ARTICLE VIII.—*Geological Sections across New Hampshire and Vermont.** By C. H. HITCHCOCK.

THE geological surveys of New Hampshire and Vermont were based upon the measurement and delineation of several geological sections, crossing the formations at nearly right angles to their course, and running east and west. Colored profiles, with the accompanying descriptions, will be found in the geological reports of these two States. Since the completion of these surveys, I have had occasion to go over the ground again; collecting specimens for the illustration of these sections in the rooms of the American Museum of Natural History. These additional explorations have enabled me to correct doubtful points, to confirm truthful representations, to change the section lines where improvement was possible, to take advantage of discoveries made by other observers, and especially to present a connected view of what has been learned concerning the geological succession in the two States. A knowledge of this territory furnishes the key to unlock the mysteries of New England geology, as well as that of the whole of the middle section of the Atlantic geographical area. Profiles drawn to the horizontal scale of one mile to the inch, $\frac{1}{63360}$, and twice as great vertically, and colored to exhibit the variety and order of the formations, have been prepared to accompany the specimens upon the shelves in the cases. In the vicinity there may be seen a large colored geological relief-map of New Hampshire, having the same horizontal scale with the profiles. The sections illustrated are thirteen in number, accompanied by nearly 2200 specimens.

Our object in preparing this sketch is to so record the most important facts connected with our explorations, that those who visit the Museum may have the opportunity to verify our conclusions for themselves by studying the specimens, both lithologically and stratigraphically. The work of exploration was undertaken with the determination to discover what the rocks themselves taught, and not in the interest of any theory. Hence students may rely upon the truthfulness of all the representations. The

* This article was prepared in June, 1882.

specimens come from ledges in the localities indicated, and the positions of the strata are stated according to our best judgment from personal observation. If there is ever any want of symmetry in the folds, if one side of an axis seems to possess an exaggerated thickness, it is because all the facts needed for full delineation are not known. Pains are taken not to represent curves and faults except those whose existence is unquestionable. Hence the inquirer can utilize the ten years of field and office work embodied in these collections, nearly as well as if he had gone over the ground himself. He will also understand for himself the localities where supplementary observations are needed.

About 90,000 feet thickness of strata occur over this territory. As they have not been particularly investigated elsewhere, it follows that many groups must exist not generally recognized, and peculiar designations must be employed, which will be perplexing. To assist the inquirer, I will, at first, present a few general conclusions, based upon a terminology readily understood; reserving the fuller details of our scheme of classification and structure for the sequel, to be fully appreciated only by a painstaking examination of the larger profiles and specimens in the cases.

It should also be borne in mind that our various groups or formations are classified according to stratigraphical reasons, and not lithology. Lithological names may be used for convenience, or so as to avoid the multiplication of local designations. A lithological similarity is useful in tracing a formation from farm to farm, or town to town throughout a county; or to identify the opposite side of a synclinal basin or anticlinal ridge. Furthermore, unlike rocks are never assumed to be identical. If a hornblende schist and clay slate dip towards each other, they are assumed to be of different age and separated by a fault. All the igneous rocks of our field are held to be truly eruptive, and are devoid of marks of stratification. If a granitic rock shows foliation, it is classed among the gneisses. Many speak of "gneiss passing into granite." All such examples are called *gneiss* in our scheme.

The published sections accompanying this bulletin have the horizontal scale of $\frac{1}{300000}$, and the vertical of about $\frac{1}{160000}$. They are arranged geographically correct with reference to each other, and the meridians and longitude are drawn as upon a map. In some cases the extreme east or west ends of the sections are not represented. The base line of all the sections is 1650 feet below tidewater. The exact courses of these section lines are also shown upon an additional plate. Twelve variations of lines, dots and dashes indicate as many groups of rocks upon which our primary conclusions are based. They are: 1. *Niagara group. 2. Upper Cambro-Silurian slates and schists. 3. Cambro-Silurian limestones. 4. The Connecticut Valley mica schists, quartzites, etc., referred to the Coös group in the New Hampshire reports, and the calciferous mica schists of the reports of both States. 5. Potsdam sandstone. 6. Clay slates and argillitic and other schists, supposed to be of Cambrian age. Of these, the "Georgia slates" of the Vermont report contain the *Olenellus* and *Angelina*,† the others have not yet yielded any organism. 7. Mica schist of eastern New Hampshire, a part of the "Rockingham group" of the report. 8. Huronian, including the chloritic, argillitic, dioritic schists, quartzites, and protogenes flanking the Green Mountains, and adjoining the Connecticut River, or the rocks usually referred to this group by authors; also the "Merrimack group," "Ferruginous slates," "Kearsarge group," and part of the "Rockingham group" of the New Hampshire report. 9. Montalban rocks, as defined in the New Hampshire report, including the schists holding the coarse granite veins carrying merchantable mica. 10. Ordinary gneiss, including the "Green Mountain," "Lake Winnipiseogee," and "Bethlehem" varieties of the reports. 11. Porphyritic gneiss. To these may be added another distinction for the unstratified rocks, in which are embraced granite, syenite and porphyry.

THE CAMBRO-SILURIAN.

Probably the whole of this division of the Paleozoic rocks occurs in the Champlain Valley. Sections I.–VII. display a mass of green hydro-mica schists overlying the fossiliferous limestones of this series, and may, perhaps, represent the Loraine slates of New York. On our section lines the Trenton is wanting in immediate contiguity to these schists, so that the question arises

* Formerly regarded as Lower Helderberg, but recently shown by Prof. R. P. Whitfield to belong to the Niagara.—*Am. Sci. Jour.*, III., vol. xxv., p. 368.

† As determined by Prof. R. P. Whitfield, in Bulletin No. 5, vol. 1.

whether these schists may not represent beds that were laid down in the Trenton age. So far as recognized, the Trenton beds are limestones; but there must have been sediments coeval with those limestones in the ancient seas: still it is but a rude conjecture that would refer them to this age. They are called Loraine upon the sections. These beds were called "Magnesian slate" by Prof. Emmons, and constituted the upper member of what he styled "Lower Taconic." The relations of the limestones to the schists are well shown upon section IV. in Mt. Eolus. There about 500 feet of the schists are isolated from all connection with the main range, and rest upon about 2000 feet thickness of limestones, almost horizontal, except at their base. The same schists reappear in what is called the Taconic range of mountains, a few miles west of Mt. Eolus. They universally dip east, and would be regarded as older than the limestones except for the section in Mt. Eolus. This fact has led to careful search at the junction of the two formations for evidence of a fault. Section V. shows this break very plainly, in Tinmouth. Section I. affords the most satisfactory evidence of the passage of the limestones beneath the schists of the Taconic range. At North Pownal a fault has brought up the limestones from beneath the heart of the mountain range. To the east, near the Massachusetts line, the limestones dip west towards these schists, contrary to the nearly universal position of these rocks west of the Hoosac Mountains. By following the Troy and Boston Railroad to the north from North Pownal, we find the limestones nearly or quite continuous to Hoosick Falls, where the characteristic fossils of the Chazy and calciferous sandrock occur in them. This section, therefore, demonstrates the inferior place of the limestones as compared with the schists. This is in the heart of the classic Taconic grounds, where the late Prof. Emmons deduced the conclusions giving rise to the existence of the noted *Taconic system*. I cannot ascertain that he discovered this western dip in Pownal, and the consequent connection, ledge by ledge, of his Stockbridge limestones with the Chazy and calciferous at Hoosick. It is just here that the fatal defect to the establishment of the Taconic system, as defined by Emmons, exists. His paleontological arguments were better than the stratigraphical. Our sections are too small to show the occurrence of the subdivisions of the limestone. Upon VII., according to the late Rev. A. Wing, the following members are recognizable: first, "Hudson River slate," a mile or more west of Middlebury C. H.; second, Trenton, or sparry limestone, without fossils; third, *Rhynchonella* beds, or Chazy, this and the preceding of unusual thickness; fourth, "trilobite bed and conglomerate," the probable equivalent of the Levis limestone of Logan; fifth, the *Ophileta* beds, or calciferous sandrock. These, as our section shows, are followed next by the red Potsdam sandstone of Snake or Grandview Mountain, whose top is in Addison.

The same author has described a section along a part of No. VII., from East Shoreham, through Whiting and Leicester. The "Hudson River slates" are in the centre, dipping east, flanked on both sides successively by the "Trenton and Chazy," calciferous and Potsdam. It is an overturned synclinal, as all the strata dip to the east. Instead of a red sandstone on the west, we find a gray sandstone, having the usual aspect of the Potsdam on the New York side of Lake Champlain. North of Shoreham, the color of this western band is red entirely through the State to Canada, while the eastern range is gray and often vitreous. This is one of the most satisfactory of our sections across the Champlain Valley, as it demonstrates the relations of the different Cambro-Silurian limestones to the Potsdam sandstone.

THE CAMBRIAN.

On the west flank of the Green Mountains, sometimes rising higher than the main range, is a band of quartzite which received from Emmons the appellation of "Granular quartz," and it was made the base of his Taconic system. Our sections show that it immediately underlies the calciferous sandrock, and having fossils similar to those found elsewhere in the Potsdam sandstone, it is clearly a member of the Cambrian series. In some quarters the effort has been made, unsuccessfully, to refer it to the Middle Silurian sandstones. Upon sections III. and VII., besides other localities mentioned in the 1861 report, the basal beds contain pebbles of blue quartz, which are recognized as having been derived from the adjacent gneisses of the Green Mountains. Hence this quartzite has been formed since the elevation of the

Green Mountains above tide water. The calciferous sandrock had its origin posteriorly to the quartzite, and likewise the several other members of the limestone group in their turn, and there is a natural order of succession in time of the formations from the gneiss to the west.

Three bands of sandstone, therefore, are referred to the Potsdam in the Champlain Valley: first, the normal gray sedimentary beds at the foot of the Adirondacks, always known under this name since 1840; second, the quartzite on the flank of the Green Mountains; third, a range of red sandstone and dolomite from the Canada line to Bridport, where it is succeeded by outcrops of a material not distinguishable from the first-named band. Partly accompanying the middle band is a series of slates and hard sandstones, passing into roofing slates, called Georgia group in the State report, which carries such fossils as *Olenellus* and *Angelina*, and is, therefore, thought to be somewhat older than the typical Potsdam sandstone. These are partly connected with a series of schists gradually increasing in thickness and width of territory from section VII., east of Middlebury, to the Canada line. The quartzite first named terminates between sections VII. and VIII., save as it may merge into these schists. The continuation of these schists into Canada is an area partly of Cambrian and partly of Levis age.

We can now understand the physical history of Western Vermont in the early Paleozoic age. The Adirondacks and Green Mountains had been elevated above the sea, and constituted dry land, connecting on the east with the large Atlantic area—Newfoundland to Alabama—and on the northwest with the generally recognized Laurentian of British America. The waves dashing at the Vermont and New York shore lines accumulated the quartz derived from the disintegration of the gneisses into banks of purely silicious sands, frequently termed "primordial sea-beaches." The other materials, of finer texture, were washed out into the deeper waters, but reached sufficiently near the surface to allow of the existence of trilobites, annelids and sea-weeds. At length the silicious sediments ceased to accumulate, and limestones took their place, falling down upon the slaty foundations. In the Trenton age, the last of the limestones, this sea became disconnected with the Atlantic Ocean through the present Gulf St. Lawrence, as shown by the distinctively American types of life existing throughout the interior. The limestones were finally covered by the Utica and Loraine slates.

Partial elevations of the Champlain country had been in progress during the building up of the Cambrian and Cambro-Silurian, but there must have been a very important one after the deposition of the Loraine group. The whole Champlain Valley seems to have been then raised above water level, since no rocks of later age have been deposited in this basin within the limits of New England. The final results of all the elevatory movements have been the crowding towards each other of the primitive land-areas; the faulting of the primal slates ; the raising of the beach beneath Burlington and St. Albans—and changing its color from gray to red—overturning many of the limestones and sandstones ; developing the symmetrical folds in the red sandstone about Monkton and Ferrisburg, and the alteration of the calcareous beds into snow-white marbles.

THE GREEN MOUNTAIN ANTICLINAL.

The existence of the anticlinal ridge of the Green Mountains was the most important contribution to science made by the late geological survey of Vermont, though its value was not then appreciated. Nearly all our sections illustrate the existence of this structural feature. Only No. VI. is purely monoclinal, and this like VII. and VIII. is to be regarded as an inverted anticlinal. The elevatory pressure seems to have been greatest along the middle part of the State, so as to have overturned this main axis. In I. a mass of mica schist of undetermined age—possibly Montalban—constitutes the summit of the highest ridge, continuous from the Hoosac Mountain over the celebrated tunnel to No. II. in Searsburg, where it rests upon the eastern flank of the elevated country. The gneiss is narrowest at the tunnel and widest along section I., where it may readily be seen to be composed of three parallel axes. The more western one may not extend many miles northerly ; and it is more like the typical Laurentian than any other area. Very satisfactory sections are obtained in the valleys of the Winooski, La Moille and Missisco rivers, cut down across this formation more than 3000 feet, just north of Camel's Hump, Mt. Mansfield and Jay Peak (compare IX. to XIII). Upon the high mountains the strata are apt to be obscured by extensive deposits of till. Logan's scheme of structure involved the existence of a synclinal instead of an anticlinal, while his description of Sutton Mountain* showed that the true structure could not be suppressed. Selwyn, his successor in office, declares that the physical character of the region entirely favors the anticlinal structure for the Green Mountains in Canada. Prof. J. D. Dana has also announced his conviction that these gneisses in southern Vermont are older than the quartzite and of Archæan age.†

In southern Vermont, where the elevated region is widest, the rocks are usually well-defined gneisses, including protogene. North of VI. the feldspar diminishes in amount, and at length is manifested in scattered crystals, seen chiefly where the layers are broken. An inexperienced observer will overlook the feldspar upon the higher mountains in the northern part of the State. It is properly a feldspathic mica schist. Adams, the first State geologist, suggested the name of "Green Mountain gneiss" for the whole terrane, in view of this marked lithological feature. We find, on examination, that this micaceous band is probably the equivalent of a mica schist or micaceous gneiss in several gneissic terranes of this age in the Connecticut hydrographic basins, in both States; and that it is overlaid by hornblende schist.

It follows from the relations of the Cambrian quartzites to the gneiss that the latter is of pre-Cambrian age. The "primordial sea-beach" defined the western limits of this ancient land. If we use a similar criterion for the determination of the eastern limits of the island, we must travel to Braintree in Massachusetts or far down in Maine to find them. There are unfossiliferous quartzites and limestones, probably the equivalent of these western bands, in Plymouth, Vt., Rhode Island, and near the mouth of Penobscot Bay. The first are about ten miles in length. There are also areas of slate of undetermined age. In later times the Connecticut Valley deepened sufficiently to allow of the growth of Niagara and Helderberg coral reefs.

* Geology of Canada, 1863, page 251. † Quar. Jour. Geol. Soc., XXXVIII., 397, 1882.

CORRELATION OF THE GREEN MOUNTAIN AND NEW HAMPSHIRE GNEISSES.

The sections will enable us to proceed a step further and correlate the gneisses just described with those of southeastern Vermont, the Connecticut Valley, and both flanks of the highlands between the Connecticut and Merrimack rivers in New Hampshire. First of all, upon Nos. II., III., IV. and V., the Green Mountain terrane repeats itself in the well-defined range marked on the Vermont map as extending from Halifax to Hartland. Next, passing the small Guilford, Brattleboro and Vernon areas, we find the terrane again rising with greater width from Winchester to Fitzwilliam in I., Swanzey in II., Surry, Gilsum and Stoddard in III., but largely covered by later rocks, Acworth and Lempster in IV., Croydon and Springfield in V., Hanover and Canaan in VI., Orford and Wentworth in VII., Haverhill and Benton in VIII., Bethlehem in IX., Jefferson and Berlin in X., and Milan in XI. This is the northern termination of the terrane. It next shows itself upon the Merrimack slope, viz.: at Peterborough in II., Deering, Weare and Dunbarton in III., Warner in IV., Andover in V., in very limited amount. It seems on this flank of the highlands to lie more in small patches than as a broad belt. The next appearance of this gneiss is in the remarkable range from Mason (I.), through Milford and Amherst (II.), Manchester, Candia in III., Northwood and Barrington in IV. This range is characterized by the thoroughly crystalline saccharoidal aspect of the constituents. No one familiar with typical Laurentian ground will find himself far from home between Mason and Deerfield, nor in Berlin and Milan at the northeastern extremity of the previously mentioned gneissic wave.

Upon V., VI., VII., is another conspicuous area, partly coincident with the hydrographic basin of Lake Winnipiseogee. This area, as colored upon the map, suggests a northwest rather than a northeast trend. Compass observations, however, show the northeast to be the common direction; hence the whole of the original area is not visible, being concealed by later formations. This is the broadest of all of the terranes, and it comes up again in Maine, between Denmark and Bethel. Many would mistake the Winnipiseogee Lake exposures for granite, but the lines of foliation can almost always be discerned. The difficulty of distinguishing the two rocks is greater in the Maine than the Lake terrane. The descriptions given by Selwyn to the oldest Laurentian gneisses of Canada will apply well to those in the Lake district. The next fold is seen at Nashua and Hudson in I., Hampstead in II., and West Epping in III. There are still other areas of small size below section III.; especially in Massachusetts, where our published map shows the northeast terminus of the band which has afforded the *Eözöon* in Chelmsford.

Inasmuch as these several gneissic ranges resemble one another, and exhibit the usual phenomena of stratigraphical connection—whether by folding beneath superior formations or bending over still more ancient groups—it is but a necessary generalization to conclude that they came into existence in the same geological age, and that they are all to be ranked as the equivalents of the Green Mountain series, pre-Cambrian, Archæan or Eozoic. It may be remarked that the first has a northerly trend in southern Vermont, verging more easterly in the northern part of the State, and not extending into the Dominion of Canada more than twenty miles. The other ranges gradually course more easterly, and lie nearly in the normal northeast range of the corresponding terranes south of New England, or in the Highlands of New York, New Jersey, and the Blue Ridge of Virginia. We have, therefore, an extensive group of gneissic areas essentially continuous from Newfoundland to Alabama on the Atlantic border of this continent. They are of Eozoic age, coeval with the formations of the Laurentian highlands, and developed along a different line of growth. They constituted an Archæan Atlantis, now partially submerged, but playing an important part in the building up of the North American continent.

THE OLDEST OF THE GNEISSES.

The map, plate 18, shows the distribution of areas of gneiss, supposed to be the equivalent of the Green Mountain Gneiss, in eastern Vermont and New Hampshire, by the areas colored red.

These common gneisses overlie a peculiar rock, whose largest development follows the watershed between the Connecticut and

Merrimack systems of drainage—the tract of highest elevation in the State south of the White Mountains—and the group passes beneath the mountains north of the Merrimack basin. This rock is a gneiss, containing distinct crystals of orthoclase—from one-half to three inches in length—which are usually arranged in lines of supposed bedding. A more conspicuous ledge is rarely seen; and hence geologists have universally recognized and described the rock. It is the *Augen gneiss* of Europe, and Logan mentions it as a constituent of the Laurentian in Canada. It is not met with in Vermont.

Nearly thirty areas of this formation have been delineated on the New Hampshire map. The largest extends continuously from Jaffrey to Groton, dips beneath mica schists to rise again in Ellsworth, continues to Franconia, and then underlies the Bethlehem group of gneiss to arise for the last time to the surface at the Wing Road railroad junction. The extreme points thus indicated are 105 miles apart. On section I., this rock just rises to the surface in Rindge; on II., the southern extremity of the main range is touched in Jaffrey; on III., IV., V., VI. and VII., the rock is very conspicuous. Two ranges are seen in VI., VII. and VIII., and it unconformably underlies the other gneisses in several instances. The apparent doubling in VI. is occasioned by the crossing of a crooked range. Other rocks interstratified with and integral parts of the formation are ordinary gneisses, hard mica schists, ferruginous quartzites and fibrolite aggregates. The stratification is often obscure and entirely obliterated in many localities, or where the crystals of feldspar are irregularly disposed. No lower group than this has been recognized in any sections, or anywhere else in New England.

HORNBLENDE SCHIST GROUP.

Having ascertained the stratigraphical relations of the gneisses, we find the first rock covering them to be a band of hornblende schist, occasionally feldspathic, and not unfrequently 1500 feet thick. It is best understood in the southern parts of our field, partly because better exposed, and partly because it has been less studied in the north. First noticed in the Guilford and Brattleboro, Vt., anticlinals, I. and II., it was detected only by exploration to hold the same position on both flanks of the Halifax-

Hartland gneiss, II., III. and IV. On I. it also overlies the Green Mountain terrane. In New Hampshire it borders a tract of gneiss between II. and III. in Cheshire county; flanks the west border of the Hanover gneiss, and covers the Canaan synclinal in VI.; and overlies gneiss in Surry, III., and Haverhill, VIII. There is a continuous range of it close to the Connecticut River between Cornish and Haverhill. In fact, it is so constant next the older gneisses, that if it be clearly absent, the presence of a fault or of an unconformity may be assumed. In Vernon it encircles an area of gneiss, and the structure indicated is that of an overturned anticlinal. The rocks over the hornblende are the green schists formerly called talcose. This is proved upon I., III., IV., in Vermont, and the Connecticut River range about Cornish. Similar beds are associated with the green schists in Marlboro, II., and the Ammonoosuc gold field. It seems more intimately connected with the green schists than with the gneiss—though often only the hornblende band will be present.

HURONIAN.

This name is used as a matter of convenience to designate all the various schists of chloritic and argillitic aspect overlying the gneisses and inferior to the Cambrian, so far as known. The terranes in Vermont and western New Hampshire are the ones that have been studied the most, and are the most valuable for the determination of age, because more nearly related to the original Canadian exposures called by this name. The superiority of the main Huronian belt upon the east side of the Green Mountains to the gneiss is obvious upon every section from I. to VIII. This view is confirmed upon II. to V. by the inferior position of the Halifax-Hartland range of gneiss.

The Connecticut River range is first seen in IV.; and from thence to Maine and Canada upon every section, it adjoins the hornblende schist or older gneisses, resting upon them. From VI. to XI. it is easy to connect the Green Mountain and Connecticut River ranges by a synclinal fold. Upon XII. and XIII. the direct connection is interrupted by granites and schists that seem to occupy the place of the Halifax-Hartland range, II.–V. The apparently overlying position of the Huronian west of the calciferous in IX. and XIII. is due to inversion, as proved by the occurrence of the fossiliferous Helderberg in similar position just to the north of XIII. in Canada (Lake Memphremagog). West of the Green Mountains the Huronian has its normal development in Canada and in the northernmost counties of Vermont, gradually diminishing in breadth southerly. It is not found south of VII. In southern New Hampshire the argillitic, quartzose and micaceous divisions predominate nearly to the exclusion of the chloritic schists, which with the characteristic dolomite is seen in Raymond and Derry. Steatite occurs in it at Francestown in the ferruginous slates and in the mica schists of Derry. All the schists referred to this series invariably overlie the gneisses.

MONTALBAN.

So far the assignment of the formations to their proper order has been comparatively easy; but the introduction of the word *Montalban* immediately suggests discussion. Inasmuch as the typical locality, as shown by the name, lies within our territory, the relations of the group must be briefly discussed. The name of "White Mountain Series" was first employed by myself in 1869 as a matter of convenience, in the discrimination of the crystalline rocks of the White Mountain region and their extension into Massachusetts. Previously our geologists had usually regarded these crystalline schists as of Paleozoic age, probably Devonian. My studies in the Ammonoosuc district enabled me to advocate their pre-Silurian origin, and hence to give them a special name. It was not intended to describe them as a *system* separate from the Laurentian, though the conviction had been more than once stated in public that these rocks would probably prove to belong to a more recent series. This name was also applied with this original signification to the gneisses of central Massachusetts in Walling and Gray's Official Atlas in 1871.

A different use of the equivalent term *Montalban* was proposed by Dr. T. Sterry Hunt in 1871. It was applied to a somewhat similar series of schists overlying the Huronian, and expressly stated to include the rocks called Coös group and calciferous mica schists in our reports. In our belief, he has included under this designation rocks of different age, the one a system below, and the other above the Huronian. He has not yet given us any proofs of the later age of the Montalban derived from the study of the group in its typical locality along the presidential range of White Mountain summits ; but the conclusions have been derived from general considerations concerning rocks developed in several states, provinces, territories and countries. There is a mica schist group later than the Huronian which will be noticed presently, but our observations, so far, have led us to believe that the feldspathic mica schist group of the White Mountains belongs to an older series, which might be called, as Professor Kerr has named it in North Carolina, the upper Laurentian. I have examined the gneiss of Lake Winnipiseogee in company with Dr. Hunt, who pronounced it Montalban. As this Lake gneiss has been shown above to be clearly older than the Huronian, and as it constitutes the axis of the Green Mountains—allowed by him to be thus ancient—it is obvious that the Montalban series, as defined by Hunt, embraces two groups of very different age. Hence the word has been used in two senses; but we invariably employ it in its original signification of pre-Huronian and post or upper Laurentian. The relative positions of the Montalban and Huronian have been sufficiently set forth in the New Hampshire reports.* They do not often come into juxtaposition. The examples cited in this report are from the northern part of the State.

MICA SCHISTS.

That there exists an enormous thickness of mica schist above all the rocks thus far described, especially in southern New Hampshire, is unquestionable. No author, who has devoted any attention to these groups, has suggested an inferior position for them. They may be called Silurian, Cambrian, or pre-Cambrian, according as each author is inclined to regard New England, very ancient, or on the verge of the Paleozoic. Such of the Rockingham group as is not referred to the Huronian belongs here, as shown in the Pack Monadnock Mountains (II.), Belmont, Gilmanton and Milton (V.) It constitutes the substance of several interesting mountains, like the Pack Monadnock, Temple and Lyndeborough west of the Merrimack, and Catamount, Fort, Not-

* Vol. II., p. 666.

tingham, Blue Hills, Blue Job, Hussey, Chesly and Teneriffe to the east. This orographic feature is paralleled in Mts. Monadnock, Kearsarge and Ragged of a possible older group carrying andalusite.

In the Connecticut Valley there are 10,000 or 12,000 feet of mica schists and associated rocks. Many of them are characterized by the presence of staurolite and garnet, and by this feature distinguished from a contiguous band of Cambrian clay slate. Its basal member is a quartzite, 1000 feet thick in Cheshire and Grafton counties, and frequently occurring in immense masses, as in Croydon, Grantham, Moose, Cuba and Piermont mountains. This rock resembles the Potsdam at the west base of the Green Mountains. In Washington county, Vermont, it may be replaced by a quartz schist often micaceous. The calcareous member occupies a great many square miles in Vermont, amounting to more than one-fourth of the entire area of that State. Logan regarded the Canadian extension of this band as of Niagara, or upper Silurian age. Dr. Hunt refers those rocks to the Montalban. Dana supposes the fossils at Bernardston, Mass., to be so connected with this terrane that they determine its age—being upper Silurian or Devonian. There are many difficulties involved in readily referring this entire series to the upper Silurian; but if any collector will bring in fossils from characteristic localities proving its Niagara age, there will be nothing in our interpretation of its stratigraphy inconsistent with such a discovery. The rocks are evidently the newest of any of the great systems of strata described in our reports. To elevate them to the upper Silurian would not carry any higher the chloritic, silicious or feldspathic schists already enumerated.

A brief discussion of the stratigraphy of the Coös and calciferous mica schist groups will show why they take their high place in our system, and illustrate the nature of the difficulties encountered in understanding the various dips and overturns of the strata in our field. These groups are not separated in our sections, as they are supposed to be essentially the same series, and their lithological differences such as result from local causes. The calcareous division lies chiefly in Vermont, and on XI., XII, XIII. west of a granitic area. The most eastern of the micaceous areas upon XIII., and a part of the same in V., are calcareous; all the other schists of this age in New Hampshire lack the limestone. There is no foundation for the statement sometimes made, that the staurolite and andalusite crystals have been produced by the proximity of granite or other igneous rocks at the time of their eruption. On the contrary, these igneous rocks are common in the calcareous areas where silicates are rare, and are absent where these cruciform minerals are abundant.

The natural relations of the micaceous group and the neighboring series are displayed upon VI., VII., VIII. Four series of rocks are disposed in a synclinal form: the micaceous group is at the summit, underlaid first by clay slate, second by the Huronian, and third by gneiss. The synclinal is complex, as is to be expected where elevating forces have been so active. Upon VI. there are nine, and upon VII. there are seven axes in the mica schist west of the Connecticut. So many groups in synclinal attitude must represent the natural order, and hence afford a basis for explaining apparent exceptions by overturns, faults and unconformities. Upon the other sections some one or more of these four groups are wanting, but those present invariably sustain the same relations to one another.

The calcareous division is widest where the natural relations of the four groups are manifested. To the south of VI. it has narrowed very much, and lies further east than the axis of the area northwards. This deflection has been occasioned by the elevation of the Halifax-Hartland range of gneiss, since it occupies the line of the central axis and has its northern end environed by the mica schists, as shown on V. Repetitions of this gneiss with the accompanying hornblende schist are seen upon I. and II., and there are others in Massachusetts. It would seem as if the clay slate and the Huronian were less constant than the mica schists and gneiss, since they do not appear along this range. The eastern band of the Huronian does not appear at all south of III., and its place over the gneiss may be taken by the hornblendic group. The absence of the clay slate alone is sufficient to enable us to assume the existence of an unconformity of the mica schist over the hornblende group. If the slates and Huronian were ever deposited over the Halifax-Hartland gneiss they have been subsequently removed by elevation and denudation before the deposition of the mica schists.

An examination of the more northern sections shows that older or eruptive rocks take the place of the Halifax-Hartland gneiss on IX., XII. and XIII. Upon IX. the granite has uplifted the adjoining strata so that if our order of the groups were determined by their succession on this line, we would call the micaceous rocks older than the slates, and the Huronian newer than the slates. The intrusion of this immense mass of granite gave an unusual dip to the mica schists, and being of unyielding character after consolidation, it has caused the more flexible slates and chloritic schists to be overturned upon both sides. The fundamental gneisses upon both sides seem to have been unaffected, except that they stand more nearly erect than before. Upon XII. and XIII. the granite is larger in amount, and accompanied by gneiss and Huronian—though scarcely shown upon the profiles—and the overturns are less conspicuous. Just to the north of XIII. the overturning of the Huronian is made more obvious by the presence of Helderberg fossils in strata dipping beneath it. The eruptive granites have penetrated fissures in the mica schists, so that the latter must be the oldest. Logan and the Vermont report regarded the granites as of Devonian age, because the disturbed rocks were thought to be upper Silurian.

It seems likely that these granites upon IX., XII., XIII., were connected with the uprising of the Halifax-Hartland gneiss in southern Vermont. If granite is derived from the fusion of schists, these bosses might have originated from the melting of rocks connected with that range deep down in the earth. Small areas of gneiss are connected with these granites upon the same axial line in the middle of the calciferous groups, and Selwyn finds them near the United States border in Canada; saying these "are apparently repetitions of the crystalline schists of the great Sutton mountain anticlinal to the northwest."* Granite also occurs there. The end of the gneiss range is connected with the granites upon IX., XII. and XIII. by an anticlinal line, seen upon every intermediate section. Upon VIII., X. and XI. this line is developed into a mountainous range, and the strata

* Geology of Canada; report of progress for 1879-80, page 5.

have very low dips. Thus the normal structure of this great basin is that of a synclinal with an anticlinal in the middle more highly elevated than the sides, and sometimes bringing up the underlying gneiss. This feature is not confined to the calciferous group. Dozens of similar folds can readily be seen upon our chart; and the discovery of this type of structure aids materially in the understanding of the New England folds. Authors have pointed out a similar type of basin in the Appalachian region of Pennsylvania and Virginia, as instanced in Taylor's section across the coal measures near Nesquehoning, Pa.

There is no great significance to be attached to the subordinate foldings of the calciferous group apart from this central line. In the middle of the area upon I. the underlying hornblende rock is brought up twice, and there are as many as five folds. Upon III. the strata are entirely monoclinal, and separated by a band of clay slate and a fault from the non-calcareous division. Along White River, upon VII., but not delineated in our figure, we have discovered a horizontal fault in this group, and there must have been an extensive shoving westward of part of the series. The effects of the dislocation have not been observed outside of the formation, nor for a distance of more than 500 feet.

MT. ASCUTNEY GRANITE.

Upon V. we have delineated two peaks of granite or syenite known as Mt. Ascutney and Little Ascutney. The igneous rock seems to have been erupted from below through one or more vents and spread over the rock adjacent, very much in the manner of modern lava. The importance of these facts leads us to give them more in detail than usual. All the varieties of rocks occurring upon the mountains are well represented in the Museum.

The summit of Ascutney lies near the southeast corner of Windsor; but portions of the mass are situated in the towns of West Windsor and Weathersfield. If the two mountains were just alike, the granitic area, when protracted upon a map, would resemble a pair of spectacles; as it is, the eastern higher area is four and one-half miles long, two and one-eighth wide, and the summit 3186 feet above sea level, while the base of the cone is 1200 feet above the sea. The western area is nearly circular, one and one-fourth miles in diameter, and the apex 1700 feet above the sea. The rock is often a hornblende granite—mica not being excluded—and the variety called *granitell* by Dr. Hawes, containing neither of the accessory minerals, is abundant in irregular patches in every part of the cones. Brecciated masses composed of the underlying stratified rocks are plentiful upon the west side of the larger mass and upon the smaller mountain; insomuch that one can easily believe portions of the granite have been made from the melting down of the fragments. The major axis of the "spectacles" is six and one-half miles long, at right angles to the course of the strata. Two stratified groups underlie the unstratified area. Most of the eastern cone is located upon the calciferous mica schist. The rest of it, and the smaller cone, lies upon gneiss. The gneiss underlies the mica schists at the same angle of dip, and we do not yet discover any stratigraphical axes in the latter. The relations of all these rocks appear upon section V. This granite seems to occupy a position similar to that of the gneissic anticlinals in Guilford, I., and Brattleboro, II., and is like Black Mountain in Dummerston.

There is no evidence of elevation of the schists in consequence of a disturbance, when the igneous mass came up. The same local variations appear upon the south that are visible upon the north side of the mountains. The mica schists manifest the presence of heat for a distance of 500 feet or more from the granite. The slates have been indurated so that they ring like iron when struck by a hammer. The limestones are sometimes calcined, and even glazed. Veins enter both the rocks from the granite for several yards distance. The gneiss is not altered at the contact line. It would seem, therefore, as if we had here examples of contact-phenomena, and only the later strata are affected, because the gneiss had been already made crystalline before the eruption of the granite.

The adjacent hill-tops of the mica schist country are approximately 1200 feet above the sea, which corresponds with the elevation of the base of the granite. On entering the valleys of erosion at the base of the granite, where small streams have removed considerable rock, it is discovered that the schists run under the igneous rock, certainly for 300 feet. Were a tunnel driven through the mountain, as through the celebrated Kammerburg of Bohemia, similar phenomena would be found; below a certain horizon—say 1200 feet—only the schists would be cut through, excepting the central plug of granite. This cone of granite has its base upon the floor of schists, while its height is about 2000 feet. It is to be regarded as an overflow of igneous matter upon the common rock of the neighborhood, and where it comes in contact with clayey layers they were baked; and where limestones were heated, the result was calcination, induration and glazing. Upon this view it is easy to understand why there should be an indurated belt about 500 feet in width enveloping the cone. The heated mass covered the surrounding country just so far, and that outer shell has since been removed by denudation.

My father, in the Geological report of Vermont, advocated the doctrine of the derivation of the granite from below; but supposed the cone continued to enlarge below the surface, and as he conceived of it as a liquid, suggested its enclosure by walls of schist, which have subsequently been removed by erosion. The prevailing modern view of the origin of granite is like this, except that it demands a greater degree of erosion. Says Prof. J. W. Judd in his work on volcanoes, 1881, p. 252, "The plutonic rocks, as we have already seen, exhibit sufficient proofs in their highly crystalline character, and in their cavities containing water, liquified carbonic acid, and other volatile substances, that they must have been formed by the very slow consolidation of igneous materials under enormous pressure. Great pressures, it is evident, could only exist at great depths beneath the earth's surface. Mr. Sorby and others have endeavored to calculate what was the actual thickness of rock under which certain granites must have been formed, by measuring the amount of contraction in the liquids which have been imprisoned in the crystals of these rocks. The conclusions arrived at are of a sufficiently startling character. It is inferred that the granites which have been thus examined must have consolidated at depths varying from 30,000 to 80,000 feet beneath the earth's surface," etc.

If Ascutney were the only granite mountain in New England, it might be easy to imagine an erosion of from 20,000 to 70,000 feet from around it; but what is true of this mountain must have been true of all New England and of the whole crystalline area of the Atlantic coast. A tract of country, say 1000 miles long and 300 miles wide, according to this view, has been covered by rock from four to fourteen miles in thickness, which has been eroded and transported by streams of water oceanward. If that were true, then our Atlantic coast line would have been several hundred miles nearer the old world than it is now.

Such extreme views are entirely unnecessary. Two other agencies may be called upon to explain the existence of compression—lateral pressure and the weight of the column of lava. Or, if it be necessary to believe that the liquids condensed so far below the surface, the igneous mass may have flowed upward through fissures without losing its inclusions, and kept them intact till within a few hundred feet of the light. If slides under the microscopes can hold drops of liquid carbonic acid restrained by the twentieth part of an inch of rock-wall, why could not several hundred feet of pasty cooling lava be equally effectual? At the surface the inclusions must have escaped into the atmosphere just as upon streams of modern lava, steam and vapors boil and disappear. After solidification, all these imprisoned vapors are firmly enclosed whether within ten feet or ten miles of rock. The original surface, now denuded, may have been a genuine lava. Some modern lavas, like granites, contain inclusions of condensed gases, and present many of the phenomena characteristic of the older rock; yet no one supposes that five or ten miles of rock have been removed from above them. The conditions of modern aqueo-igneous lava fusion are not very different from those invoked for the origin of granite.

It is easy to name other mountains of granite and porphyry, which so resemble Ascutney as to make one believe they will present evidences of a similar origin. Such may be found upon our sections—as Moose Mountain near the east end of V.; Green Mountain, Effingham, and the Ossipee Mountains in VI.; Pequawket in VIII.; and Starr King, near Jefferson, in IX. There are many others in the White Mountains.

Another class of volcanic ejections, probably older than the granites of the White Mountains, are largely developed upon sections XI. to XIII. in Vermont. The rocks are referred to the Huronian in our descriptions, and consist of stratified diabases, protogenes, epidotic and chloritic schists, fine-grained quartzites, etc. It is supposed they may have been metamorphosed from volcanic ashes and scoriae. Some of the mountains exhibit dome-shaped features, and therefore resemble volcanic piles much degraded. Selwyn calls the extension of these rocks into Canada the "Volcanic group," and was the first person to call attention to their resemblance to rocks of igneous origin in Great Britain and Australia. These views will commend themselves to those who are familiar with the lithological character of igneous rocks.

COLONIES.

M. Jules Marcou has published in the *Bulletin de la Sociéte Géologique de France*, 1880, a paper upon the Colonies in the Taconic rocks upon the borders of Lake Champlain. He thinks that the Taconic (Cambrian) rocks in the northwest part of Vermont contain lenticular masses of limestone, characterized by the presence of more recent fossils than those imbedded in the slates. Potsdam slates, for example, carry beds of limestone in which Chazy fossils are imbedded. It is supposed that these animals were prophetic types of those that were to be introduced more abundantly in the later periods. He subdivides these "Taconic slates" into the Swanton group, 800 metres thick; the Phillipsburg group, 1000 metres; and the Georgia schists, with *Olenellus*, 130 metres; total 1430 metres or 6465 feet. In the Vermont report all these beds are included in the Georgia group. Of these groups, the Swanton slates contain graptolites similar to those at Point Levis, near Quebec, and he believes that the Trenton limestones of Highgate Springs exist as lenticular masses imbedded in the graptolitic slates. The Phillipsburg group contain the lenticular beds called locally "dove-colored marble." Fossils of Chazy age have been obtained from them and described by Billings. The Georgia slates contain *Olenellus*, without any colonial concomitants. Below these several groups, Marcou locates the St. Albans slates, 1000 metres thick, and containing colonies of *Bathyurus* and an *Orthoceras*.

My own observations, made before the visits of Prof. Marcou to Highgate Springs, represent the Trenton as resting unconformably upon the Swanton slates rather than imbedded in them. Sir W. E. Logan published sections of the Highgate and Swanton rocks in the Geology of Canada at variance with the idea of colonies. Logan's view, as presented in an ideal section of the rocks near Montmorency, seems to afford the proper explanation of the present condition of the strata along the Champlain Valley west of the middle Potsdam range. He supposes an overturn of the east side of the synclinal of Cambro-Silurian, and a shoving westward of Potsdam rocks, so as to overlie them, sometimes in one way and sometimes in another. By such a motion the Potsdam may be made to overlie unconformably any of the Cambro-Silurian series, and even itself. At Lone Rock point in Burlington, section X., our catalogue represents the Winooski (Potsdam) dolomite as overlying this dove-colored Chazy limestone, which in its turn is above the black slate. The limestone is cuneiform in aspect, and we regard it as naturally folded beneath the Potsdam. The slates have been regarded by Emmons as older than the Potsdam because of their inferior position. It is so represented upon our sections VII., VIII., IX. This same slate skirts the west side of the middle Potsdam range all through the Champlain Valley. A partial sketch of the relations of these slates and Cambro-Silurian groups, at Snake Mountain (VII.), is given by Professor Dana from the notes of Rev. A. Wing.* It represents the Potsdam as crossing transversely the Chazy limestone, Trenton limestone and Loraine slates upon the steeply inclined part of the synclinal. The slates have been completely doubled upon themselves, so as to lie nearly horizontally beneath the red Potsdam sandstones. The explanation of this structure supposes first a fold of all the beds from the Potsdam to the Loraine. This becomes steeper and steeper and finally breaks. The rupture allows the Potsdam to remain with a small dip, while the limestones stand nearly vertical. As the pressure continues, pushing westwardly, the red sandstones are shoved towards Lake Champlain, so as to cover all the Cambro-Silurian groups. A slight irregularity in the motion, combined with denudation, has caused an angle of the sandstone to jut over the limestones, and reveal

* Amer. Jour. Sci., III., Vol. XIII., p. 413.

them in their natural succession upon both sides of the flat-topped Snake Mountain.

The Vermont report identified these black slates of Snake Mountain with the Utica or Hudson River beds. They seem to lie altogether upon the west side of the red sandrock range, while the Georgia group is commonly upon the east. These two slates may both be present, the former being often calcareous and full of white calcite veins, the latter being usually silicious. The veins appear only in the neighborhood of the fractures.

After reviewing the question of the "colonies," the presence of the cuneiform segments of Chazy limestone—whether injected into the slates or folded beneath the Potsdam—and the marked lithological differences in the slates, I am at present inclined to believe that future investigations will confirm the reality of Logan's theory—that the folding of the limestones and slates, combined with a subsequent shoving of the sandstones over them, will correctly explain the present position of the several groups upon the east side of Lake Champlain.

THICKNESS OF THE FORMATIONS.

For a thousand further details the reader is referred to the published and manuscript sections and catalogue, accessible to all inquirers at the Museum. I will close by adding a list of the several formations of New Hampshire and Vermont in their supposed natural order, with their estimated thicknesses.

	FEET.
Devonian Helderberg, near Memphremagog Lake,	200
Niagara group, at Littleton, etc.	500
CHAMPLAIN VALLEY.	
Loraine slate,	400
Hydro-mica schist (Taconic range),	2,000
Trenton limestone,	400 to 600
Black River and Birdseye limestone,	40
Chazy limestone,	400
Levis limestone,	600
Carried forward,	4,740

[*Feb. 13th,*

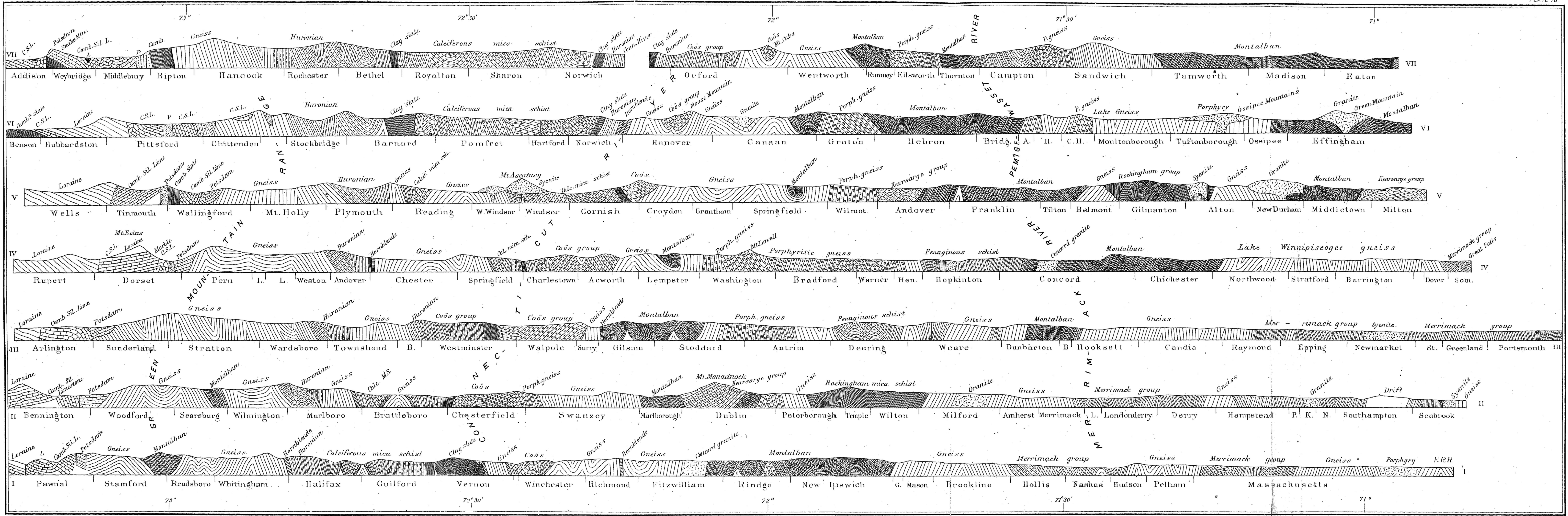
Brought forward,		4,740
Upper calciferous sandrock,		200
Lower " "		400
Fucoidal layer,		200
Potsdam sandstone, red,	500	
" " gray,	310	
" " quartzite,	1,200	1,200
Georgia slates,		3,000
Cambrian slates and schists,		4,000
Total of Champlain Valley,		13,740

CRYSTALLINE GROUPS.

Calciferous mica schist and Coös group,	12,000
Kearsarge group,	1,300
Rockingham mica schist,	6,000
Merrimack group,	4,300
Huronian,	12,000
Hornblende schist,	1,500
Montalban,	10,000
Lake Winnipiseogee (Green Mountain) gneiss,	18,600
Bethlehem gneiss,	6,300
Porphyritic gneiss,	5,000
Total crystalline,.	77,000
Grand total,	90,740

NOTE.—*In the American Museum of Natural History, the series of rock specimens illustrating the above described sections are placed on exhibition, together with colored diagrams of the sections numbered to correspond.*

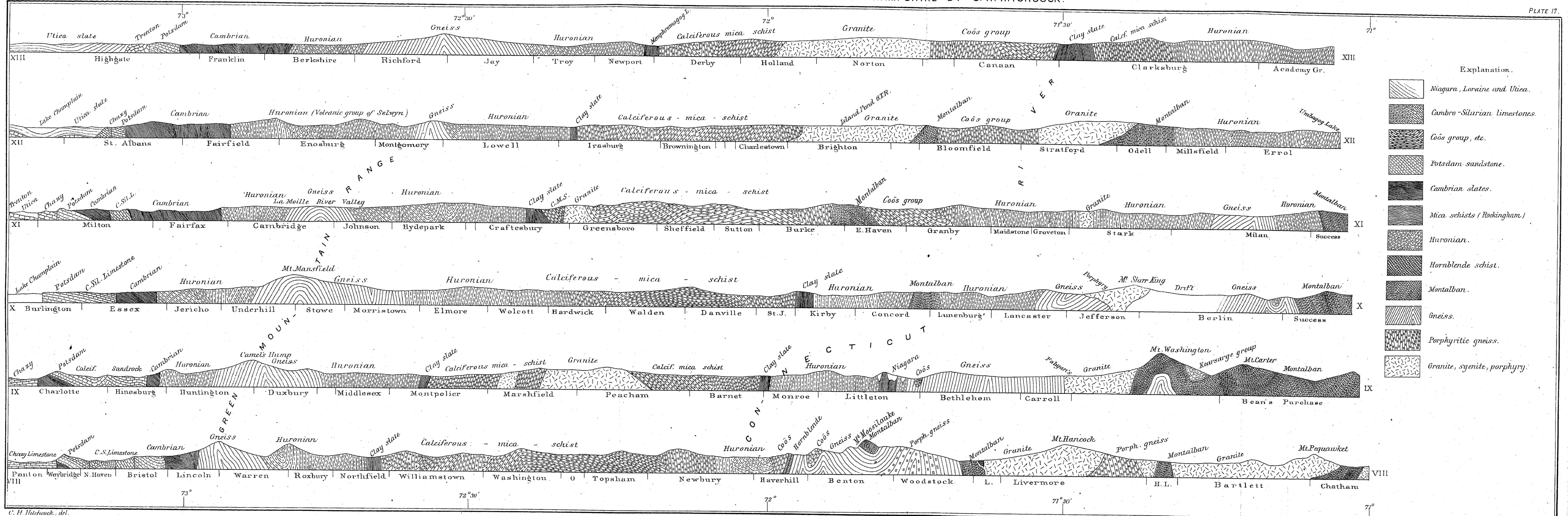
A SERIES OF GEOLOGICAL SECTIONS ACROSS VERMONT AND NEW HAMPSHIRE BY C. H. HITCHCOCK.



C. H. Hitchcock, del.

T. Sinclair & Son, lith. Phila.

A SERIES OF GEOLOGICAL SECTIONS ACROSS VERMONT AND NEW HAMPSHIRE BY C. H. HITCHCOCK.



C. H. Hitchcock, del.

T. Sinclair & Son, lith. Phila.

Vol. 1, No. 5.

Plate 18.