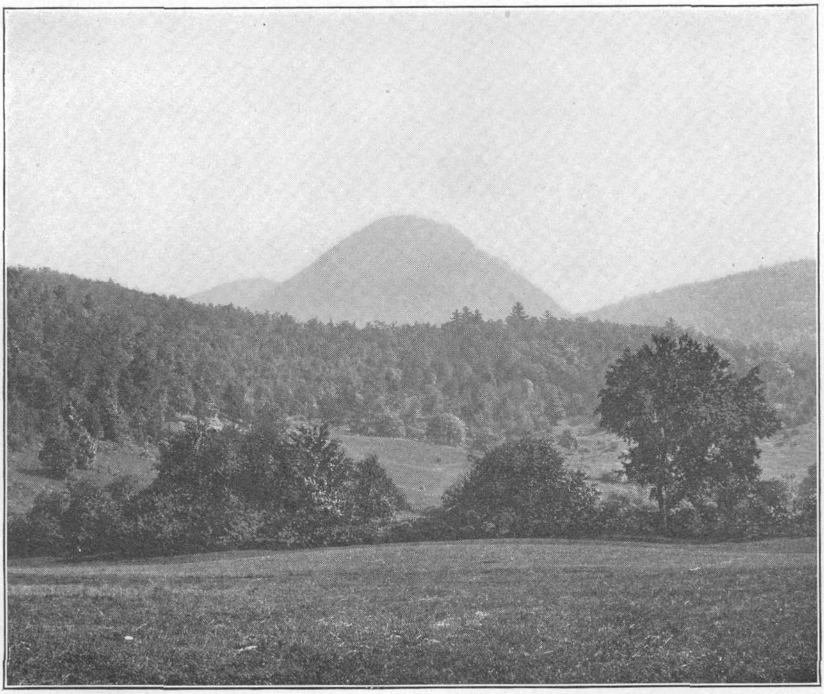
In the schist area there is a general parallelism between the crests of the ridges and the axes of the synclines. This is more noticeable in the southern part of the range and its spurs and outliers, but the course of the ridge near the southwest corner of Vermont seems to have been determined by the erosion of the Hoosic River, which crosses the strike. (See map, Pl. I.). Farther north this parallelism is less perceptible. The forms of Mount Anthony and Grass, Bear, Woodlawn, and Dorset mountains give no clue to their structure. The schist appears to have behaved practically like material of homogeneous structure and composition.

The longitudinal valleys are anticlinal, synclinal, or both, and lie in calcareous rock. Both structure and material have had to do with their formation. The transverse and diagonal ones are independent of material and bedding. In Pawlet, Arlington, Hoosick, and Pownal they cross limestone. The diagonal system of joints may have had something to do in determining their course. On the western side of the Taconic Range in Berlin and Stephentown a very narrow anticline of limestone 5 miles long is crossed by four



*A*. VIEW OF THE OFFSET IN THE GREEN MOUNTAIN RANGE.

From Williamstown, Mass., looking east. In the upper half of the mass the lines dipping gently to the south are the sides of pitching folds of quartzite which pass under the limestone of the valley. The horizontal bench is a glacial lake terrace resting on a moraine.



*B*. VIEW OF HAYSTACK MOUNTAIN, PAWLET, VT.

Looking north: the central part of a very open syncline of schist. Photograph by Charles D. Walcott.

transverse hollows, neither material nor structure affecting the topography.

The northwest-southeast limestone area in Whitecreek, N. Y., corresponds to a peculiar change in the strike which recurs at the northeast edge of the Rensselaer Plateau.

The easterly dipping cleavage so prevalent in the schist masses often determines the angle of the eastern slope of the hills, while strike and dip joints account for most of the north-south and east-west cliffs, and the rest are fault scarps. The sags in the crest lines are sometimes due to axial pitch, the larger saddles to limestone anticlines, and the lesser points to thick beds of quartz conglomerate or to large quartz veins in the schist.

Of the two long incisions in the Green Mountain Range that of the Walloomsac is evidently more dependent upon structure than upon material, while that of the North Branch of the Hoosic is consequent upon structure as well as upon material, the limestone and schist extending up into the valley. The short incisions farther north are independent of structure and material. The gorge of Middlebury River has been cut for a length of 2½ miles indifferently through gneiss, schist, and quartzite and across their strike. But the north-south incision opposite Manchester coincides in its lower part with a limestone syncline, as shown in Pl. V, *B*, but in its upper part crosses an anticline of quartzite.

The embayment in the Green Mountain Range may be attributed either, according to Dana, to an original irregularity in the pre-Cambrian surface or, according to Pumpelly, to a horizontal movement which altered the relations of the pre-Cambrian crystallines to the Cambrian and Ordovician sediments, or possibly merely to north-south compression along the axes of the folds, resulting in pitch (p. 27, and Pl. VI *A*). This last possibility would be more apparent in a section in which the Paleozoic sediments had been restored to the Green Mountain Range than it can be from the present surface relations of the formations. Possibly all these factors had a share in producing the embayment.

## EROSION.

### GENERAL EFFECT.

It is evident from what has been stated that neither rock material nor structure, singly or jointly, suffices to account for the land form. There remains to be considered the important factor of erosion.

Before determining the character and amount of the denudation which this region has suffered, the probable surface features as they emerged during the Ordovician movement should be restored, and for a large part of the tract this is not difficult. The order and estimated thickness of the formations are here given:

*Typical rock section of the Taconic region.*

| | Feet. |
|---|---|
| (5) Silurian grit | 1,400 |
| (4) Ordovician schist, or slate and shale (including some quartzite, unaltered grit, and limestone) | 2,600–3,500 |
| (3) Ordovician and Cambrian limestones | 1,000–2,000 |
| (2) Cambrian quartzite and schist or slate | 1,000–1,500 |
| | 4,600–8,400 |
| (1) Pre-Cambrian gneisses, etc., not estimated. | |

As the limestone of the valleys underlies the schist, these valleys must have been originally covered with schist, and therefore about a half mile of schist besides the amount of the eroded limestone ought to be conceived as restored to the valleys. In such localities as Stone Hill, Rattlesnake Hill, and Monument Mountain, in Berkshire County, where the Cambrian quartzite comes to the surface in anticlines, the entire limestone formation as well as the schist ought to be conceived as added—i. e., at least 3,600 and possibly 5,000 feet, leaving out the Silurian grit, which probably did not here extend into the Taconic Range. The schist masses themselves, whose forms now diverge so widely from their structure, ought to be conceived as restored to their original height and breadth and their transverse hollows and amphitheaters as filled. The synclinal mountains must correspond to original valleys, and the anticlinal valleys to original mountains. The resulting form would be very much like that represented by Willis in his Mechanics of Appalachian Structure,[a] reproduced in Pl. V, *C*, if one conceives the drawing reversed so as to bring the landward side on the right.

The entire belt between the Green Mountain Range and the Hudson and Lake Champlain must have been buried in argillaceous sediments, all folded and metamorphosed in degrees of intensity decreasing from the Green Mountain axis westward; but, for reasons not fully evident, there was more metamorphism within the area of the Rensselaer Plateau than its distance from the Green Mountain Range would lead one to suppose. There may have been some irregularity in the original sea floor here.[b]

The Taconic folio (in preparation) affords evidence that east of Bennington the Cambrian quartzite extended to the center of the town of Woodford, almost to the 2,800-foot level, and also south of it in Stamford, and may have been continuous with that in the valley of the North Branch of the Hoosic, and Pumpelly and Wolff[c] evidently regard it as having probably covered the gneiss of Hoosac

[a] Thirteenth Ann. Rept. U. S. Geol. Survey, pl. 47.
[b] See Bull. U. S. Geol. Survey No. 242, 1904, pp. 48, 54.
[c] Mon. U. S. Geol. Survey, vol. 23, 1894, pl. 3, Sec. B, and pl. 6.

Mountain, which has now been denuded to the 2,400-foot contour. Exactly what portions of the Green Mountain Range remained above water during Cambrian and during Ordovician time is still uncertain. The recent discovery by the writer of beach pebbles of pre-Cambrian gneiss, 2 and 5 feet in diameter, in the Cambrian conglomerate along the edges of the gneiss area in Ripton, Vt., shown in the northeast corner of the map, Pl. I, points strongly to the existence there of shore conditions in Lower Cambrian time, but there is no way of determining how long such conditions lasted after the Cambrian transgression. In Pownal, and again in Dorset, the Ordovician schists of the Taconic Range come very near the Green Mountain Range. In the town of Florida, on Hoosac Mountain,[a] Cambro-Ordovician schists, some of which represent those of the Taconic Range, cross the axis of the range. Whether the absence of the limestone from the range be explained by a horizontal transition to argillaceous sediments or by such an unconformity as that shown by the sections in the western part between the Cambrian and Ordovician, preventing calcareous sedimentation,[b] the western part of that portion of the Green Mountain Range shown on the map was probably once covered by granular and schistose materials like those, and as thick as those, which occur on its western flank and on the Taconic Range.

As the surface of the Green Mountain Range is generally above the 2,000-foot level there should be added to the tinted areas of the map representing the 2,000-2,500-foot levels just east of the granular rock boundary—i. e., to the western rim of the anticlinorium—an amount equal to the average thickness of the granular and schistose rocks (2) and the schistose or slaty rocks (4), which is 4,300 feet, in order to restore the original Ordovician surface.

That great changes must have taken place will be apparent to any student of the subject in looking across from the pre-Cambrian gneiss area on Hoosac Mountain on the line of Section *A* to the Greylock schist mass, when he finds that he has to look up from the anticlinal sea bottom on the 2,400-foot contour to the mass of sediments making up the adjacent synclinorium, the vertical difference being 1,100 feet. Either the anticline has been denuded of a vast mass of sediments, or it was a land surface which has itself been greatly denuded, or the Greylock trough has been thrust up. Of these alternatives the first is the most probable.

It appears, then, that the amount of denudation has been very much greater on the once submerged portions of the Green Mountain anticline than on the Taconic synclines, although this difference is not quite so marked when points on the Green Mountain Range in which

[a] Mon. U. S. Geol. Survey, vol. 23, 1894, pl. 1.

[b] Professor Wolff regards this interpretation of the relations on Hoosac Mountain as inadmissible.

longitudinal troughs occurred in the axis are taken for comparison. It is also evident that the general descent of the original surface westward as it emerged from the Ordovician sea was much more marked than the present surface indicates.

At this point it is well to examine afresh the peneplain theory as applied to this region.[a] This supposes that during the periods between the end of the Ordovician and the end of the Cretaceous the entire region was, with the exception of a few residuals (monadnocks), reduced to a peneplain or base-level, remnants of which can now be seen on the Green Mountain Plateau. But, commencing with the beginning of the history, the supposition is that in pre-Cambrian time a mountain system existed in New England and another in the Adirondacks, and that after the Cambrian-Ordovician transgression the denudation of these mountains furnished materials for the mechanical sediments which now occupy the Hudson-Champlain valley and the Taconic region. However much uncertainty may attend the reconstruction of Green Mountain Cambrian and Ordovician geography, we know the approximate minimum thickness of Cambro-Ordovician mechanical sedimentation, and thus have at hand some measure of the denudation of the pre-Cambrian land masses during Cambrian and Ordovician time. It may be seen from the map (Pl. I) that after deducting the Green Mountain and Adirondack border areas, together with those Cambrian areas which may have been above water during Ordovician time, there are yet about 2,400 square miles over which mechanical sediments measuring at least 3,500 feet, and quite possibly 4,500 feet, in all probability extended. This amount of detritus, if added to those portions of the Adirondack and Green Mountain islands whose drainage entered this arm of the Atlantic, would suffice for a small mountain system. Whether the Cambro-Ordovician period of erosion alone was sufficiently long to reduce this mountain system to sea level can hardly be determined.

The Ordovician movement folded the entire region, sea bottom and sea deposits, as well as portions of the land masses, and thus arose another mountain system. If another transgression took place in Silurian time over a portion of the Taconic region, as seems probable from a study of the Rensselaer Plateau and Bird Mountain,[b] the second great period of erosion must have been interrupted in Silurian time and to have had a duration bearing the same proportion to the earlier cycle as Devonian, Carboniferous, Jurassic, Triassic, and Cretaceous do to Cambrian and Ordovician, and it is during this time that the Taconic and Green mountains are supposed to have been base-leveled. Have we any satisfactory evidence of this? As has been shown, the surface of portions of the Green Mountain Range

[a] See the quotations from Davis, Emerson, and Tarr, on pages 13, 15, 16.
[b] See Bull. U. S. Geol. Survey No. 242, 1904, p. 53.

does not correspond to its structure, and it has been greatly denuded, but the Taconic Range is far removed from the peneplain type. On the other hand, the Rensselaer Plateau is a typical peneplain. The preservation of its surface may be due to the massive character of its rocks, while the softer schists of the intervening ranges yielded more readily to sculpture.

If the lower western part of the peneplain represented by the Rensselaer Plateau be between the 1,500- and 2,000-foot levels and its eastern part fall between the 2,000- and 2,500-foot levels on the Green Mountain Range, then those portions of the intervening masses which belong to the plain will appear between the same levels as shown on the map. The few elevations above 2,500 feet on both ranges would then be residuals. But the theory requires an elevation of from 1,500 to 2,000 feet at the beginning of the Tertiary. The scantiness of the peneplain on the Taconic Range must, therefore, be ascribed to the denudation which has taken place since the uplift. As approximately one-half of the denudation of the Taconic topographic belt has taken place below the 2,000-foot level, that part of it must have occurred during Tertiary and Quaternary time, and only an equal amount during the much longer Paleozoic and Mesozoic periods.

In order to restore the relations as far as possible to their condition at the time of the uplift, a depression of the present surface some 1,500 or 2,000 feet, to its original " base-level " altitude, may be imagined. Such a depression would be sufficient to admit the Atlantic, whose waters now reach Albany, and are only 101 feet below Lake Champlain, through both the Hudson and the St. Lawrence, and transform the Taconic Range into an archipelago, whose configuration would be determined not by the present complex outline of the 1,500- or 2,000-foot levels, but largely by the contours of the original anticlines and synclines at those elevations. According to this idea the submerged areas of this archipelago were those upon which stream erosion began to operate in Cenozoic time, when the later uplift took place, while Paleozoic and Mesozoic erosion must have operated upon whatever was above the 2,000-foot level.

Again, it seems remarkable that if the Cretaceous sea invaded the Champlain Valley it should have left no vestige of itself in the form of either marine deposits or sea cliffs, although there seems to be a rock terrace on the southern side of the Greylock mass at the 3,000-foot level and indications of terracing at the 2,500-foot level. To explain this feature four alternative suppositions are available: (1) The valley was filled with Ordovician sediments to the 1,500- or 2,000-foot level, so as to shut out the Cretaceous sea and its sediments, in which case Cenozoic erosion must have removed all this Ordovician material; (2) the Cretaceous sediments and sea cliffs have themselves all been eroded; (3) land barriers at the north and south prevented access of the sea in Cretaceous time, in which case we should have Cretaceous lake shore lines; (4) there is some error in the estimated amount of the post-Cretaceous elevation.

The disproportionate amount of erosion called for in Cenozoic time as compared with that in Paleozoic and Mesozoic time, and the absence of Cretaceous sedimentation and sea cliffs, seem to call for a careful restatement of the peneplain theory as far as it applies to the Taconic region.

Whether in consequence of the Ordovician movement alone, or because of that and subsequent uplifts, the Taconic region has suffered a vast amount of erosion. It is a deeply dissected upland. An inspection of the map and sections will justify the estimate that the amount of denudation which has taken place between the western foot of the Green Mountain Range and the western limit of the schist belt alone is not very much less than the bulk of the present schist masses. If to this be added the amount of denudation suffered by the western rim of the Green Mountain Range, the total will be vast indeed. This feature is the most impressive one in the region, and continued study serves greatly to increase its impressiveness.

All the products of this erosion have been transported into the Atlantic, the schist in the form of fine sand, into which it easily disintegrates under long-continued mechanical action, and the calcareous material mainly in solution.

## PROCESSES OF EROSION.

Denudation in this region was either general, consisting in the truncation of major anticlines and in the exposure of the limestone along the axes of the folds, or special, consisting in the crosscutting and the minute sculpture of the truncated folds and in the erosion of fault scarps. In a general way it was the effect of the exposure of the rock surface to atmospheric agents. While these were chiefly the action of streams and of ice, the operation of the atmosphere itself, through its carbonic acid and its vapor of water, should not be overlooked, nor should the effects of changes of temperature nor the chemical and physical effects of vegetation. In view of the lapse of time between the close of the Ordovician or the Silurian and the close of the Tertiary, and of the succession of floras which must have flourished in this region during that interval, the amount of erosion due to plant life alone must have been considerable.

### STREAM EROSION.

The principal streams of the region (see Pl. I) include two that follow the axes of the folds—Otter Creek, which flows northward into Lake Champlain, and Housatonic River, which flows southward into Long Island Sound. The Kinderhook, Hoosic, and Batten Kill flow more or less westerly into the Hudson, and the Mettawee and Poultney similarly into Lake Champlain. All these westerly flowing streams have made easterly cuts into or completely across the schist range. In the latter case, however, they have had the aid of streams on the eastern side of the range. The Hoosic and Batten Kill drain portions of the Green Mountain Range, reaching to the watershed of the Deerfield River and thus to that of the Connecticut. The area under consideration thus embraces parts of the basins of Lake Champlain and of the Hudson, the Connecticut, and the Housatonic rivers. The boundaries of these basins are indicated on the map.

The first effect of the elevation of such a folded region above sea level must have been the collection of rain water in the synclinal troughs and the flowing of streams down the sides of the anticlines. The inclination of the axes of the synclines being less than that of the sides of the anticlines, the erosive power of the longitudinal streams must have been far less than that of the former. Transverse cuts on the anticlines, therefore, were formed first and the longitudinal streams eventually became tributaries of the transverse ones. As the anticlines became reduced to valleys, the synclines remained as mountains, to be in turn cut by transverse streams, so that the drainage of both anticlinal valleys and synclinal mountains was carried westward in the direction of the decreasing folds to the Hudson-Champlain valley. It is apparent from the present drainage lines and from the position of the watershed of the Taconic Range on its eastern margin and, in places, even farther east on the Green Mountain Range, that the erosion of the Taconic Range has been done chiefly on the west. The transverse cuts are evidence of the long duration of erosive processes.[a]

The greater solubility of the limestone anticlines and synclines, when once denuded of their overlying schist, perpetuated the courses of the longitudinal streams and tended to increase the width of their valleys. The due east-west course of the Hoosic between the Green Mountain spur and Greylock seems to have been determined by the presence of limestone between underlying quartzite on the north and overlying schist on the south, all with a southerly pitch.

Glacial and post-Glacial deposits have modified the ancient drainage. The choking of narrow valleys by moraines and the deposit of sheets of sediment by glacial lakes in wider ones must have given the new streams much work to do, and probably, in some places, prevented them from returning to the channels of the pre-Glacial ones. The influence of these later formations is very noticeable in the Hudson-Champlain valley. Thus the Hoosic, when it reaches the

[a] Löwl, F., Über Thalbildung, 1884, Prague, p. 105.

upper terraces of the Hudson, has a meandering course owing to the horizontality of the surface (Pl. VII, *A*). At Schaghticoke it flows first southwest, then northwest and south, then north-northeast, and finally west-northwest, all in a distance of 2 miles. It has cut a canyon from 100 to 200 feet deep through over 100 feet of glacial drift and terrace material and a varying thickness of shales and grits. During this part of its course the fall is 100 feet. As shown by the arrows in the figure, some parts of its meanders are parallel to the strike of the shales cut by the river, but the outline of the edge of the gorge shows that the course of the stream was fixed long before the rock was reached and was of post-Glacial date. The post-Glacial work of streams is also shown by the fact that the ravines on the Green Mountain Range, ancient as they must be, are usually choked with huge bowlders. For several miles north and south of the mouth of the Hoosic the lowest terrace of the Hudson is cut by small ramifying east-west ravines, from 1 to 3 miles long and up to 100 feet deep, which reach down to the shales in parts of their course and cross their strike (Pl. VII, *B*). These must all be of later date than the post-Glacial uplift of the Lake Champlain region.[a]

## GLACIAL EROSION.

Although glacial deposits are outside the province of this paper, yet, inasmuch as glaciation of the rock surface was a factor in the topography, it will be here briefly considered. As is well known, the prevailing course of the glacier in this region was southeast or south-southeast. The striæ on Mount Greylock are S. 40° E. The course of the well-known Richmond bowlder, one of the largest in New England, from its source at the Knob in Canaan, N. Y., to its site about 6 miles distant at the eastern foot of the Taconic Range, was southeast. That course was traced about a half century ago by Edward Hitchcock and Charles Lyell.[b] A bowlder of metamorphic grit recently observed near Pittsfield, Mass., lies over 11 miles, southeast, from its source in Rensselaer County, N. Y. Bowlders from

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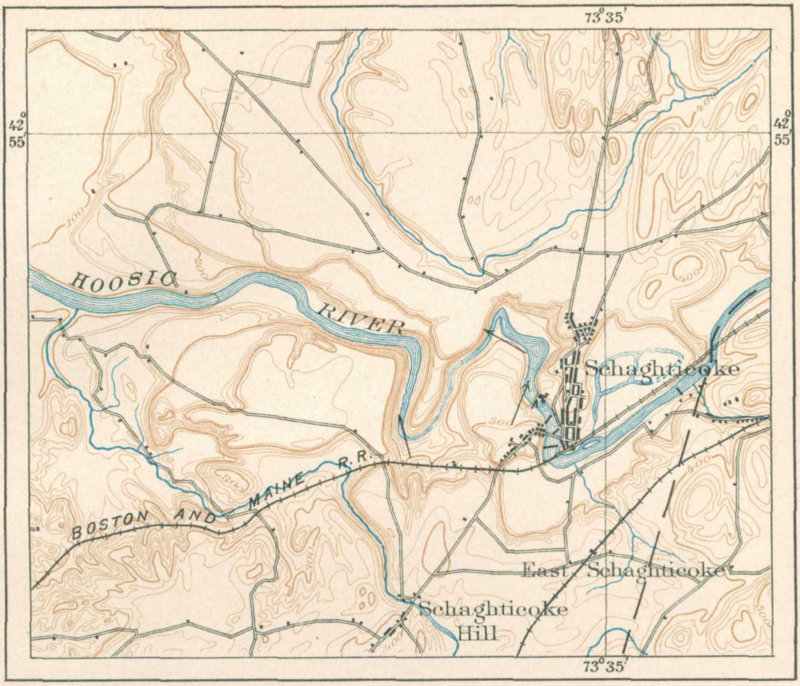
[a] Warren Upham gives the vertical amount of marine submergence along the basin of that lake, as shown by fossiliferous beds of modified drift supplied from the melting ice sheet and resting on till, as from 300 to 400 feet, increasing from south to north. (Upham, Warren, The Champlain submergence: Bull. Geol. Soc. America, vol. 3, 1892, pp. 508–511.) Baldwin shows that the valley in pre-Glacial time was occupied by a river, the level of which was far below the present lake surface. The valley was then glaciated, depressed, filled with a glacial lake, then submerged below sea level so that sea beaches were formed in its northern part at what is now the 500-foot level, and finally elevated to its present position. (Baldwin, S. Prentiss, The Pleistocene history of the Lake Champlain Valley: Am. Geologist, vol. 13, 1894, pp. 170, 184, Pl. V. See also Peet, Charles E., Glacial and post-Glacial history of the Hudson and Champlain valleys: Jour. Geol., vol. 12, 1904, pp. 415–469, 617–660.)

[b] Hitchcock, Edward, Am. Jour. Sci., vol. 49, 1845, pp. 258–265. Lyell, Charles, Proc. Royal Inst., 1855; also, in "Geological Evidences of the Antiquity of Man," Chapter XVIII.




*A.* MAP OF THE LOWER COURSE OF THE HOOSIC RIVER


*B.* MAP OF EAST BANK OF THE HUDSON IN SCHAGHTICOKE

Bird Mountain in the northern part of the Taconic Range have traveled from 47 to 58 miles S. 5° W., S. 12° W., S. 25° W.,[a] and Mr. Moffit recently found one on the top of Grass Mountain in Arlington about 38 miles S. 10° W. from its source. The presence on the Taconic Range in northwest Massachusetts of many quartzite bowlders from the Green Mountain Range confirms evidence from some of the striæ that there was also a southerly motion to the ice sheet. Pl. VIII, *B*, shows a broad glacial furrow with a S. 10° E. course in Pittsford, Vt., a half mile west of Otter Creek; and Pl. VIII, *A*, shows a quartzite bowlder lying upon marble at the eastern foot of the Taconic Range in the same town, which originated in the Green Mountain Range, and must therefore have traveled in a southerly direction. Portions of the schist masses show rounding north and northwest shoulders, and there are also southerly facing east-west cliffs, as Bird Mountain and Rounds Rock on Greylock.

The beautifully preserved glacial striæ along Lake Champlain and in the New York and Vermont slate belt show what must have once characterized the entire region, and what, but for the mantle of drift and vegetation, would still be visible.

Glacial erosion, however, appears to have been of less importance than pre-Glacial stream erosion, though perhaps more of a factor than was post-Glacial. Probably the ice sheet, aside from its general erosive effect, aided materially in the sculpturing of those valleys, ravines, cuts, ridges, and spurs which have northwest-southeast or north-south axes; but in view of the vast amount of time which elapsed between the Green Mountain elevation and the advent of the glacier compared with even the most liberal estimates for that which covered the period of glaciation, it is likely that the principal factor in the sculpture of the region was pre-Glacial stream erosion. This is the more certain, as the preservation of the striæ on the schist and quartzite surfaces away from the ravines is so perfect that it is evident that at such points post-Glacial erosion was practically nothing, while the protection afforded to the limestone valleys by Glacial and post-Glacial deposits has effectually preserved large areas of them to this day. And, although, as has been pointed out, a considerable part of the work of the post-Glacial streams has consisted in undoing the work of the Glacial epoch, the time these streams have had to work is relatively so short that their effect can not be very considerable.

One effect of glacial erosion which should not be overlooked is "rock shattering."[b] Though doubtless supplemented later by frost,

[a] A Study of Bird Mountain, cit., pp. 20, 21. On page 20, third line from bottom, "west" was erroneously written for east.

[b] Geikie, James, Earth Sculpture, or the Origin of Land Forms, London, 1898; Chapter X, Land Forms modified by Glacial Action, pp. 170–185.

the first shattering of the ledges was by the mechanical action of the ice sheet, and such shattered ledges may well have furnished material for bowlders. When the moss- and forest-clad summits of the Taconic and Green Mountain ranges are deforested they are frequently found to consist of shattered ledges. Such ledges, when still covered with vegetation, are probably the sources of the higher ice-water brooks or springs which now and then surprise the summer traveler.[a] In some localities blocks of quartzite 20 by 10 by 5 feet have been moved several feet either horizontally or up slightly inclined bedding planes. At "The Burning," on the Green Mountain Range, near the town line of Manchester and Sunderland, such blocks and a large area of shattered quartzite may be observed. The relative position of many of these blocks is such as to preclude the probability that the action

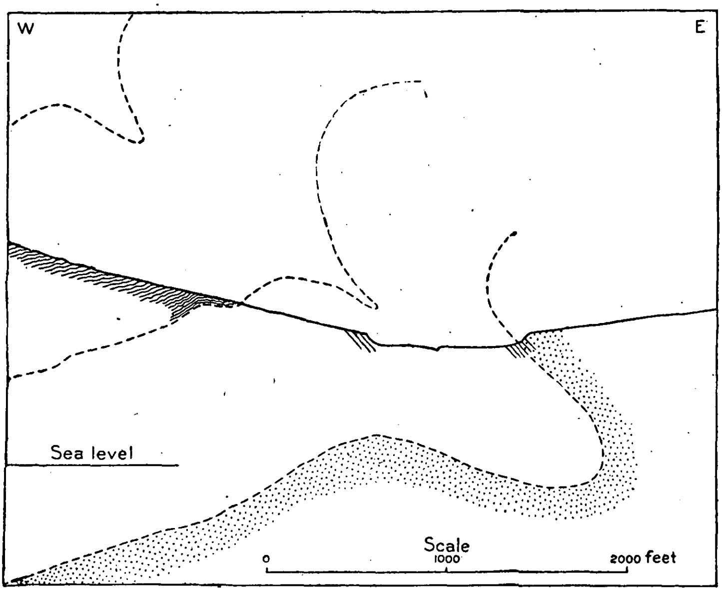



FIG. 1.—Section across the western side of Stone Hill and Hemlock Brook Valley to the Taconic Range in Williamstown, Mass., showing the eroded fold. The lowest rock is quartzite, the next dolomite, then schist.

of frost alone brought it about, although it has undoubtedly had a share in the work. (See Pl. IV, p. 24, foreground.)

For the action of frost in the production of talus slopes see page 46.

## PARTICULAR EFFECTS OF EROSION.

The more minute sculpture of the region and the particular forms resulting from the action of the various erosive processes upon material and structure remain to be considered.

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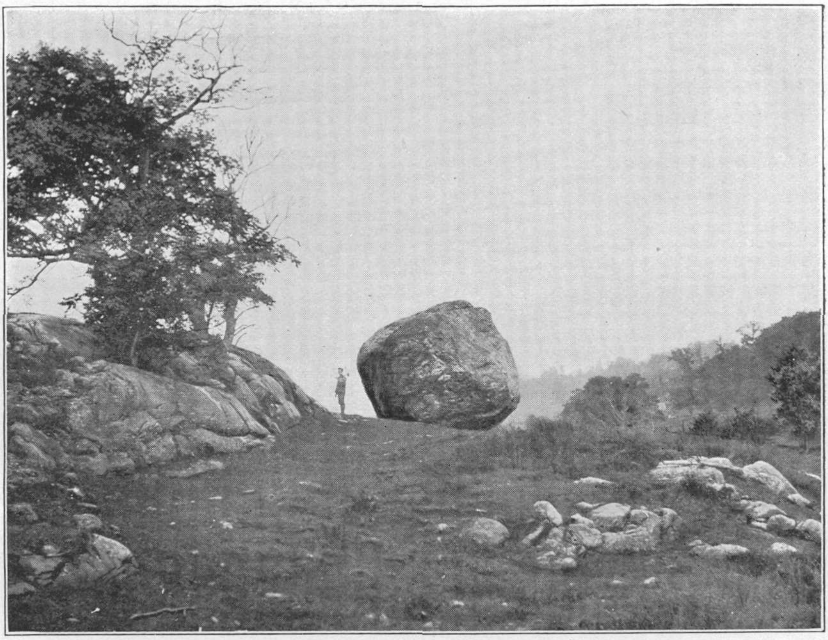
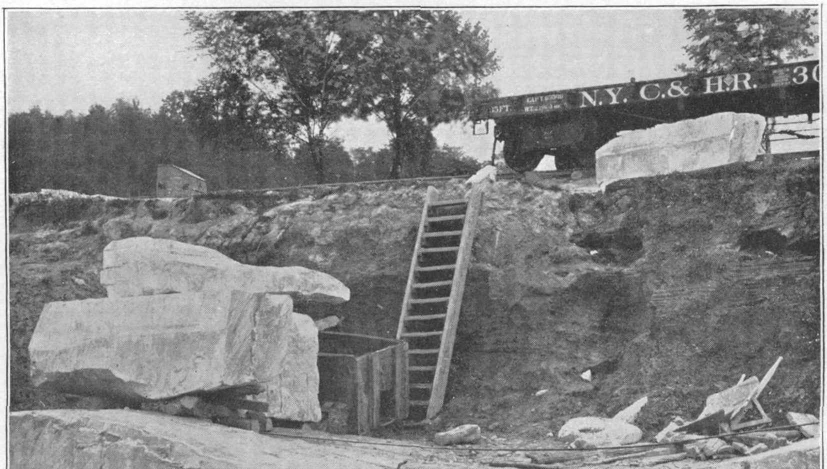
[a] See Water-Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1905, p. 127.



*A.* GLACIAL BOWLDER OF QUARTZITE RESTING ON MARBLE.

West foot of Taconic Range, 1¾ miles southwest of Pittsford Village, Vt. Looking south.




*B.* GLACIAL FURROW IN WHITE MARBLE.

Two miles west-northwest of Pittsford, Vt. The marble is in close, erect folds, striking N. 20° W. The course of the furrow is S. 20° E. On the marble are 20 feet of clays probably deposited by a glacial lake.

ANTICLINAL HILLS.

In an anticlinal structure, when a hard rock underlies a soluble or a soft one, the effect of erosion is to denude the anticline and expose its hard substratum. Stone Hill, in Williamstown, a westwardly overturned anticline of quartzite, was once covered with the limestone which now surrounds it (see fig. 1). The small transversely folded quartzite and schist anticline a mile north of Stone Hill has a like history.[a] That anticline in places has remnants only a foot thick of the great limestone formation, the total original thickness of which was not less than 1,000 feet. Rattlesnake Hill, in Stockbridge, is a normal anticline of micaceous quartzite similarly denuded. Monument Mountain, in Great Barrington (fig. 2) which is a complex anticlinal block of Cambrian schist and overlying quartzite thrust

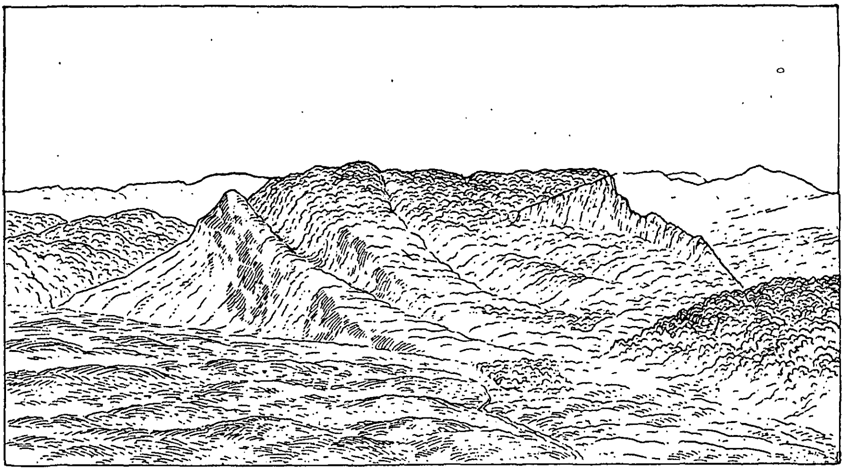


FIG. 2.—Sketch of Monument Mountain (south side) from Mount Keith, in Great Barrington, looking north, showing the fault scarps on either side.

up along a transverse and two lateral fault planes, has been denuded of its limestone covering. The quartzite area east of North Bennington is probably also a denuded anticline, as are likewise two of the quartzite areas in Addison County east of Lake Champlain.

All of these anticlines have been denuded not only of at least 1,000 feet of limestone but also of some 2,000 feet of schist or shale which overlay them. In the case of Monument Mountain, if to the present altitude of its schist summit (1,700 feet) 500 feet of quartzite, 1,000 feet of limestone, and 2,000 feet of schist be added to restore the original surface, the height of the mountain would be 5,200 feet. This assumes, however, that the folding and faulting occurred at the time of the Ordovician emergence and took place with sufficient rapidity

[a] See Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 553, and fig. 77.

to prevent atmospheric erosion from making any considerable headway before their completion. If these movements were slow, this estimate would be somewhat reduced. In any case at least 3,500 feet of strata have been removed from its summit. Fig. 2, which shows the mass rising 1,100 feet above the Housatonic Valley on the left, thus represents but 29 per cent of the original thickness of the sediments deposited there.

### SYNCLINAL HILLS.

The well-known tendency in such a region toward the preservation of the synclines of the upper and harder beds (as in the case of Bird Mountain [a]), rather than of the anticlines of the same, need only be mentioned. The synclinorial character of the Taconic Range, as shown in Pl. V, *A*, is repeated on a small scale in many a hill. Ragged and Sugar Loaf mountains in the Greylock mass, and Tom Ball in West Stockbridge, are excellent examples (see p. 19). These synclines vary greatly in longitudinal and lateral structure. Haystack Mountain in Pawlet (1,919 feet), shown in Pl. VI, *B*, from a photograph taken several years ago by C. D. Walcott, Director of the United States Geological Survey, is the central horizontal part of a very open syncline of schist, crossed by a steep easterly dipping cleavage and by vertical east-west joint planes. The eastern slope of the mass was largely determined by cleavage, and the cliffs at the south end by joints, but otherwise there is little relation between its structure and its form.

### DISSECTED HILLS.

Erosion has attacked the schist masses on all sides, and in some cases the dissection has proceeded so far as to leave mere spider-like forms, such as Grass, Bear, and Dorset mountains in Bennington County, Woodlawn and Tinmouth mountains in Rutland County, as shown on the relief map. In such masses a spur may still correspond to the strike of the bedding or the jointing, but in general the forms are without structural significance. Marr calls such hills dissected moels.[b]

This process of dissection may occur on one or several sides of the mass. Dissection chiefly on one side is shown in the Taconic Range, south of the Vermont-Massachusetts line, along the New York border, and, indeed, is a general feature of that range. The westwardly flowing streams take their rise well on the eastern edge of it, in accordance with the general process of stream erosion in the region,

[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, Pl. II.

[b] Marr, J. E., The origin of moels, and their subsequent dissection: Geog. Jour., vol. 17, 1901, pp. 63–69.

which has caused the watershed of the Hudson to advance eastward on the Taconic Range, just as that of the Connecticut has worked westward on the Green Mountain Range. The crest of this particular mass has many small saddles, due to erosion by lateral streams.

Where erosion is equal on opposite sides and the underlying soluble rock occurs at a high level, there result such relations as those south-southwest of Mount Equinox in Sandgate, where the limestone has become exposed in irregular strips, possibly corresponding to minor anticlines, with intervening schist strips, perhaps corresponding to minor synclines. By continued erosion from the east and the west these limestone strips would eventually merge into one another, and a limestone saddle would be formed like that which constitutes the divide between Mount Equinox and Bear Mountain. In Bear Mountain itself sculpture has occurred toward the east, west, and north, but in Grass, Dorset, and Woodlawn mountains sculpture has proceeded toward all four points of the compass, and has consequently resulted in the formation of very irregular spurs. In Dorset Mountain only the three longer southerly spurs have any structural significance.

### OUTLIERS.

A still later stage of erosion is seen in the pyramidal mass of Mount Anthony, in Bennington, and yet a more advanced one in Green Peak, south of Dorset Mountain, in which a triangular schist cap, about a square mile in area and from 750 to 1,150 feet thick, is all that is left of the mass which once filled the Vermont Valley and connected Dorset and Equinox mountains. This is properly an outlier—i. e., a part of the overlying formation isolated by dissection. Two such schist outliers occur between Bennington and Hoosick; another lies in Alford, west of Tom Ball; another constitutes Maple Hill, north of the latter. The synclinal schist hills, Ragged and Sugar Loaf mountains, belong here. Bird Mountain, if the remnant of an extensive formation and not a local deposit, would be an outlier also.

The two quartzite areas on the Green Mountain Range, east and southeast of Bennington, and the dolomite areas east of Brandon and Lake Dunmore, are also outliers. The shred-like remnants of schist and shale overlying the limestone of the Berkshire and Champlain valleys owe their peculiar forms to structure and erosion.

### INLIERS.

The same process which leaves isolated masses of the overlying formation may expose such masses of the underlying one, without reference to their relative hardness or structure. The limestone areas in Pawlet and Pownal were formed in this way; also that in

Cheshire. This last is now regarded as an anticline refolded into a syncline, but in Monograph XXIII was represented as a syncline of an overlying limestone. A very small inlier in New Ashford was described in detail in Appendix B of the same monograph. There are two inliers of pre-Cambrian gneiss on the Green Mountain Range, one in Sunderland, the other in Pownal, formed by the erosion of the overlying Cambrian quartzite and schist.

### ANTICLINAL VALLEYS.

De la Noë and de Margerie [a] show that anticlinal valleys of soft or soluble rocks may have been produced by the simple denudation of the top of the anticline instead of by longitudinal rupture facilitating erosion. Whichever theory be correct, anticlinal valleys of limestone formed by the removal of the overlying schist are frequent in the Taconic region. Three such are easily recognized: The Hancock Valley, between the Taconic Range and its spur, in Massachusetts; the West Rutland marble valley, the structure of which was long ago pointed out as an isoclinal anticline with an easterly dipping axial plane,[b] but which in places is more nearly a normal anticline, the schist on the west dipping low west,[c] and the Notch between Greylock and Ragged Mountain, which is a conspicuous feature in the landscape in looking south from the offset in the Green Mountain Range in Stamford.[d]

### SYNCLINAL VALLEYS.

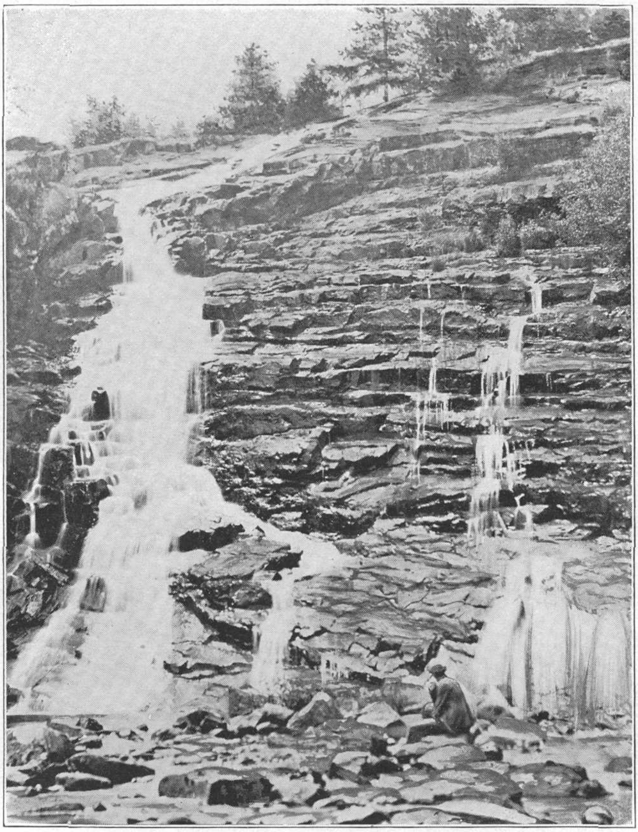
The southern part of the Lake Champlain Valley is a broad syncline, from the western part of which the limestone and from the central part of which the shale has been eroded. Judging from the westerly dip of the quartzite which flanks the Green Mountain Range and which is so finely exposed in White Rocks, in Wallingford (Pl. XII, *A*), and in Downer Glen, in Manchester, the Vermont Valley is probably synclinal, although probably with some minor folds (Pl. V, *B*). The lower part of Lye Brook Hollow, in Manchester, is a syncline with quartzite anticlines east and west of it, which have been denuded of their limestone (see map and Pl. V, *B*). Between Stone Hill and the Taconic Range, in Williamstown, Hemlock Brook has cut its course into a sharply overturned limestone syncline (fig. 1 and p. 39). The view up this valley is a charming one and

[a] Noë, G. de la, and Margerie, E. de, Des causes déterminant le tracé des cours d'eau, Paris, 1888; Vallées anticlinales, pp. 148–151.

[b] Wing, Rev. A., Am. Jour. Sci., 3d ser., vol. 13, 1877, pp. 337–339.

[c] Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, pp. 321–324; Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 547, 548.

[d] See view from opposite direction in Mon. U. S. Geol. Survey, vol. 23, 1894, pl. 16; also Pl. V, *A*, of this bulletin.



*A.* VIEW OF THE FALLS OF THE POESTEN KILL.

Near Barberville, Rensselaer County, N. Y., on the western edge of the plateau. The stream is cutting the limb of an anticline of grit and shale.

*B.* VIEW OF "THE GORGE" IN PITTSFORD, VT.

Near the Chittenden line, taken looking N. 20° E. The cut is in quartzite and is attributed to a fault.

few would suspect that a difference of fully half a mile exists between the topography due to erosion and the original topography due to structure.

A very marked synclinal valley occurs on the western edge of the Green Mountain Range east of Lake Dunmore (Pl. XIII). This syncline begins at Sucker Brook and can be traced almost 5 miles to a point 2½ miles south of Silver Lake. It is in places U-shaped, and forms a wild glen, in which lies the carriage road from Brandon village. The steep sides of this glen are from 300 to 500 feet high. The rock is quartzite overlain by dolomite, which, however, has generally been eroded from the sides of the syncline. Where the sides of the syncline are very steep the quartzite has fallen in blocks, forming a talus covering the edges of the dolomite.

## RAVINES.

By far the most interesting pieces of land sculpture in the Taconic region are the ravines. To these is largely due the picturesqueness of the region as well as its abundant brooks and its dense vegetation. These ravines are either parallel to the folds and then longitudinal, or transverse or diagonal to them, and frequently ramifying, so that one type passes into another. There are also amphitheaters resembling glacial cirques or corries, except that they reach well down to the valley floor. In the history of many of these ravines one or another of the various systems of jointing (see p. 28) has helped to determine the course of a brook in its infancy, or, as erosion went on, the joint faces have fixed that course by guiding the stream. It is common to find the brooks flowing in these ravines bounded at intervals by joints on one and sometimes on both sides.

Although the ravines in the harder rocks of the Green Mountain Range and the Rensselaer Plateau do not ramify as much as those of the schist masses, yet some of them are so long and so deep as to imply a vast amount of time for their sculpture. A transverse cut from 800 to 1,000 feet deep, on the north side of Downer Glen in Manchester, shows a quartzite fold, cleft by an east-west joint, which forms the side of the ravine in that part of its course. The gorge of Middlebury River is about 200 feet deep, but the transverse cut in the range of which this forms the narrower part is 2¾ miles broad and extends from the 1,900-foot level down to the 1,000-foot one. The lower part of the gorge is in places a canyon from 10 to 50 feet wide and 50 feet deep. The contact between the pre-Cambrian gneiss and the Cambrian schist crosses a pothole 40 by 50 feet wide in the canyon.

Pl. IX, *A*, shows the lower part of the end of a cut in the western edge of the Rensselaer Plateau. The depth of the cut, measured from the highest part of the edge of the plateau, is 700 feet. At a point a half mile east of the edge the cut bifurcates into longitudinal ones. At this place a small stream, the Poesten Kill, is cutting the limb of a minor anticline before flowing along the strike.

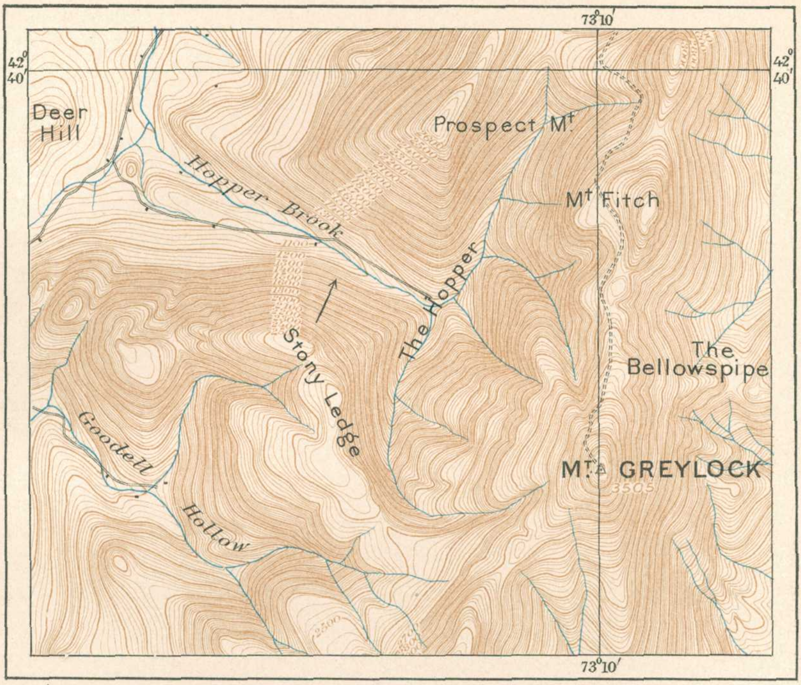
The four small parallel east-west cuts in the schist mass east of Granville are very probably related to east-west joints. One of the most instructive of such cuts is the Hopper, on Mount Greylock (see map, Pls. X, *A*, and XI). This is a 1,500-foot-deep northwest-southeast incision, which extends completely across the western syncline of the schist mass. The cut then opens into the NNE.-SSW. longitudinal hollow referred to by Dana,[a] along an anticlinal axis. The eastern wall of this hollow is cut into by six transverse mountain torrents, which are extending the work of the first one and attacking the central syncline of the mass. The most southerly of the branches of Hopper Brook describes a peculiar curve in its descent of 1,600 feet, its upper and lower courses being parallel to the strike, but its middle course across it. A similar curve is described by a ravine on the north side of the Greylock mass. As may be seen by Pl. X, *A*, the amount of material removed from the transverse incision alone, if inverted, would make a pyramid 1,500 feet high with a base a mile square.

The most complete amphitheater in the Taconic region is Skinner Hollow, on the eastern side of Mount Equinox, in Manchester (see Pl. X, *B*). But the map does not do full justice to the mathematical regularity of the excavation. It is across the strike, although the inclination of the beds is slight. The depth from the crest to what may be called the back of the hollow or the bottom of the steeper slope is from 1,600 to 1,700 feet, and from that point to the mouth the descent is 500 feet and the distance 1 mile. The spurs on the north and south are from 900 to 1,000 feet above the mouth. As shown on Pl. I, limestone rises to the 2,500-foot contour in the hollow, so that the amount of material eroded would, if inverted, make a conical mass about 1,550 feet high with a base 1 mile in diameter, and of this cone the lower 550 feet would be siliceous (schist), while the upper 1,000 feet would be soluble rock (marble). The very symmetrical character of this amphitheater suggests the bare possibility that a local glacier may have had something to do with its sculpture.[b]

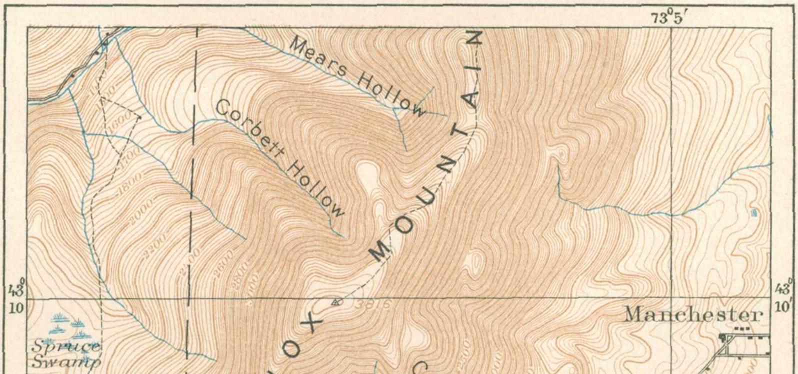
Where the brooks reach the soluble rocks chemical action comes strongly into play, and miniature canyons of white marble sometimes occur, as at the "Natural Bridge" near North Adams, where both the axis of a fold and the strike of several systems of joints

[a] Dana, James D., Am. Jour. Sci., 3d ser., vol. 6, 1873, p. 273.

[b] See Tarr, Ralph S., Glaciation of Mount Ktaadn, Maine: Bull. Geol. Soc. Am., vol. 11, 1900, pp. 433–448 and pls. 33, 34. Also Hitchcock, Charles H., New England local glaciers: Ibid., vol. 7, 1896. Emerson, B. K., Glacial cirques and rock terraces on Mount Toby, Massachusetts: Science, vol. 17, p. 224.




A. MAP OF THE HOPPER AND MT. GREYLOCK




B. MAP OF SKINNER HOLLOW ON MT. EQUINOX

VIEW OF THE "HOPPER," IN THE GREYLOCK MASS.

From Deer Hill, looking across the strike. On the left, Mount Prospect; on the right, in distance, Mount Greylock; in front of it, Bald Mountain or "Stony ledge." A ravine of erosion.

have determined the course of the brook. The development of this canyon is also due to the mechanical action of bowlders of granite and quartzite rotated upon the marble.

Some ravines, however, have a very different history from these. For instance, in the eastern edge of Pittsford, Vt., is a notch known locally as "The Gorge" (Pl. IX, *B*), which is from 100 to 300 feet deep, 70 feet wide at the bottom, and from 500 to 1,000 feet long. It is choked below with great angular blocks of quartzite which have fallen from the sides. At the north it ends abruptly in a mass of brecciated quartzite, and the western side is similarly brecciated. Neither glaciation nor the bedding can well account for this notch, as both cross it, the striæ, which run S. 15° E., making an angle of 30° with its sides. But as it is in exact line with the Pine Hill overthrust on the south,[a] and as breccias are usual about faults, its origin may be attributed to the fault. Ice Glen in Stockbridge, Mass., may be likewise due to a fault or to a parting along a plane of frac-

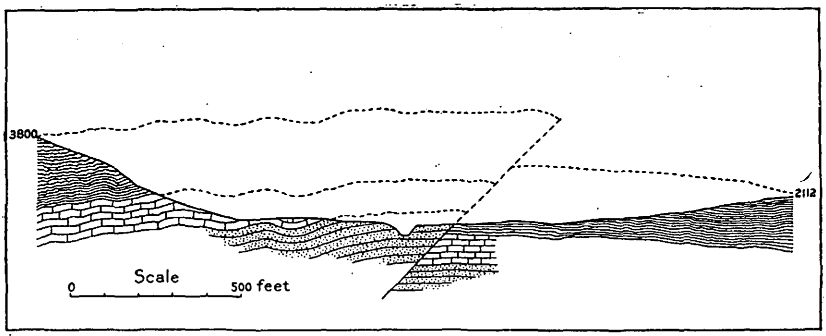



FIG. 3.—Section from the top of Dorset Mountain, on left, to Danby Hill, in Danby, Vt., showing the eroded fault scarp. The lowest rock is quartzite, then marble with dolomite, lastly schist.

ture. A small canyon in Poultney has already been referred to as due to the erosion of a basaltic dike in slate[b] (pp. 17, 25).

## FAULT SCARPS.

The conspicuous quartzite cliffs on the east and west sides of Monument Mountain in Great Barrington are fault scarps (fig. 2).[c] The east-west face of Dorset Mountain, already referred to on page 15, is really an eroded fault scarp (Pl. II, and fig. 3). The north-south section (fig. 3) shows that the mass of limestone and schist eroded on the upthrow side of the fault was about 3,000 feet thick and not less than 2 miles long. About 22 miles north-northwest of the northern

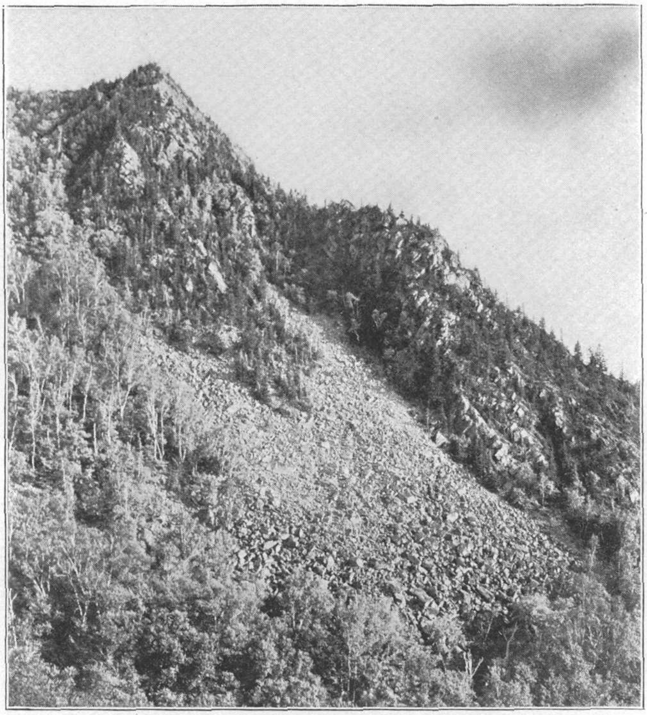
[a] See Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 548, 549, and fig. 64.
[b] See diagram, Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, fig. 12, p. 222.
[c] See also Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, 563, fig. 71.

end of the Taconic Range and 4 miles north of the northern edge of the area mapped is the fault scarp of Snake Mountain, in Addison County, Vt. The cliff faces west and is nearly 1,000 feet higher than the surrounding portion of the Lake Champlain Valley. This fault scarp is the first conspicuous topographic feature north of the Taconic Range. The southern end of this fault appears at the northern edge of mapped area.

The two longer quartzite inliers in Shoreham, Vt., are faulted monoclines, whatever scarps may have formed their western sides having been eroded.

### TALUS SLOPES.

The action of frost on the much-jointed quartzite cliffs of Monument Mountain has probably formed the talus shown on each side of the mountain (fig. 2 and p. 45). To this additions are made year by year. Wherever the quartzite of the western flank of the Green Mountain Range is exposed a talus has likewise been formed, the size of which depends upon the position and magnitude of the outcrop and the character of the primary and secondary structure. A very large talus of blocks up to 20 feet in diameter occurs at the foot of White Rocks, in Wallingford, Vt., 5¼ miles east of Tinmouth village and beyond the edge of the mapped area. (See Pls. II and XII, *A*, *B*.) The gentle western slope of the range in places may be due to a similar talus mantled by vegetation. Another but much smaller talus of large blocks occurs on the same range north of the Bear Spring in Williamstown. Here longitudinal and transverse joints and minor folds with cleavage planes furnished the requisite structural conditions. On the western side of Mount Moosalamoo, which rises to an altitude of 2,088 feet above Lake Dunmore (Pl. XIII), there is an extensive quartzite talus masked by forest. Some of the blocks are over 40 feet in diameter. The origin of this talus may be associated with the fault which occurs on the cliffs above it. Indeed, the structural relations of the Silver Lake syncline and Mount Moosalamoo seem to require a transverse or diagonal fault there. There is a grit talus at Slide Mountain on the northwest corner of the Rensselaer Plateau, in Pittstown, N. Y. An extensive talus of schist, exposed a few years ago by a forest fire, occurs a short distance east of the top of Mount Greylock and 800 feet below it. A pronounced cleavage foliation, dipping steeply to the east, crossed by vertical east-west jointing and a low westerly dipping stratification, afforded favorable conditions, and the erosive power was supplied either by frost or the motion of the glacier diagonally across the summit. The recent landslide has finely exposed this steep east face.

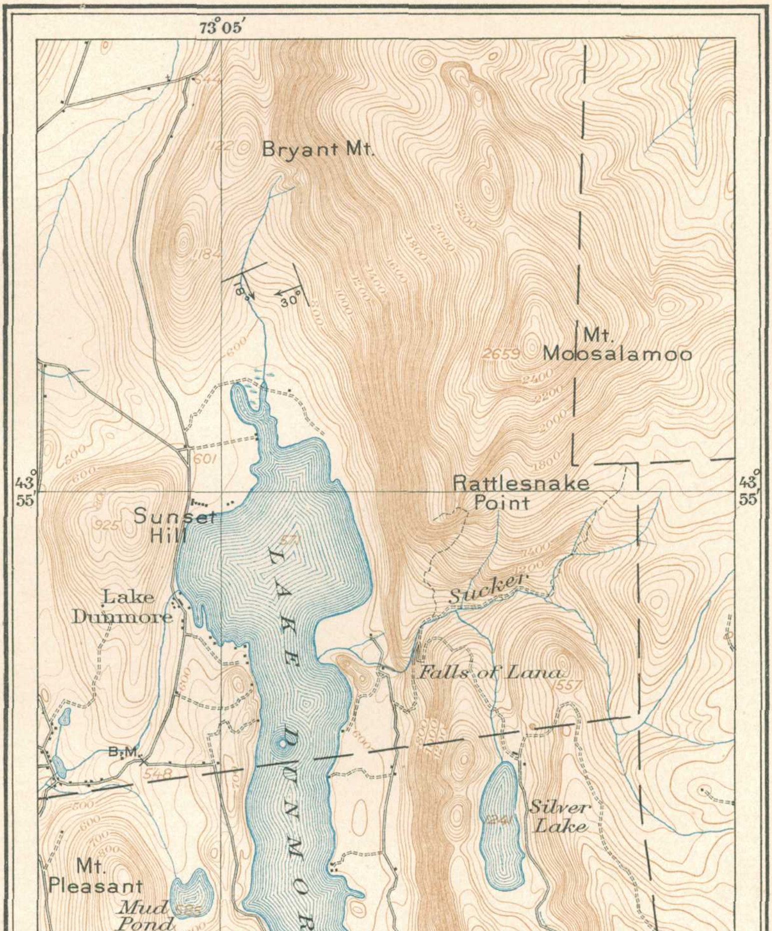


*A*. VIEW OF WHITE ROCKS ON THE GREEN MOUNTAIN RANGE IN WALLINGFORD.

Looking south along the strike. The rock is quartzite.

*B*. VIEW OF THE QUARTZITE TALUS ON THE WEST SIDE OF WHITE ROCKS, WALLINGFORD, VT.

Looking south-southwest along the flank of the Green Mountain Range.




MAP OF LAKE DUNMORE AND SILVER LAKE, VERMONT

Scale 0 ½ 1 2 miles

Contour interval 20 feet

## THE LAKES AS RELATED TO ROCK STRUCTURE.

Most of the lakes of this region (enumerated on p. 22) have little if any relation to rock structure. Their presence was determined either by the distribution of glacial deposits or by the silting of channels in such deposits. Others lie upon the rock in shallow depressions formed by erosion and in some cases dammed up on one or more sides by glacial deposits. Of such character are the numerous lakes on the Rensselaer Plateau, the lakes of Berkshire County, and most of those of the Hudson-Champlain valley.

Lake Cossayuna, in Argyle, lies in a rocky basin, but the structure of its surrounding ledges furnishes no clew to its origin. It may be part of the channel of an ancient river. Lake St. Catherine, in Poultney and Wells, is bounded on the west by a slate ridge and on the east by a schist ridge. As the boundary between the two formations crosses the lake diagonally and the slate is probably anticlinal in structure, the hollow in which it lies has been eroded. Lake Bomoseen, in Castleton and Hubbardton, lies entirely in a region of small folded slates, etc., which crop out along its shores. The general trend of the lake corresponds approximately to the strike of the folds. But there is a cut through which the outlet of Glen Lake flows into Lake Bomoseen, and the shore of Lake Bomoseen west of Cedar Point is in line with this cut. The parallelism of this cut and this shore line to some of the joints, and also to a camptonite dike which crosses the lake a mile north of Cedar Point, indicates structural relations between them. In other respects this lake is to be attributed to erosion and to both glacial and stream deposits. Lake Dunmore, in Salisbury and Brandon, Vt. (Pl. XIII), seems to lie in a southward-pitching syncline of quartzite, with overlying dolomite, the dolomite having been largely eroded. The valley at the northern end of the lake is formed by this syncline. The damming up of the syncline at the south by Glacial or post-Glacial gravels may be the reason for the outlet of the lake not being in its natural place. Silver Lake, 670 feet above Lake Dunmore, lies within a narrow syncline of dolomite underlain by quartzite (p. 43 and Pls. XIII and XIV). The deep transverse cut between Silver Lake and Moosalamoo crosses this syncline without having penetrated all of the dolomite. The lake is retained in its syncline by glacial gravels. Both of these lakes are thus associated with rock structure.

## CONCLUSION.

The history of the Taconic landscape, from a geological point of view, is a long one. Its chief events, briefly summarized, were the accumulation in a broad arm of the ocean of arenaceous, argillaceous, and calcareous materials by erosion and by mechanical and organic sedimentation; then the formation in these stratified sediments and their crystalline basement of a series of great parallel folds, diminishing in altitude from east to west, which caused a retreat of the sea. This folding resulted in faults, metamorphism, and secondary structures of several kinds. There were three periods of folding—one at the close of the Lower Cambrian, affecting the central portion of the basin; another at the close of the Ordovician, more far-reaching in its effects, and a third seems to have occurred in post-Silurian time (Devonian or Carboniferous), as shown in the Rensselaer Plateau and Bird Mountain. The various materials thus collected, folded, altered, and traversed by structural planes became exposed as great longitudinal ridges and valleys to stream erosion, and that erosion was retarded as it approached base-level or was accelerated by uplifts. The first anticlinal ridge became, in places, denuded of all its sediments, although these amounted to several thousand feet, and the ancient sea floor became exposed (see Pl. V, *A*). The anticlinal ridges west of this were carved into valleys and the synclines remained as ridges, but in some instances the original forms persisted with modifications. Erosion operated laterally completely across these synclinal and anticlinal mountains, and also sculptured them on all sides into forms bearing little resemblance to their structure. Eventually, completely buried under the continental glacier which moved both southward and southeastward, the surface features became still further modified by the shattering of ledges, the removal of blocks, the gouging and scouring action of bowlders and gravel held in the ice. The melting of this vast body of ice gave rise to streams which freshly eroded the surface, scattered morainal material, and formed glacial lakes.

The Taconic landscape is thus the result of erosion acting upon rock material of various composition and structure.

The amount of this erosion depended on the relative solubility and hardness of the material. The resulting forms depended largely on the direction and pitch of the axes of the folds, their anticlinal or synclinal form, faulting, jointing, and cleavage. Some of these factors, however, must have counteracted others; hardness may have been rendered of no avail by details of structure, while erodibility by physical processes in one rock may have been balanced by greater solubility in another. Some of the schist masses appear from their general outlines to have behaved as if largely homogeneous in structure and composition.

The chief agents of erosion were the mechanical action of streams through the material they transported or rotated, of frost operating in fissures due to structure, of ice operating through bowlders and gravel, of roots growing into structural openings and acting as

LAKE DUNMORE AND SILVER LAKE.

View along the western anticline of the Green Mountain Range, showing the two synclinal lakes, Silver Lake on the range and Lake Dunmore at its foot. In the distance the Vermont Valley and the Taconic Range. Taken from Rattlesnake Point on Mount Moosalamoo in Salisbury, Vt., looking south across the transverse hollow of Sucker Brook.

wedges, and chemical action by the carbonic acid of the atmosphere and by the organic acids of vegetation upon all calcareous rocks and even to some extent upon siliceous ones.

Of the three topographic types described on page 23, the plateau type may be ascribed largely to the toughness of its granular, granitic, or gneissic material, which offered more uniform resistance to erosion. Here structure was of minor and often of no consequence. The ridge-and-valley type is probably due to the complex structure and the mutual relations of its soluble and its schistose rocks and the varying resistance of both structure and material to erosion. This is sometimes reflected in the vegetation, for limestone, when near the surface, promotes fertility by its additions to the subsoil, and even when deep and covered with drift and alluvium oftener underlies the arable land, while schist areas, constituting the hilltops, being more rugged, usually bear less drift and weather less readily, and suffice for the support of forest growth. The Hudson-Champlain valley type, consisting of an undulating surface with several series of low hills, is traceable to the behavior under erosion of soft but insoluble rocks in small folds with occasional more resistant miniature anticlinoria or synclinoria. Here, however, the general rock surface has been modified by the addition of morainal and terrace material.

To such a history and to such causes the Taconic landscape owes its varied and picturesque features.

# INDEX.