# New York State Museum Bulletin

Published by The University of the State of New York

No. 286 ALBANY, N. Y. July, 1931

NEW YORK STATE MUSEUM

Charles C. Adams, *Director*

# GEOLOGICAL PAPERS

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# GEOLOGICAL PAPERS

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## ILLUSTRATIONS

# THE FAULTS SYSTEMS OF THE NORTHERN CHAMPLAIN VALLEY, NEW YORK

BY

George H. Hudson

*Collaborator, New York State Museum*

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## THE FAULTS OF THE MERIDIONAL SYSTEM

The discovery in 1907 of meridional faults bounding the east and west sides of Valcour island, their parallelism with the Plattsburg and Beekmantown faults at the west, and the regularity of the distance separating any one from another led the writer to question whether this parallelism could be traced farther north or south, and whether these four faults might not be accompanied by a series of similarly placed faults both at the east and west.

The area chosen for study was that represented by the Plattsburg and Rouses Point sheets of the United States Geological Survey, and all heretofore recognized faults of this area were plotted thereon. In the attempt to trace the probable extension of these faults, use was made of the general direction of the faults themselves; of the main directions of modified fault scarps; of changes in dip indicating drag; of minor parallel faulting; the evidence of deep erosion on lines of special weakness; the character of outcrops and surface drift; and the preponderant direction of contour lines indicative of strike.

The faults as thus drawn are doubtless still incorrect in many details but they clearly express two important truths which must ever be borne in mind by students of this region.

One of these truths was clearly recognized and stated by a profound student of Adirondack geology. Cushing (1905, p. 406), in speaking of this locality, says: "Faults most abound and attain their greatest magnitude along the eastern border of this region. . . . The greater breaks of the region are meridional, trending from a north-south to a northeast-southwest direction. They therefore rudely parallel the strike of the Paleozoic rocks in the Champlain region, . . . The large majority of them downthrow to the east and with their rude parallelism divide the region into a series of strips or slices, this slicing apparently characterizing the bulk of the Adirondack region."

Our map then (figure 1) but makes manifest a condition already recognized by an eminent authority.

The second truth here shown is expressed by the uniformity of the course of the individual lines. Major breaks usually follow remarkably straight lines. Supposedly curved faults have been often so drawn because the observer has connected up some fault with one of its auxiliaries or with some other member of a parallel series. If a curve really exists there must assuredly be a reason for it that is well worth looking for. If any one of our series of submeridional faults is correctly drawn there is every presumption that its immediate neighbors were influenced by very similar conditions and that their courses would be subparallel with its own.

The large areas covered by glacial and recent deposits, including the waters of Lake Champlain, make the region represented in our map a difficult one to study. The difficulties are increased by the presence of numerous branch faults and by the fact that many of the main faults are paralleled by minor step faults which near the major break lie close together but which at some distance from this line are frequently many rods apart. The major breaks thus form lines of exceptional weakness and are usually covered, while the minor breaks, when placed at some distance apart, are less easily eroded and are frequently to be found in exposed areas. Unless this condition of the field is realized there is danger of connecting up two or more different faults of a parallel series and thus to plot a curvature which does not exist.

Attention to the multiplicity of these minor faults is of importance in other directions as will be seen in the following quotation from Cushing. In suggesting a possible difference in character between Pre-Cambric and Post-Cambric faulting he says (1905, p. 404, last paragraph): "The Paleozoic faults are fewer and of large throw, and so far as noted do not consist of numerous small slips along closely recurring joint planes, with the production of a multitude of slickensided surfaces." More detailed studies of Post-Cambric faulting may show that this statement needs modification.

The building of a dam across the Saranac river at Treadwell's Mills, about a half mile west of the area covered by the Plattsburg sheet, has allowed surplus water to flow over the western edge of the river's gorge in two different places and carry away trees, soil and shaly rock from the surface of a more resistant bed of Beekmantown age. Because of the special interest now connected with the question of step faults in the Paleozoic beds of the region we have published figures of both of these areas.

In Plate VII of Hudson's "Preliminary Paper Concerning the Faults Systems of the Northern Champlain Valley," the freshly exposed rock surface is seen to be cut by nine fissures running east of north, subparallel with the river's edge, and some three or four feet apart. In each case the eastern side of the fault has gone down. That we have here a true displacement of the beds is made manifest not only by the fact that we are viewing an original surface of deposit but also that the same displacements may be seen in still lower beds in the foreground. Note particularly fissures 6 and 7. The displacement of the steps there shown is slight and in no case amounts to more than a few inches. The effect of recent water flow over this area is well shown by the prostrate undergrowth in middle distance.

The more southern of these exposures is shown in figure 2 of this paper. Here one can better note the shaly character of the uppermost bed whose removal has brought the step faults clearly into view. Here too we find additional fractures toward the east. The block on which the figure is seated has gone down some three feet as shown by the displacement of the beds marked "a, b, c, d." Nearer the river the displacement was no doubt greater still, for the cliff edge is abrupt and we can see the opposite wall of the gorge over the tops of young trees below. Additional evidence for the prevalence of these parallel series of minor breaks will be given later.

Before taking up the fault lines in detail it will be proper to consider a few facts concerning these lines as a whole. We may notice first (figure 1) that the trend of the main waterways and shore lines in the vicinity of Isle La Motte and Alburg Passage, as shown by lines 6, 7 and 9, is N. 19° E. Following lines 6 and 9 down the map we shall see that they outline the general direction of the east and west shores of this portion of the lake and yet maintain a close parallelism with each other. This feature of the lake outlines would be still more impressive did our map include the marked convexity of the Vermont shore to the east of Grand Isle. On approaching the middle portion of figure 1, lines 6 and 9 take a nearly meridional direction but as we leave the latitude of Valcour island their trend seems rapidly to change to about N. 30° W.

In any region known to be modified profoundly by ancient faulting this strongly marked trend of contours becomes a very important guide to its study. If the region is one largely covered with water and glacial drift, this trend must be accepted as the main guide to the direction of major fault lines and particularly so if it can be shown that the movement of glacial ice over the region followed preglacial channels.

That the surfaces of the islands in Lake Champlain were not profoundly modified by glaciation is shown by the preserved shore lines of preglacial Lake Valcour (Hudson, 1909, p. 159–63) and by the preglacial open joints and joint caves of Valcour island (Hudson, 1910, p. 161–96). In a subsequent paper this evidence for slight modification of solid rock surfaces in this region as a result of former glaciation will be further strengthened by calling attention to still recognizable benches on Valcour island which were due to the action of interglacial seas. Lines 6 and 9 should then be accepted as guides to the general direction of all the local meridional faults belonging to Logan's Line.

When we remember that the region under discussion has several times been subjected to great thrusts from the east we shall see a reason for the westward bending of these fault strips, and when we recall that the resistance of the old Adirondackian headland, near what is now Trembleau mountain, registered its effects in the direction taken by the dike fissures we shall see an additional reason for the shape of the fault curves in the southern part of our map.

Then, too, if any area of deposit having northerly running fault planes with an *easterly dip* should subsequently yield to load in any one part more than in another, this yielding would of itself, at any horizon in its mass, carry westerly the line where the fault plane would cut the newly established level and thus turn a formerly straight line into a curved one.

Both of these causes have been at work in the region we are examining and we must expect that the fault lines south of Valcour island will be bent toward the southeast, while at the same time those north of Cumberland Head will be bent toward the northeast.

On, or very near, each meridional "guide line," with the exception of line 8, there are one or more known major faults which must possess extensions in the directions indicated. The very evident "slicing" here shown is but a part of that already noted by Cushing. How far this bent series could be extended westerly into the

Trembleau-Lyon Mountain embayment we do not know but the Saranac river, when it cut through the glacial dam at Elsinore and took its course easterly over new territory, soon found a broken up fissure near Woods Mills which abruptly turned it northerly and compelled it to follow this course for more than half a mile (see topographic sheet, Dannemora Quadrangle, U. S. Geol. Survey). We shall now leave this preliminary discussion and take up the meridional faults in order.

**Champlain fault** (figure 1, line 1). This fault lies for the greater part outside of the Rouses Point and Plattsburg quadrangle, and we will consider it but briefly. Cushing (1897, p. 572), on his geologic map of Champlain township, drew it as an unbroken and nearly straight north-south line that ran through Champlain village and ended nearly four miles south of the Canadian border. Its southern end was then extended by a line of dashes that reached the southern boundary of the township. This conjectural portion of the fault line was made to swing a little east of south.

In a more recent map Cushing (1905, plate 12, opposite p. 405) did not indicate the southern portion of this fault line although this map included a mile wide strip from the southern Champlain township border. This would indicate doubt on his part as to whether the former conjectural extension was a valid one.

There is no reason why we may not bring the southern extension of the Champlain fault more into harmony with the trend of the Champlain valley as shown by lines 6 and 9, or to the position shown by the line of longer dashes in figure 1. Could the line follow more closely the trend of the Tracy Brook fault (line 2), the wider spacing would suggest that another covered fault of this series might lie between the two faults mentioned. This question must be left for future studies.

**Tracy Brook fault** (figure 1, line 2). As drawn on Cushing's map (1905, plate 12), this fault for a length of two and a half miles runs N. 36° E. but at the northern end the trend is turned to N. 15° E. In 1897 Cushing indicated a north-northeasterly running fault to the southwest of Rouses Point and gave it conjectural extensions to carry it across Champlain township. The position as there drawn would place it a little westerly of the course of the Tracy Brook fault but as Cushing, in his later map showed but one fault where these lines would so closely parallel each other, we may infer that the southern extension of the fault southwest of Rouses Point was considered to be but part of the now better-known Tracy Brook fault. Connecting these lines we have a fault over ten miles long and running as a whole N. 25° E. but with a southwestern convexity at Chazy village that calls for explanation. If now we carry this fault farther southerly we cross the border of the Rouses Point quadrangle. If our guide lines may be safely used this fault would enter the Plattsburg quadrangle near Keeseville. About a mile or three-quarters of a mile southwesterly of Chazy village, and again at a point about three miles northeasterly, this fault is bordered on its western side by four different outcrops of Potsdam sandstone. Just north of Chazy village it is bordered on the east by outcrops of Trenton age. The downthrow there must be in the vicinity of 3000 feet.

**Little Chazy fault** (figure 1). Cushing (1905, opposite p. 406) represents this fault by an unbroken line indicating confidence in its location for a distance of a little over a mile. For a half mile near the southwest corner of his map the Little Chazy river runs along this line with upper Chazy beds on the left and middle Chazy beds on the right. Where most clearly discerned then the throw is not great. Cushing uses broken lines to show the probable course of this fault for two miles northeasterly but here he makes its course deviate toward the east more than the field evidence seems to warrant. In figure 1 of this text it has been made to run more nearly parallel with the Tracy Brook fault. The southern extension is also made to follow the general trend of the local faults of the meridional system and this again brings its course along another part of the Little Chazy river and for some two miles of its course. Continuing southerly the line soon runs outside of the Plattsburg quadrangle and crosses the Saranac river where we have seen the evidence of step faulting in figure 2, and probably returns again to the area under examination where it seems to be responsible for one of the Ausable Chasm faults.

**Beekmantown fault** (figure 1, line 4). In 1897 (p. 556) Cushing gives a map of the outcrops from Halsey Corners, Plattsburg township, north to the Beekmantown border. On this map he draws a wavy fault line, twice concave westerly, and running between scattered exposures of Beekmantown age on the west and of Chazy age on the east and labels it the Beekmantown fault. The northern end of this line runs N. 24° E. and would cross the Beekmantown township line nearly 0.8 of a mile west of Dead creek or about where the highway to East Beekmantown crosses the same line. A wriggling fault line is also drawn east of the outcrops of Chazy age and wholly on territory deeply covered by till and later deposits. This line as a whole is made to run N. 6° W. and is labeled the

Plattsburg fault but its sponsor, when in the field, evidently saw no reason for connecting it with the Beekmantown fault. In 1897 (p. 560) Cushing gives a map of Beekmantown township and on it traces a line with a double curve represented as following the western border of an area of Trenton beds (we shall soon see that there is no Trenton there) and separating them from Beekmantown beds on the west. This line is labeled "Beekmantown fault" although it begins on the southern border of the township at a point *a mile and a half east* of the crossing of the same border by the previously named "Beekmantown fault." The line of the new fault, proceeding northerly, runs at first N. 19° E. as does our fault line 5 whose position it at first apparently occupies, but it is soon made to turn to N. 58° E. and follows this new course for about three miles, crossing our line, and then turning N. 7° W. to recross line 6 and enter Monty bay near it.

Now we find the fault strip lying between lines 2–3 to be cross faulted seven times in the restricted area shown in Cushing (1905, plate 12), and the strip 4–5 twice cross faulted in Cushing's map of the still more restricted area just north of Halsey Corners (1897, p. 556). Doubtless cross faulting on strip 5–6 is responsible in part for a portion of the N. 58° E. curve of the so-called "Beekmantown fault" of Cushing (1897, p. 560), but evidently there seems to have been an idea that a fault separating Beekmantown and Chazy outcrops in the northern part of Plattsburg township must continue in its northerly course to keep all Beekmantown outcrops on its west side. There is no reason whatever why the Beekmantown fault of his map (1897, p. 556) should not continue northerly along the west edge of the wide band of Pleistocene deposits, shown to cross Beekmantown township in Cushing (1897, p. 560), and join the fault which he shows in 1905 (plate 12) to occur about three-quarters of a mile west of Little Monty bay and to run N. 8° E. Although as he shows no outcrops immediately east of this fault, and as he hesitated to make it cross the Trenton outcrop north of it, it may trend here as does our line 4 and be strictly a part of that line. It is doubtful if Cushing, after later studies of the region, would have drawn this erroneous "Beekmantown fault" as he did in 1897. Its easterly trend of N. 58° E. and marked western concavity just before entering Monty bay are abnormal features much more marked than those of the Tracy Brook fault, yet in 1905 (p. 407) he said of the latter: "A small portion of the course of this fault is shown on the accompanying map (plate 12). Just within the map limits its course is more nearly northeasterly than is usual with the great faults and more nearly so than is the case with most of the course of this special fault." This apology for the behavior of the Tracy Brook fault would not have been made if the author still believed that other great meridional faults of the region took still more erratic courses.

In 1905 (plate 13) Cushing abandons the wavy character formerly given the true Beekmantown fault in Plattsburg township, making it convex westerly and suggests a southerly extension which would closely follow our line 4. The northern end of his new line, however, is made to turn more abruptly easterly where it crosses the Beekmantown border and to run N. 38° E. instead of N. 24° E. as before. The line to Kenyon brook represents a true and straight fault with no Chazy on its western side. It is the rest of this line that was erroneously placed by Cushing. The more northerly trend given in his earlier map was used by us for our fundamental scheme. North of Beekmantown it would have been better to let the conjectural course of this fault follow more closely the curves of the faults at the west. This we shall discuss later. It is well to note all changes in position and in direction which Cushing himself made, for these are due to difficulties presented by the field.

In tracing the probable direction taken by the true Beekmantown fault (our line 4) in its course south of the Saranac river, the general trend lines must be our guide. This fault probably runs between the pair of outcrops of Beekmantown age near Salmon river and also between the more southern pair of outcrops of the same rock just north of the Ausable river. South of this the contour lines will indicate the direction taken and the line would cut Trembleau mountain where the contours show greatest structural weakness. The greatest throw of this line is in southern Beekmantown and there brings upper Chazy beds down to the level of Beekmantown. The downthrow is on the east side and must be over 1000 feet.

Passing northerly we find that the course of the true Beekmantown fault makes it encounter the easternmost meridional fault drawn in Cushing's plate 12 (1905, opposite p. 406) and deviate but little from the direction of the fault as there plotted. Still farther to the north it would run along the axis of King's bay and along the marsh to the west of Catfish Point. At Stony Point we apparently find Canajoharie beds on the east and Trenton beds on the west. The line then enters the lake channel between New York State and Vermont. Is there not here sufficient evidence that the Beekmantown fault, as now extended, is one which may be traced from the immediate vicinity of Rouses Point to Trembleau mountain, a distance of some 38 miles, and that in its course it closely follows the trend of this portion of the Champlain valley?

**Plattsburg fault** (line 5). Cushing in 1905 (plate 13, opposite p. 408) extended this fault southerly to cross the Saranac river as well as northerly to join the Beekmantown fault. From the Saranac river to Bluff Point he indicated the continuation of the Plattsburg fault by a line of dashes but from this point to the southern extremity of his map he indicates it by an unbroken line. On this map then he has shown this meridional fault to reach a length of more than ten miles. Before suggesting an extension of this fault line we desire to make a few corrections as to its true position. We will use first two outcrops in the city of Plattsburg which do not seem to have been noticed by visiting geologists.

Just north of Cornelia street the line cannot lie much farther west than Lafayette street for the 160-foot contour line, in its more northerly portion, here lies along a low cliff line of exposed Chazy rock. The fault, on the other hand, can not run east of Waterhouse Street for Trenton beds are there exposed in the river bank where this street would cross if extended northerly. There is evidence there also for close proximity to the fault line. Across the city of Plattsburg then this line runs nearly parallel with and slightly to the west of Williams street. Its course there is practically N. 1° E. and its downthrow on the east amounts at least to 1000 feet. From the western edge of the area of Trenton rock at the mouth of the Saranac river as indicated by Cushing in 1905 (plate 13) one can pass westerly for at least three-tenths of a mile and still find Trenton beds exposed in one or both banks of the river. The fault must cross the river at least a quarter of a mile farther to the west than the position given it in Cushing's map, or near the middle of the arch of the oxbowlike course which this fault here compelled the river to take.

In indicating the extension of this fault southerly Cushing uses at first a line of dashes but from Cliff Haven to beyond Valcour station he uses an unbroken line and calls this part of the line the "Bluff Point fault." Here the Plattsburg fault cuts Beekmantown beds. Just west of the railroad track at Bluff Point there is a small outcrop of this formation on which probably the basal Chazy rested, though the railroad itself may occupy a minor parallel fault line. Cushing's easterly swing of this line at Cliff Haven was apparently made in order to bring the fault line nearer the Chazy exposures encountered at "The Bluff" and which, from here to a point about three and a third miles southerly, lie on the east side of the fault. This easterly swing was unnecessary. The exposures at "The Bluff" dip easterly and on the western edge of the mass very weak beds of Lower Chazy age are exposed. This has caused an easterly retreat of the cliff edge from the fault line and this retreat was made still easier by a cross fault which brought down shaly Trenton beds on the north and thus further weakened the northwest corner of the southern fault block and also exposed it to strong scouring by glacial movement. The distance from the exposed Chazy beds to the fault line can not be judged from evidence of small displacements parallel with the fault line, for while at Treadwell's Mills we saw these minor faults closely bordering the major one we shall soon have ample evidence that they may be nearly a half mile distant from the greater displacement. For instance a bare rock cliff or fault scarp, indicated on the Plattsburg topographic sheet by the closeness of the 160 and 180 foot contours where they cross the northerly road (Boynton avenue) leading west from Cumberland bay, lies a quarter of a mile west of the Plattsburg fault as Cushing drew it in 1905 (plate 13). In the face of this cliff and parallel with it there was recently visible a minor fault with a throw of a few inches but with a very noticeable down drag of the bed edges on the west side. The front containing this fault has since been blasted away but the fault scarp itself, rising some 30 feet above recent lake deposits at its base, might be readily taken for the west wall of a major fault. As the rocks here dip northeasterly and are very resistant there can not have been so great a recession of the cliff base as that just south of Cliff Haven. If, then, Cushing could draw the fault line a quarter of a mile to the east of the more northern cliff there seems to be no reason why he might not have drawn it still farther to the west of the more southern cliff.

From Plattsburg southerly the general trend line becomes an excellent guide. The lake shore from south of the Ausable river to Port Kent lies close to this line and seems to have been influenced by it. This fault may cross Trembleau mountain where Woodworth (1907, p. 23–24) saw the "trench a few feet wide" that indicated a postglacial slip. Schuyler island, just below our map area, seems also to be the summit of an eroded fault block lying between the Plattsburg and Beekmantown faults.

For some miles north of Plattsburg there are no outcrops that closely bound the Plattsburg fault on the east. If in this position of its course it maintained any parallelism with the Beekmantown fault it would lie along that manifest line of greatest topographic weakness—the north-northeasterly marsh line of Dead creek. This guide would bring us to a position a mile east of East Beekmantown. That Cushing recognized a fault here is shown by the position and direction of the southern portion of the erroneously called Beekmantown fault as he indicated it in 1897 (p. 560). This was drawn to run about N. 28° E. and at first it showed numerous outcrops of Cumberland Head shales on its eastern side. The Dead Creek marsh line was there left some distance to the west of the fault line but in 1905 (plate 13) this "Beekmantown fault" line was drawn to cross the Plattsburg township northern boundary more than a half mile *west* of Dead creek. The southern end of the fault called "Beekmantown" by Cushing in his 1897 Beekmantown map was thus left at a spot more than a mile east-northeasterly of the northern end of his Beekmantown fault of 1905 (plate 13). He never connected these loose ends which were separated by the Dead Creek marsh.

In his later map he drew a conjectural fault along the main axis of the Woodruff Pond marsh. Had he similarly treated the Dead Creek marsh he would have had a line lying nearly halfway between the unconnected faults just discussed. In other words he did recognize the true Plattsburg fault in southern Beekmantown but drew it too close to the outcrop of weak and much disturbed Cumberland Head shales. The true fault line was deeply eroded by glacial action and this carried away not only a considerable amount of the shales on the east side of the fault but also much from the weak beds of Upper Chazy which are found on its western side near the township border. We carry then the Plattsburg fault along the deepest line of this glacial channel and attribute Cushing's connection of the two faults just above the Plattsburg township border to the influence of a preconceived easterly trend for the Beekmantown fault on the one hand and the marked loss of outcrop and cliff edges due to erosion, on the other, for these might be taken to indicate a westerly turn for the Plattsburg fault. The many cross faults of the region also helped to increase the field difficulties.

Farther north in Beekmantown the line of the Plattsburg fault runs over a low and covered territory and nowhere in a distance of 15 miles cuts a surface higher than 40 feet above lake level. At the north end of Monty bay we again meet Cushing's greatly curved fault of 1897. We claim this conjectured fault (but not its trend) as evidence for the position of the Plattsburg fault in this locality. We have no other guides to fall back upon save the general trend line and those of the not far distant Tracy Brook and Little Chazy faults. Northerly from Little Monty bay the line, as drawn, runs along the western side of the Lake Champlain channel, parallels the Point au Fer coast and enters the westernmost, northerly running marsh of Alburg township.

**Woodruff Pond fault** (line 6). We find the presence of this fault recognized by Cushing in two places. In 1905 (plate 13) it is indicated as cutting off Cumberland Head by a line running N. 19° E. Our general trend lines would indicate a course of N. 14° E. This difference is small. The new trend however carries the line northerly along the rather straight west shore of Treadwell bay, and back of Point au Roche along a natural depression where it soon meets the erroneous 1897 Beekmantown fault and makes exit at Monty bay with the same 1897 fault. We shall meet this older curved fault of Cushing's again when we come to take up the system of cross faulting. We shall there see just why the great easterly bend was drawn. Here we desire to claim the easternmost portion of this bend for our more regularly running Woodruff Pond fault.

Continuing northerly this fault line would run just west of southern Isle La Motte and quite close to the more northern half of the west shore of this island. This straight bit of coast, more than two miles long and rising to 80 feet and more above the level of the lake, is probably an eroded fault scarp.

Southerly from Plattsburg this line runs close to the high and nearly vertical fault scarp on the lake shore at Bluff Point and also close to the fault scarp at the Valcour island lighthouse. The channel separating Valcour island is evidently due to an eroded fault line and the trend lines of the region would most certainly indicate this line as belonging to the Woodruff Pond fault.

Valcour island has some interesting evidence to give for this line and it will also emphasize the need of caution in locating lines of major displacement where there are likely to be many minor displacements running parallel with them. It will be seen that in connecting up the local evidences of such displacements one might easily be led to use a single wavy line instead of a series of more nearly straight and parallel lines. We shall refer now to figure 20 (p. 79–80) and in its study use, in part at least, the decimal system. As the meter is but 3.37 inches longer than our yard we may stretch the yard a bit in our imagination or use it in a generous manner. Where for purposes of comparison we shall need to use the English system, we shall give the English equivalent. The map referred to possesses marginal coordinates and we shall use these (connected by a hyphen) more accurately to determine position.

We have divided the Chazy of the Champlain valley into seventeen zones based on changes in conditions of deposit, due to alternate sinkings and fillings of the Champlain basin. The exposures of these zones are shown in figure 20. In referring to them the letter Z is used, the period following it is a decimal point, and the two figures represent the height of the middle of the zone above the Chazy base, expressed as a per cent of the total thickness of the Chazy formation. The first six of these zones (Z.05, Z.12, Z.21, Z.31, Z.36, Z.38) are practically identical with the A1, A2, A3, A4, B1, B2 of Brainerd and Seely. Their B3–B5 we divided into five instead of three zones. Their C1 is our Z.73 but above this we recognize five zones instead of two. Whenever we refer to these zones the symbols expressing them will at once give a fairly definite idea of their horizon in the formation.

That a north-south fault lies between Valcour island and the mainland at the west is indicated first by the fact that the easterly dipping beds on a line running from the shore of the island at Q-27 to the shore at G-27 measure 1000 meters and expose Chazy beds from a zone whose middle is 0.87 above base (Z.87) to a zone whose middle is but 0.61 above base (Z.61). The total thickness of the beds crossed by this line is 67.96 meters. Should we continue across the channel, the same rate of exposure would bring us down to the weak beds of Z.38 but instead of these we really find those of Z.31 (the A4 of Brainerd and Seely). This indicates the presence of a fault in the channel with a downthrow on the east side of 40 meters (some 131 feet). That a fault runs close to the western side of the island is shown by a comparatively sudden increase in dip of 5 or more degrees at both Dove and Arnold Points (F-5 and G-33). These two points also present true fault scarps and by connecting them with a straight line we shall find it to run close to the rock shore (low cliff) at F-12; to pass by slight parallel faulting at F-13; through the depressed contour at F-15; along the rock ledge at G-19; across the neck of the little peninsula at F-20; along a fault scarp at G-22; and from here subparallel with the rocky coast of the island for over 600 meters. This fault of small throw to the east has another close to it at G-25 where in a glaciated trough a short portion of the actual contact may be seen. Another slight and parallel fault is indicated by the clean-cut cliff line at C-12-13-14 and the glaciated cut through the isthmus at D-15-16-17. The western cliff face of the lighthouse peninsula is indicative of still another parallel or auxiliary fault of this series.

We feel that we have abundant evidence to indicate that the Woodruff Pond fault is really an extended break which closely follows the trend of the series and which is also spaced in harmony with those already noted. The throw is not great and in no visible portion of its course does it present a formation on the right that is distinct from that on the left.

**Cumberland Head fault** (line 7). Brainerd and Seely (1896, p. 311) give a map of Isle La Motte and indicate three faults on its eastern edge. The southernmost of these is drawn as curved and made as a whole to run about N. 30° W. At Holcomb Point there is a marked increase in dip of beds and Jordan Point is cut off by a fault whose north end is indicated as running N. 27° E. A syncline here seems to run N. 10° E. In the face of the next cliff to the north a fault is indicated as running about N. 5° E. To the east of the last fault we find small exposures of downthrown Canajoharie shales. At Jordan Point an eastern strip of Canajoharie shale rests against Chazy beds at the left. Here all the Lowville, Black River and Trenton beds are faulted out. Perkins in 1904 (plate opposite p. 113) gives a map of this area. On page 125 (*loc. cit.*) he says "About forty-five rods south of Jordan Point there is a curious brecciated limestone which is thrust up against the more regular Chazy beds. There has probably been some faulting here and more or less disturbance. The breccia is a very dark mass including fragments, generally angular, of a compact, fine-grained, bluish limestone." The eastern side of Isle La Motte is very evidently due to the presence of another fault of our meridional series. Our line 7 here runs about N. 20° E. and enters Alburg township along the weak Sucker Brook line.

Taking the course of the trend lines and proceeding southerly we find that the new line will closely parallel the Point au Roche headland from the lighthouse to the southern end of Long Point—two and three-quarters miles of rather straight coast which in turn is paralleled by the general trend of its own contour lines. Still passing southerly and keeping parallel with the Plattsburg fault our new fault line will enter Martin bay, where there is very marked evidence of disturbance. It then crosses Cumberland Head along a line of topographic weakness and exits about a mile to the northwest of the lighthouse. The fault here is seen to consist of several parallel breaks—a condition also to be noted along eastern Isle La Motte. As a continuation of this line would pass close to the east of Valcour island we should look there for such evidence of its presence as may be found.

Returning now to our figure 20 and crossing Valcour island from Dove Point easterly we find some indications of a minor fault along the east edge of Reef bay. The reef at Danger Point, if exposed by low water, would carry this shore line more than a hundred meters farther north. Southerly we encounter cliff edges at I-8 and again at H-13. At Reef bay 19.2 meters of soft rock are covered, most of which is of Z.78. At the south end of the island this zone is but 15 meters thick. The extra thickness of the weak beds at Reef bay may possibly be considered as indicative of faulting. The evidence however is not conclusive and we have to pass nearly 1300 meters east of the Dove Point fault before we encounter the first of a new series.

Along the north-south fault scarp in Spoon bay at S-8 we find slickensided walls with a thick vein of calcite between them. Along the cliff face on the south shore of Spoon bay are several minor faults with very small throw. One of these can be traced southerly along the line separating T from U-11-12 and shows in a few closely parallel calcite seams where it enters Sloop bay. Less than a hundred meters east of this is a group of minor faults with calcite fillings and these have been instrumental in determining the position of a little cove near the east side of U-10; the glaciated ravine running from thence southerly to Paradise bay; the north cove of this bay; and the moulin, with horizontal discharge, figured in Hudson, 1910 (plate 21). About fifty meters east of this is a fault which has a throw of about one meter, the eastern wall being raised. This also can be followed over the head of the peninsula by the contour lines and shows in the north cliff of Paradise bay where the preglacial cavern with a fallen roof is encountered. This cavern was figured in Hudson (1910, plate 1 [third recess from left], 2 and 22). Soon after this we meet with two greater displacements which indicate our close approach to line 6 and to these we shall give more attention.

Spoon island (figure 3) appears as if it had been sliced off from Indian Head and pushed 100 meters or more to the north. The rocks of Indian Head are capped by the hard and resistant beds of zone .61 while under these are the weaker and somewhat shaly beds of zone .55. The dip is southerly and the faulting off of the Spoon Island block, which went down about 18 meters or 20 yards, brought the weak underbeds of this block where waves could no longer act on them though the rest of the south shore of Spoon bay continued to break down and recede southerly. Where now we have a channel about 25 meters wide, which has been excavated along this fault line (or lines), there doubtless existed in preglacial times, one or more north and south running caverns while overhead a natural bridge probably connected Spoon and Valcour islands. A view of this narrow channel as it appeared in 1898 is shown in figure 3. A part of the glaciated west wall of the little island was shown in the 1910 paper, plate 4. The fault here has an increase in throw northerly. Along the eastern wall of Spoon island another fault plane shows slickensides and a calcite filling but the amount of displacement is not easily determined.

In Sloop island we have another example of the surface shifting of beds due to faulting. The beds of Z.73 here exposed are the same as those of Tiger Point but apparently they have been moved 420 meters northerly. The inclination toward the south of the beds at both localities would indicate that the total downthrow between the Tiger Point escarpment and the west wall of Sloop island must be in the neighborhood of 76 meters or some 250 feet.

We have noted this new series of step faults, as we approach line 7 from the west, in some detail because of the interest in their close parallelism; their increasing downthrow on the east side (with one or two minor exceptions) and their very evident effect on the topography of the eastern side of Valcour island. We shall place the major fault line, number 7, just to the west of Sloop island and give it here the direction of the series as shown by Spoon island and the contours already noted at the west of it. South of Valcour island the soundings given on the local chart of the United States Coast Survey must serve in part as guide. Our line very nearly parallels what would be the western underwater contour of 200 feet depth.

We have already noted that line 7 consisted of more than one parallel break at both Isle La Motte and Cumberland Head. At Valcour island we have at least two parallel faults of considerable throw and here these are paralleled on the west side by several faults whose throw varies from a meter to less than a centimeter. The strip there disturbed by the Cumberland Head fault appears to be about three-tenths of a mile wide. That of the Woodruff's Pond fault, bounding the west side of Valcour island, had a similar width. Of Valcour island there remains then about six-tenths of its width which is not faulted by the meridional system but should the cliff line at I-13-14 prove to be also a fault line the undisturbed strip would be considerably narrower. It is highly probable that all the main lines of this system are paralleled by faults of small throw and that all undisturbed strips between the faults will be limited in width to a mile or a little less.

**Champlain Basin fault** (line 8). From the Little Chazy fault, where it crosses the Saranac river, east to the Cumberland Head fault the distance is about 5.2 miles. As four fault strips lie between their average width is here 1.3 miles. From the Cumberland Head fault to the westernmost extremity of Grand Isle at Wilcox Point the distance is about 2.4 miles. We shall for the present consider that in this covered portion of the Champlain basin there lies another fault of the meridional system and that its northern end runs along the marshy tract of Southern Alburg.

**Alburg Passage fault** (line 9). This line we have drawn along Alburg Passage and southerly through Pelot bay. A weak line in rock structure is here very plainly indicated. Parallelism with our other lines would carry this line outside of, but parallel with, the west coast of Grand Isle. We found the east and west shores of Valcour island plainly to be influenced by marginal faults and the long and fairly regular trend of the west shore of Grand Isle is strongly suggestive of a coast also cut back from a fault line.

For the more eastern faults of this series see Hudson, 1923 (p. 88).

Before taking up the system of cross faulting it seems proper again to call attention to the difficulties presented by a field more than nine-tenths covered by water and postglacial mantle rock. This difficulty is experienced in all portions of the field. We have seen that it has led authors to vary both form and direction of fault lines previously drawn, for Cushing did this in his 1905 paper. The earlier lines therefore did not pretend to exactness in all instances but were to a certain extent suggestive both as to location and direction.

Would it not be practical in a new field to designate the direction of a covered fault line by some such formula as "runs between N. 8° W. and N. 19° E."? Then too where the true bearing of a fault line was unknown the drawn line might give its probable direction and this line be crossed, in x form, by a pair of short and inconspicuous lines which would indicate the possible limits of error. Had our faults been so recorded this paper might have been both presented and received with greater confidence.

## THE EAST-NORTHEAST SYSTEM OF CROSS FAULTS

This system appears to have had its origin at a date later than that of the meridional system. Its faults do not attain such length, parallelism, uniformity of spacing, regularity in direction of downthrow, or on the whole so great a displacement as those of the older system. Their effect on topography is much less pronounced and glacial erosion and deposit, because of their direction across the glacial path, has served only still further to obscure the evidences of their presence.

In the northern and more covered portion of our field these faults have been but little noticed by visiting geologists. Wherever faults of this series have been observed to cut the shores of Lake Champlain they have invariably given rise to small coves or bays, and such signs of weakness in a coast line whose main outlines should reflect glacial modification may be taken as suggestive at least of the presence of a possible cross fault. As the members of this system were briefly given in Hudson, 1923, we will here begin our more detailed descriptions with the Mooney Bay fault.

**Mooney Bay fault.** Impressed by the fact that the downthrow of the meridional faults in northeastern New York was on the lake side and finding Trenton from Cumberland Head north to Mooney bay, Cushing, in 1897, believed that the exposures along the shore from this place to North Point were also of Trenton age but of a character not duplicated elsewhere in the Champlain valley. He therefore cut off these eastern rock exposures by his curved fault running from near Dead creek to Monty bay, for this line gave him everywhere Beekmantown on the west and supposed Trenton on the east.

In 1916 the writer spent two days going southerly over the exposures from North Point to Mooney bay. To him all the rock outcrops along this shore line were of Beekmantown age and could be duplicated in minute details of lithologic character at other Champlain valley exposures of known Beekmantown such, for instance, as those on the Saranac river at Treadwell's Mills. Fossils were exceedingly rare but in an old quarry about a mile south of North Point an Ophileta was found. At the point itself one layer showed many fragments of small forms which obtained a temporary footing during the deposition of the beds. Specimens of these sent to Doctor Ruedemann were found to be fragments of immature shells which he believed to be of Beekmantown age.

At Mooney bay the shear zone of a great westerly running fault was clearly to be seen in the cliff face and from here southerly the rocks belonged to the Cumberland Head shales. The displacement recognized by Cushing, about a mile to the southwest of Point au Roche and estimated by him to amount to "probably 2000 or more feet," (Cushing, 1897, p. 561), is on an east-northeasterly running fault line and this makes it exit at Mooney bay.

The direction of this fault may be determined with considerable accuracy. Just north of Beekmantown is a road running easterly across Allen brook and just past this brook the road runs over a small elevated boss of Beekmantown rock. Continuing on this road a mile and a quarter easterly we arrive at the "state road," which here runs N. 13° W. to Ingraham. Before joining the "state road" we climb a hill of Cumberland Head shales whose beds are either very steeply inclined or else have been given a nearly vertical fissile structure due to near-by faulting. Turning now northerly on the state road we soon leave a road-cut in the Cumberland Head shales and enter one passing through Beekmantown beds. The latter outcrop forms a boss rising to a height of a little over 120 feet above lake level and trending N. 65° E. Cushing evidently noticed this outcrop and intended to make his "Beekmantown fault" run along its southern edge before he again turned it northerly. We have already given the evidence for its exit near Mooney bay.[1] If now we connect Mooney bay with the southern end of the isolated boss of Beekmantown age, which we met just after crossing Allen brook, we shall have a line running about N. 63° E. and passing between the Beekmantown and Cumberland Head exposures on the state road. The downthrow is on the southern side. There are evidences for a line of topographic weakness where we have extended this fault line across North Hero township.

That so profound a fault as the Mooney Bay fault should have hitherto escaped notice (save in one place and there as a bend in a northerly running fault) is not at all remarkable. The several glacial planations which the Champlain valley has received all moved across its east-west fault lines and reduced or buried their fault scarps. It therefore becomes necessary to suspect others and to indicate their possible positions. The Mooney Bay fault may also turn out to be one of special interest for there seems to be evidence that a small portion of its line is now covered by Cumberland Head shales which

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[1] This fault was visited in 1927 by Dr A. W. Quinn and the writer. Doctor Quinn found the true fault line to cut the lake shore just north of the Mooney bay indentation. Undoubted Canajoharie shales in place were found against the yellowish weathered beds of Beekmantown with their large-conchoidal-fractured surfaces. This area of exit is usually covered and should be carefully looked for.

were thrust over it from the southeast. Shifting this fault line a little northerly, as the new evidence requires, will leave more of these shales on the southern side of the fault.

It will also be of interest to note that the faulted strip lying between the Monty Bay and Mooney Bay faults is of the nature of a horst, possibly supported by an easterly buried extension of the Lyon Mountain outlier. The areas north and south of the horst have dropped into less resistant basins. The horst itself was probably faulted by four members of the meridional system (lines 3 to 6 inclusive) without suffering any great displacement, but none of these faults have been traced across it. The lines indicated in our figure 1 may yield some evidence. Along line 7 or 8 it was profoundly broken, leaving Beekmantown on the west at the south end of Isle La Motte and Canajoharie shales on the east at North Hero.

**Bay St Armand fault.** Cushing (1897, p. 556) gives a field map of the region between Kenyon brook and Halsey Corners. On this map he indicates a cross fault as concave southeasterly but on the whole running N. 67° E. Its influence on topography is not very marked but it may have been instrumental in determining the trend of the southern shore of Bay St Armand and in causing the very evident line of weakness which separates North Hero from Grand Isle. Where drawn by Cushing its downthrow is on the north side and is probably not over 100 feet.

**Cooper Bay fault.** On the north of Cushing's map (*loc. cit.*) and between the Beekmantown and Plattsburg faults we find beds of Upper Chazy age. The dip here is north-northeasterly and on going south we meet in succession the beds of Middle and Lower Chazy age. On passing the Bay St Armand fault we again find beds of Middle Chazy disturbed by a minor branch fault but followed by Lower Chazy beds just at the bottom of the map. Turning now to Cushing's map (1905, opposite p. 408) we find the Lower Chazy beds extended to the south bank of the Saranac river, although south of the Normal School building (represented by a black cross) there are no Chazy exposures in the colored area. A mile south southwesterly from the Normal School we again find beds of Middle Chazy age. The dip here is about 6½ degrees and approximately N. 60° E. Just north of the Normal School the average dip is N. 50° E. and its amount varies from 6 to 12 or more degrees, the greater dip being nearer the Plattsburg fault. We have here evidence of another cross fault which must run near the east-west bend of the Saranac river where it is bridged by South Catherine street. Evidence of this fault is visible in the disturbance of the Trenton limestone on the lake shore just south of the abandoned ore dock. Looking for topographical features which were perhaps due in part to this fault we may note that Riley brook, from a point a mile south of Morrisonville (Dannemora Quadrangle), has three branches that for some distance take a marked easterly direction—the middle branch follows this direction for more than two miles. Still farther east we find this line limiting the southerly extension of Cumberland Head. On Grand Isle it would enter the cove north of Gordon Landing, from there pass easterly through Pearl Swamp, and make its exit in Cooper bay. Because of the more marked easterly trend of this fault line and because of lack of evidence for the exact location of its New York State portion we have not continued it across Grand Isle. We shall, however, temporarily call it the Cooper Bay fault. At Plattsburg its downthrow may be as much as 400 feet and this is also on the north side.

**Rockwell Bay fault.** Cutting the lake shore at Cliff Haven is an easterly running fault with a still more profound downthrow on the north. The south wall is of Middle Chazy age and the north wall of Trenton. The displacement here must amount to some 600 feet and its effect on the local topography is quite pronounced. The strike as determined at Cliff Haven is close to N. 77° E. and this would carry it easterly to Rockwell bay. Seven miles westerly it can be seen cutting Potsdam in the bed of the Salmon river a mile west of Schuyler Falls. If it extends to Rockwell Bay it is over twelve miles long. Because of its interest we shall deal with it more fully.

The fault dip at Cliff Haven (lake shore) is 55 degrees northerly and the Chazy or south wall shows an interesting slickensided surface where the latter has not been too long exposed to the elements and therefore flaked off by frost work. The preserved grooves and scratches show that the last movements had a horizontal component which either varied in its intensity or from which temporary relief was secured through yielding. Some very definite curves were engraved on the Chazy wall as a result. One would be tempted to credit the scorings to glaciation were it not for the fact that the exposed surface forms one wall of a wave and frost excavated cavity which was very recently filled by gouge and broken Trenton from its north side. The lines of the slickensides recede from the lake on ascent. If the scorings were made while the Trenton side was falling then the Trenton fault block moved easterly with reference to the Chazy. Such a movement on the side of the weaker beds could not take place if the latest fault movements occurred during any period of easterly stress.

If now we examine the Trenton beds as shown in Hudson (1917, figure 4), we shall note that locally they dip westerly while the dip of the Chazy is on the whole easterly. Some rotation is thus evident. This westerly dip of the Trenton would indicate that the fault displacement increased westerly and decreased easterly. Over how much of the fault line these conditions prevail we have at present no means of determining.

We may ask why the Trenton beds should here show any rotation. About one-third of a mile easterly the block was limited by the Woodruff Pond fault. This should have dragged down the edges of the Trenton beds and made them dip easterly. About a mile to the west the Trenton beds should have been dragged up against the Plattsburg fault and this also would have made them dip easterly. Their westerly dip near the Rockwell Bay fault where this is exposed at Cliff Haven must be due to easterly thrust. The massive Chazy beds the better resisted this thrust, but the weaker Trenton beds yielded. If this be true the latest movement of the local Trenton must have been upward and westerly over the Chazy wall. The movement which had previously been that of a normal fault was thus reversed. We may have normal, thrust, bythrust, overthrust, reversed and rotary faults. These types are all present in the Champlain valley. A fault dip of 45° may be taken as a boundary separating thrust from overthrust faults. The term "reversed fault" should be used only where the movement of a fault has been truly reversed. There must be many such instances of a reversal and the next fault which we are here to discuss seems to give us an additional example. Before passing to this, however, we should note a few additional items of interest concerning the one we have been describing.

If we pass a little northerly along the Trenton we shall find portions of the older flexure produced by its downward movement. Next the Chazy wall is a thick sheet of "gouge" or pulverized rock due to the grinding of the fault walls. Just north of the gouge and near the land surface is a minor flexure due perhaps to local settling or to a temporary return of the normal downward movement. The Trenton shows additional minor faults, two of which may be seen in Hudson (1917, figure 3). The mass also seems to have been again faulted a short distance northerly or just before reaching the little stream which here enters the cove.

If one will take a boat and row around the point of the cove for a short distance southerly he will note that while along most of the northerly running cliff edge the strike is nearly parallel with the shore line it swings easterly as the fault line is neared. The north edge of the Chazy block seems to have been at one time lifted or dragged up by the Trenton. The minor discrepancies here noted are due in every case to the action of forces that not only varied both in direction and intensity but in geologic age as well. If we ever hope to read correctly the geologic history of the Champlain valley and adjacent territory we must attend to every scrap of evidence that nature has left us. We shall come to see that nothing is insignificant.

Those who may visit that part of the Rockwell Bay fault exposed at Cliff Haven should note also the evidence for rapid westerly recession of the cliff face on the Trenton side. The overhanging edges of turf and forest growth shown in Hudson (1917, figure 3) are eloquent witnesses of the changes now going on, and indicate clearly the reason for the present cove and its high protecting cliff on the south. The locality offers a very interesting field lesson on the effects of faults on shore lines and on surface contours. It is also one of those rare places where one may see the actual contact of the two fault walls. Because of the inherent weakness of fault lines such contacts are usually buried and brought to view only through mining operations.

**Beauty Bay fault.** Brainerd and Seely in 1897 (p. 309) gave a map of Valcour island and there represented a fault crossing its north end with a strike of N. 73° W. Raymond (1906, opposite p. 572), marked this fault "Big Fault" and gave it the same strike. The contact is nowhere seen but if the upper edge of the fault scarp be taken as a guide the strike is but little over N. 70° W. If this strike is used and the line extended easterly it will enter Sawyer bay on South Hero. On our map (figure 1) we have given it a slight concavity northerly in order to carry it just outside Kibby Point. If the line be straightened it will cut the 200-foot contour on the New York State shore at the point of its greatest, local westerly extension. On South Hero it would also run very near the line which separates Black River beds on the south from Trenton on the north. Its displacement on South Hero can not be great, for according to Perkins' map (1902, opposite p. 102) it has, near Sawyer bay, Black River beds on both sides. At Beauty bay, Valcour island, the displacement is about 350 feet with the downthrow on the north, for here the beds of Z.93 are brought against those of Z.55. Where it exits at the west shore of Valcour island it has a displacement of not over 80 feet, for the base of Z.73 is there left almost at the level of the top of Z.61. As this rate of decrease westerly is about 80 feet in a thousand we should expect to find the displacement reduced to zero at about the place where it would reach the Woodruff's Pond fault. We may have here an example of a rotatory fault which crosses but is confined to the strip included between the Woodruff's Pond and Cumberland Head faults. If the cross fracture was primarily due to thrust from the east we should expect it to be continued across other fault strips both at the east and west. The local rotatory motion might be due to the same thrust acting on one or both of the fault blocks here formed by cutting across the older meridional system. This fault is the one already noted as showing what is possibly an additional example of reversal of motion, for although the downthrow is on the north side, the older Chazy beds on the south side have been dragged up as is shown in the more westerly portion of its fault scarp (figure 20) where the present surface shows a decided southerly slope away from the cliff top and where the dip is about 8 degrees S. 46° E. The cliff face is slightly concave northerly but this probably should not be interpreted as indicating a curved fault. The cliff edge had been breached in several places by stream and frost action before the last glacial invasion and up the more central of these breaches the ice found an easier passage over the cliff. On the other hand if the present alignment of the cliff was due to glaciation the eastern and western extremities should show also the effect of ice movement passing by them and this flow should have cut them back and given them longer lines showing a northern convexity. It will be proper to note that if we take the westernmost extension of the 200-foot contour line where it crosses the three tributaries of the south fork of Silver stream, about a mile and a half north of Lapham (see Plattsburg topographic sheet), and connect this with the sharp easterly sinus of the 120-foot contour line near the southeast corner of Sawyer bay, South Hero, we shall have a line which, if extended easterly, would follow a line of topographic weakness on South Hero and run along the northern boundary of the Black River outcrop which is northwest of South Hero village. This line would run N. 73° E. but, if we trust the contours as drawn on the Plattsburg topographic sheet, it would cross Valcour island about 250 feet north of the fault line as drawn in figure 20. This we might take as evidence for a northerly concavity but the evidence is not conclusive enough to allow us to be at all positive about it. We shall soon see, however, that under the conditions noted such a concavity should be expected.

About 200 meters south of this fault and closely parallel with it is a minor shear zone at R-6 with a displacement of a few centimeters. This slip we may credit to the Beauty Bay fault.

**Sloop Bay fault.** We have indicated this fault as entering Twin bays (figure 20) just north of the peninsula separating them. West of this it seems to be responsible for the south face of the rectilinear base of the Lighthouse Bluff. Easterly it cuts the coast line just south of an exposure of rock belonging to Z.61 but the peninsula at the south belongs to Z.53; at J-18 it shows a pronounced fault scarp on the south; at M-17 it has a decided fault scarp on the north; at R-16 it makes its exit in Sloop bay through an old ravine filled with glacial deposits. At no point in its course across the island does it reveal any outcrop in its path. This line of evident weakness, with disturbance on both sides of it, runs N. 75° E. and parallels the outer portion of the north and south shores of Sloop bay. An undoubted fault exists here and it is one of particular interest on account of its very marked rotatory character. Along the western portion the downthrow was on the north and the displacement in the vicinity of 75 feet. At M-17 it developed an auxiliary running N. 61° E. On the north side of the fault this auxiliary had its northwesterly wall dragged up but like the Paradise Bay auxiliary the disturbance died out rapidly toward the northeast. The southwestern extension of this cross fault was responsible for a very prominent and apparently concave fault scarp on its southeastern side. Near O-17 there seems to have been no vertical displacement but in Sloop bay a downthrow on the south side appears which increased easterly and was responsible for the dragging down of the southeastern wall of the Paradise Bay auxiliary. Evidence for this rotatory movement is clearly seen in the westerly dip of the horst block on the north of this fault and the easterly dip of the large block at the south.

Brainerd and Seely credited the island with a syncline running through its length. There is a slight sag near the middle of this horst block but both the north and south blocks of the island are practically free from any traces of a local meridional syncline.

Before leaving the Sloop Bay fault we should note that the Spoon Bay fault probably joins it near C-20 and is perhaps another of its auxiliaries.

**Valcour Cove fault.** The study of this fault will serve in an impressive way to bring out the fact that the cross faults of the Champlain valley, although as a whole so concealed by drift or water as to enable them to escape notice, are important elements in its structure and, although their exact location may be imperfectly known, they must be looked for if one is to make any comprehensive study of the region. The need of a map such as that presented in 1923 (plates V and VI) will here receive further justification.

Brainerd and Seely (1896) gave a geological map of Valcour island and at its southern end showed three of the nine auxiliary faults indicated on figure 20. These authors recognized the fact that these auxiliaries die out as they pass northeasterly for they indicated none of them as reaching the east shore of the island. Cushing (1905, plate 13) shows but one of these faults but makes this one cut also the east shore, and near its exit places Middle Chazy beds on the south directly against Upper Chazy beds on the north. Such a condition does not there exist. Raymond in 1906 shows two auxiliaries entering the south shore but dying out rapidly as they pass northeasterly.

Now the marked elevation of the south end of the island terminating abruptly in a long line of cliff, such as that shown in Hudson (1909, plate 6), would be of itself suggestive of faulting. The increased northerly and northeasterly dip as the south cliff is approached and the rapid dying out of the small faults as they pass away from this cliff are additional evidences which should lead a field geologist to suspect here the presence of a major cross fault. Taking the general direction of the Valcour island south shore as shown on the Plattsburg topographic quadrangle of the United States Geological Survey and extending it westerly for less than a mile we shall find that it enters a little bay on the New York State mainland and here connects with a long-known fault of large throw in which the northern or Chazy wall rests against the Beekmantown formation at the south. Starting at Fault Point on Valcour island and extending the same line four miles easterly we shall find that it connects with a fault on Providence island which also brings Chazy rocks on the north against Beekmantown beds on the south. Now regardless of the fact that the Valcour Bay and Providence Island faults as mapped by Brainerd and Seely were given a direction more nearly like that of the Valcour Island auxiliaries one should be led to conceive that a major fault really exists along the line as determined above. Such a conception should lead to a search for further evidence. Let us then examine a 1000-meters length of this line as drawn on our figure 20.

Starting a little south of Arnold Point and going easterly we may note, in the cliff at I-33, a small parallel fault. Proceeding about 600 meters farther easterly we closely follow the south cliff and pass the ends of three auxiliaries, the first of which was recognized by Brainerd and Seely. Our line now enters the island itself but it does so in a clearly indicated natural recess. This recess is caused by a deep glaciated groove now filled with drift and neither fault face is visible. The nearest rocks at the north however belong to Z.55 while just at the right or south we find the lowest sandstones of Z.05. The displacement where the fault enters is about 170 meters with a downthrow on the north. Brainerd and Seely made their easternmost auxiliary enter here and no doubt credited this displacement to their fault. If, however, we will continue along our line we shall find that it soon makes exit in another recess also indicated in figure 20. Here again is a deep glaciated groove or channel filled with boulder clay and pleistocene deposits. A bit of the eroded and glaciated south wall of the fault is there exposed. At this point the highly inclined top beds of Z.12 on the south are brought up to the level of the nearly horizontal beds of Z.61 on the north and the displacement is about 140 meters. The clear evidence of profound faulting in this second cove, or at the southwest end of Pebble beach, has heretofore escaped notice. The Sandstone Point mass, thus cut off, contains all of the Lower Chazy beds seen by Brainerd and Seely on the island. Here is exposed their Chazy A1 and A2, (our Z.05 and Z.12), which they measured as 138 feet in thickness. Over this mass was originally deposited "about 200 feet" of sediments belonging to Brainerd and Seely's A3 and A4 (Z.21, Z.31), but no trace of these beds is to be found anywhere on the island. The Sandstone Point mass rests directly against beds on the north which are above the actual middle of the Chazy formation.

Before passing farther easterly on our main line we may note in figure 20 the auxiliary which determines the line of Pebble Beach and enters the cliff along another well-marked and glaciated fault channel, there also filled with boulder clay and pleistocene deposits and showing a part of its glaciated south wall. This auxiliary has heretofore escaped notice but at the northeast end of Pebble beach it shows beds of Brainerd and Seely's B1 (Z.36) brought up to the level of Z.61 at the north—a displacement on this auxiliary of some 75 meters. Brainerd and Seely suggested that Pebble beach was caused by the loss of material south of their easternmost auxiliary but it is really due to the loss of the narrow edge of the wedge where the Pebble Beach auxiliary met the Valcour Cove fault.

Taking again the main fault line we shall find between the east end of Pebble beach and Fault Point that all exposures are just north of it and in many places they show minor evidences of the main fault. Off Fault Point there exists an extensive and but slightly submerged wave-cut shelf of a preglacial sea. The waters over this shelf are so shallow as to cause considerable annoyance and some damage to small pleasure craft in the hands of persons not familiar with the locality. On October 24, 1908 the waters of Lake Champlain were low enough to bring portions of this shelf above water and a photograph taken at that time was reproduced in Hudson (1909, plate 7). Specimens from the submerged beds are easily obtained at low water and are of the siliceous sands and calcareous muds belonging to Z.05, while the cliff itself is of beds belonging to Z.61. The displacement here is about 190 meters or over 600 feet. The row boat in the plate referred to is resting between outcropping edges of the sandstone and the figure holding the vertical oar is directly over the fault line. The beds south of the fault dip gently north-northeasterly but the beds of the cliff dip northeasterly at an angle of 25 degrees. No better evidence for the existence of a major transverse fault could be desired and but for the fact that the more level and older beds on the south side are usually water covered the fault would long ago have been recognized. My attention was first called to the dip of these under-water beds by my son (Dr E. M. Hudson) in 1906.

The main fault line now leaves the island, the rather straight shore line from Fault Point to Hebertella Point being, in all probability, due to another auxiliary which runs parallel with the six shown at the west of it.

Some of the Valcour Island evidence for this heretofore unrecognized fault lends itself readily to illustration and because of its importance locally, as the introducer of elements of error in the sections of Brainerd and Seely and of Raymond, and because of its major importance in demonstrating that a system of transverse faults runs completely across the northern Champlain valley, we deem it proper to introduce a few figures from photographs of the locality.

In figure 4 (looking northerly) we have a view taken from the ice about 1903 which includes all the exposures south of the fault line. It shows also the outer portions of the two partly filled-in coves at "a" and "b" where the Valcour Cove fault makes its entrance and exit. The numbers on the rock exposures represent beds of our section "A" as recognized and measured for future publication. Two closely placed auxiliaries, to be described later in this chapter, are responsible for the fault scarp here shown. This wedgelike piece, cut from the southern block of the Valcour Cove fault, is cross faulted eight times and the position of four of these faults is indicated at "e," "f," "g," and "h." These minor breaks of themselves yield evidence that we are dealing with a narrow wedge. A westerly thrust of the north block of the Valcour Cove fault allowed fault "e" a downthrow on its western side. In figure 5 fault "f" (nearer the edge of this wedge), shows a small downthrow on its east side but this movement introduced very decided effects of drag, throwing the beds into an open letter "S" curve. This closer view of the cliff face shows also the boundary between the sandy beds of our Z.05 and the muddy limestones of Z.12, the latter beginning with bed 22. Brainerd and Seely began their A2 some ten meters farther down in the section or with bed 17 of our section A.

In figure 6 (from photograph taken in 1900) we are looking westerly at the eroded edge of the Sandstone Point fault wedge. At the right of this the Valcour Cove fault makes its exit. Here the fault line has produced a pebble and boulder-covered recess. Back of this, but hidden by low bush growth, lies the fault channel now deeply filled with till. This filling is easily found in the field. In this recess eroded portions of the southern and recently uncovered wall of the fault show unweathered polished surfaces and striae.

In figures 7 and 8 we show the eastern continuation of the fault scarp from O-30 to Z-31. The numbered beds are a part of our section C. Just off C39 in figure 2 the slightly inclined beds of the Chazy A1 of Brainerd and Seely are under water. There they meet the highly inclined beds of B4 of Brainerd and Seely. The portion of the fault scarp shown in these two figures possesses a number of cross faults of very small throw. These figures also show the cliff top to have been cut back by wave action during one of the interglacial periods and before the formation of the lower beach line of Lake Valcour (Hudson, 1909).

The forces producing the local east-northeast system of cross faults must have left evidence in a vastly wider area than that discussed in this paper and it is doubtless true that the last breaks were influenced by lines of weakness that had been developed in Pre-Cambric times. Since mapping the fault systems as shown in figure 1 the author has met with several generalizations which appear to him to place well-timed emphasis on the need of a more comprehensive vision of conditions existing during the earliest geological eras. Reaching farthest back into time we find a discussion concerning "The Juvenile Shaping of the Earth" in Chamberlain (1916, ch. VIII, p. 159–225). Based on a study of the most primitive systems of folding now traceable by geologists we have the exceedingly valuable paper by Ruedemann (1919).

Nearer to our local problem in time and in geographic area is the report of Martin (1916). There (p. 8–9) he has pointed out that we must modify the theory of Van Hise that the Adirondacks are "an eruptive core of gabbro surrounded by a fringe of various gneisses," dipping away from the center, for "If there is any single structure which may be said to pervade the whole Adirondack area, it is rectilinear, not circular in character. The trend towards this more modern generalization is seen as early as 1895; Smyth then pointed out (1895, p. 246) that the parallel belts of associated gneisses and limestones on the northwest flank of the Adirondacks extended long distances parallel to their strike, that is, northeast-southwest; and in the same year Kemp, 1895, p. 242–43) emphasized the fact that this linear structure occurs also in the interior of the mountains." This rectilinear character we find is also characteristic of the northern Champlain valley and such moderate curves as we have given our cross faults may be modifications of the older rectilinear system.

Concerning this curvature we should note that where the hade is northerly, as it is clearly seen to be with the Rockwell Bay fault at Cliff Haven, the sagging of the cross strips would make the fault line convex southerly. A similar sag of the strips on either side of the Beauty Bay fault would indicate that its hade runs also northerly. South of the Valcour Cove fault we find Beekmantown at Valcour Station on the mainland, at Valcour island, and at Providence and Stave islands near South Hero. Here is evidently another Beekmantown formation horst with its base resting against the northern part of the Trembleau Mountain headland. There is little sag on this cross strip and the Valcour Cove fault runs in a remarkably straight line from Valcour Station to Providence island.

Returning now to the Beekmantown horst which lies north of Treadwell's bay, we find that the two cross faults south of it appear to be convex northerly. On the north of the same horst, as we enter the northern sunken basin, our first two cross faults show southerly convexities. When hade and sag, or uplift, are taken into consideration it will be seen that a more exact location of some of these cross faults would give lines in part sinuous, and in most cases broken where they crossed the meridional strips. It will also be seen that where the Valcour Cove fault passed line 10 (1923, plate VI), it could not possibly continue as there drawn unless the hade was practically zero. The Canajorharie beds, however, may have been placed here by overthrust.

The two great sinking basins separated by the Beekmantown horst should also show their influence on the lines of the meridional faults for, with their easterly hades, they must have given these lines an additional westerly convexity not due to thrust. Here we have a partial explanation of the excessive bends southwest of Chazy and the westerly convexity of the visible line of separation of Chazy and

Beekmantown just south of this horst—the line which led Cushing to carry his Beekmantown still farther easterly and so cross the Plattsburg fault. It should be noted here that no actual fault lines have yet been traced across this Beekmantown horst. We have called attention to one at Treadwell's Mills, and Cushing carried a fault across it which ran southerly from Monty bay. Because of the two sunken basins we should expect the faults crossing the horst to be of small throw. Search, however, should be made for them and if they exist their lines should show a dislocation somewhat like that indicated in our figure 1.

## THE NORTHEAST AND SOUTHWEST SYSTEM OF AUXILIARY FAULTS

The faults of the meridional system we found to be paralleled by many small minor faults near the major lines. So far as we have been able to observe this parallelism is not so characteristic of the transverse faults, although a few examples have been noted. In marked contrast with this tendency toward the formation of a parallel series we find the Sloop Bay and Valcour Cove faults to possess a system of branch faults or auxiliaries. These are particularly noticeable along the latter fault and we will treat of them more fully.

The westernmost auxiliary of this fault to be found on Valcour island was apparently first recognized by Brainerd and Seely. It is easily seen from a little distance off shore and is here illustrated in figure 9. A thin sheet of gouge lies between the two walls. The rocks on the right have been much tilted because they lie close to another auxiliary about 100 meters easterly. The stronger beds at the left were not influenced so much by drag, but close to the fault plane a weaker bed is strongly bent upwards.

The next two auxiliaries have not heretofore been noticed unless represented by dotted lines on Raymond's map (1906, opposite p. 527). If this be the case, however, the two faults drawn by Brainerd and Seely are there omitted. The influence of the first of the pair is, however, clearly manifest by the contours and the second has caused a slight notch to be formed in the coast line. Neither shows the clean single fissure of the first of the series. Where they exist the cliff wall is much broken. The throw in either case is small.

The fourth of this series, going easterly, is the second of Brainerd and Seely's drawn faults. Its entry on the coast line, if it be a fault, is in the filled trough made by the Valcour Cove fault. The auxiliary following this is drawn from the contours. If there are two auxiliaries here they are both of small throw and influence the contours but for a little distance inland.

The next or Pebble Beach auxiliary is one which may be clearly recognized by its filled trough and by difference in bed characteristics and dip along its northeasterly extension. We have already noted that its displacement where it first makes exit on the beach is nearly 250 feet. A view of this exit is shown at "a" in figure 10. This auxiliary, however, does not now cross the Valcour Cove fault. Had it sliced and displaced the beds on the south side of this fault it would have been noticed heretofore. It will be seen that this is the second fault to enter the Pebble Beach hiatus and vitiate the measurement given by Raymond for his Section A as represented by the shaded area in his map (1906).

The only evidence for the next and last auxiliary of the series is the sudden change in the trend of the Valcour island shore line (see figure 20) and the parallelism of this bit of coast with the auxiliaries already drawn. A drop on the eastern side of this line would have placed weak Upper Chazy beds in a position to be carried away by erosion.

Turning now to the south side of the Valcour Cove fault line we show in figure 11 two closely parallel auxiliaries as they appeared under the exceedingly low water condition of October 24, 1908. We are here looking northeasterly. The figure in middle distance is holding an oar directly over the fissure separating undisturbed Beekmantown beds on the right from the Chazy lower sandstones on the left. The exposures of this Beekmantown bed above water are marked "B." In the immediate foreground this fissure is covered by Chazy blocks fallen from the cliff. During the low water of any season, however, a large Beekmantown area can be here distinguished under water by its dip, which is gently north-westerly, and by the pronounced orange-cinnamon color of its bed surfaces. The beds of the cliff dip northeasterly at an angle of 25° and the contrast in dip and color, under water, is striking. This outer line is paralleled by an inner line and between the two, at the time the photograph was taken, was an uncovered fault strip of the lighter colored sandstones of Z.05. These were broken but the exposed points of rock indicated by arrows were *in place* in this strip. The throw of this outer line is not more than 15 feet. With the inner line the case is very different for here our bed A19 on the cliff should have its base 22.6 m. above the topmost Beekmantown. The total throw here then is 74 feet and this rapidly increases as we pass along the cliff northeasterly. The dragged-up edge of the upper and outer portion of bed 18 is easily seen and shows the close proximity of the old fault line to the new cliff face. Note also beds 16 and 17. The more distant portion of these lines, as shown by the two oars standing up in the fault fissure in middle distance, is very straight but in the immediate foreground these lines begin to bend toward the left as shown by inner edge of Beekmantown block with hat on it, and by the position of the umbrella thrust in the left hand fault fissure. Following out the lines to the distant cliff we find no trace of the presence of these faults. Just where the throw would be greatest the fault is lost simply because it was an auxiliary of the Valcour Cove fault and had its greatest throw at its point of origin on the parent fault. Here we have the condition of the Pebble Beach auxiliary presented in reverse order.

We should note, however, that a nearly vertical open fissure shows plainly in the middle of figure 7, and that this fissure also shows in figure 11 where it may be seen high up in a distant cliff and directly above the head of the man holding the oar. It seems to lie too far to the east to be a portion of the fissure of the southern auxiliary and it also seems to have been developed after the Pebble Beach auxiliary had been dragged up to its present position.

Believing that these auxiliaries have something to say concerning the relative age of the cross faults, we desire to show that the condition seen on the north side of the Valcour Cove fault at Valcour island was to be found elsewhere on both sides of this fault and for possibly its entire length.

Brainerd and Seely evidently did not see the Valcour Cove fault on the New York mainland, but they saw there one of its auxiliaries running southwesterly. On Providence island also they missed the significance of the narrow covered neck shown in the drawing by Ezra Brainerd and reproduced by Perkins (1902, opposite p. 139). They did, however, see one of its parallels at the north of the neck and four of its north-southwest auxiliaries; two on the north side and two on the south. The southern pair are also connected by an additional cross fault on Brainerd's map. Prominent as the Valcour Cove fault has been in its influence on the topography of the region, it has heretofore escaped detection for two reasons: first, because of its eroded and glacially filled shear zone; and second, because of attention attracted by its numerous auxiliaries. This fault then is one of peculiar interest to all engaged in field work.

Returning to our Sloop Bay fault as shown in figure 20 we will note that it also has two auxiliaries on its southern side and possibly two on its northern. The easternmost of these is responsible for the high and straight wall on the northwest shore of Sloop bay; the trough back of Dawn Point; the cliff line bordering it at the northwest; and for Paradise bay. This fault is not shown on Raymond's map (1906) but appears on that of Brainerd and Seely (1896, p. 309). In Sloop bay at S-15 we may see a bit of northwestern, slickensided wall. Here its displacement is a little over 20 meters (about 66 feet) but in Paradise bay it approaches zero. If this fault line continued to Q-17, we should there find a displacement of some 120 feet or more but instead of this there is no displacement save at the deeply buried Sloop Bay fault. South of this fault the Paradise Bay fault does not exist. Here is a case where one would be tempted to draw a curved fault and cross the island with it to the cliff south of Twin bays. Should one do so, however, his curved fault would reach zero again near M-17. He would miss that greater cross fault which has permitted the south block to dip easterly and much of the north block to dip westerly. Could one but grasp the scheme of things, the peculiar behavior of the Paradise Bay fault would lead him first to suspect the presence of the Sloop Bay fault, and then to look for evidence of its existence.

The Spoon Bay fault has the appearance of an auxiliary from the Beauty Bay fault. At R-9 we seem to be on the summit of a gentle quaquaversal produced by uplift and the outcrops on the shore at S-8 are the oldest to be found on any part of the island north of the immediate vicinity of the Valcour Cove vault. As we near the ravine at R-11 the southwesterly dip is increased. On the south side of this ravine the beds belong to Z.55 and are more nearly level lying, although dip and strike both vary in passing short distances. Here is evidently the shear zone of a fault which runs close to N. 57° E. Its downthrow seems to have been on the southern side. It is small, however, and there seems to be evidence of a late reversal of movement.

Two other very small faults accompany this. One of these may be seen in the cliff face at S-9; the other next the cliff edge at T-10. The latter *shows its western termination.* In the short distance exposed its northern side shows an increased downthrow easterly.

The two fault blocks which lie either side of the Spoon Bay fault show, with reference to their outer boundaries, a strong positive movement and together they may be looked upon as having the nature of a slightly faulted and divided horst block. How far this division extends westerly can not be determined for everywhere the line is covered by mantle rock. It seems, however, to have been caused by a westerly thrust, and its greatest displacement to exist northeasterly.

The evidence for numerous auxiliaries for the transverse faults of this region of the Champlain valley is as full as could be expected. A more careful study of other island shores and bare areas will doubtless increase their numbers.

## CONCERNING POSSIBLE AUXILIARIES OF THE MERIDIONAL SYSTEM

No member of such a conjectural system can be demonstrated on Valcour island. The line drawn to cut across the neck separating Lighthouse bay from Twin bays, however, might be drawn to run in a more northwesterly direction, and so also with the line drawn near the western head of the Lighthouse bluff. Then again there is an under-water line of cliff which runs northwesterly from the head of Tiger Point and enters a small cove near the middle of the north shore of Sloop bay. This cove is now filled to the water line with glacial deposits and a huge, limestone boulder. On the shore line there is a large mass of limestone which is also partially buried. It shows a markedly different dip from the rest of the shore but it may be another erratic. There seems to be no trace of such a fault in the cliff bordering the Paradise Bay fault on its northwest side but, as an auxiliary, it might there have become zero.

In figure 1, however, it would appear that such faults had been recognized by others. For instance note the fault which Cushing drew as running northwesterly from Plattsburg; his connection of the Plattsburg with the Beekmantown fault; and his several faults crossing from the Little Chazy to the Tracy Brook faults. Note also the northwesterly running fault which Brainerd and Seely drew at the southeast corner of Isle La Motte. So many faults of the region have been drawn along covered areas where considerable latitude could be allowed for true direction that all such lines must receive further study. Valcour island, taken alone, would show that step faulting along many parallel fissures is characteristic of the meridional faults while the production of SW and SE auxiliaries is characteristic of the transverse faults. The latter do, however, show a few parallel minor faults and it is quite possible that the former occasionally developed auxiliaries of their own.

## THE SURFACE PATTERN OF THE FAULTS SYSTEMS

Before leaving the surface pattern of modified parallelograms which we now find to be presented by the fault blocks of the region let us point out its possible usefulness in giving the approximate boundaries of partly covered fault blocks.

Perkins (1904, opposite p. 103) shows an area of Chazy rocks just north of Keeler bay. Its boundaries are everywhere formed by curved lines and it might well represent an eroded peak which was later buried by Black River, Trenton and Canajoharie sediments. Against the southwestern half of its circumference it is in contact with Canajoharie shales and these also rest against it on its northeastern extension. Probably no modern geologist would look upon this mass as the buried outlier of a Chazy-capped, mature land area of Pre-Trenton times. Do we then have here a quasi-circular fault whose ends meet? To attempt so to interpret this representation of conditions would necessitate the assumption of a correctly drawn fault line where such was not intended. The outlines which here simply represent in a very general manner the distribution of bed rock in a largely covered area are intended only as field guides to probable buried conditions as indicated by relatively small and scattered outcrops. With no other guide than the outcrops themselves our approximate boundaries would have to be curved lines. If, on the contrary, we have a knowledge of the region that testifies to the rectilinear paths of most of its fault lines and which offers evidence enough to allow us tentatively to draw many of these lines, then we may with less error use rectilinear figures for the boundaries of these groups of outcrops. The area in question falls within the rectilinear area bounded on the east and west sides by the South Hero and Kellogg Island faults of the meridional system and on the north and south by the Cooper Bay and Rockwell Bay faults.

If exposures of Canajoharie shales are to be found in the borders of the parallelogram so drawn we must see first if our main fault lines have been correctly plotted. We may have placed the Cooper Bay fault too far to the north, or another unrecognized transverse fault may exist here. We found one present on Valcour island between the Rockwell Bay and Valcour Cove faults. Either the spacing there is exceptional or we have missed more than one member of this transverse system.

If we find no reason to modify our major lines we must look for the influence of possible parallel members of either series.

Then, too, the conceived parallelogram may have had one or more corners cut by an auxiliary fault.

In any case, however, the boundaries of the fault block must be made by comparatively straight lines. The boundaries between the Chazy and Black River outcrops need not be fault lines, but between Chazy and Canajoharie contacts they can be nothing else.

Lastly, a corrected map will show that the meridional system, although at first existing (geologically) as long unbroken lines, like those shown in Hudson (1923, plates V and VI), should really be represented by dislocated lines with block east and west boundaries more or less shifted from their original positions. For example, the meridional faults of the two sunken basins can not possibly cut the Beekmantown horst at the points where they now meet it. The sinking of the rectangular fault blocks and the results of westerly thrusts (bodily movement and compression) would certainly affect the original position of the fault lines where they cut any horizontal plane. In figure 1 such dislocations are tentatively indicated.

When more is known of the region under discussion it may be possible to give a map in which all fault positions are drawn where they cut sea level. Possibly one might then determine the relative value of displacement due to simple sinking on the one hand and to thrust and slight block deformation on the other.

## THE SYSTEM OF OVERTHRUST FAULTS

New York State now has in its eastern borders many rock beds which were deposited in territory that once would have come well within the present western boundaries of New England. The effects of these thrusts are well seen in western Vermont as at Rock Point, Burlington, where the Cambrian beds have been thrust over and now rest on the Canajoharie shales.[1] These disturbances were also felt on what is now the eastern part of Clinton county, N. Y. At Martin bay we may have a good view of an anticlinal fold in the Cumberland Head shales, so compressed as to form a neck and there pinch out some members of the folded sediments. This neck then broke across and the upper part of the fold moved westerly. Several overthrust fault planes are shown in this locality. We reproduced (in 1923, plate 9) a photograph which shows the pinching out of beds at "a"; a minor break at "b," high up in the fold; and a well-developed, nearly horizontal fault plane at "c." The cut edges of the beds are so bent as to show a westerly movement of the overthrust mass. In many places in southeastern Beekmantown, east of Dead creek, the outcrops of the Cumberland Head shales show a very similar condition of disturbance.

On Crab island a small area of a slightly inclined slickensided surface follows the dip and still shows white patches of its former calcite seam. The movement there may be associated with beds broken by cross faulting and then moved by local thrust.

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[1] Since the preparation of this paper in 1915 the author has read with interest the article by C. E. Gordon (see bibliography) giving numerous instances of overthrusts along eastern portions of the Champlain valley.

In McMartin's quarry, about a mile northwest of Plattsburg, there has been uncovered in recent years a very extensive slickensided and calcite-covered floor which also follows a slightly dipping bedding plane. A view of this quarry taken in 1915 was used for plate VIII (of 1923). The patches of calcite show the parallel grooves and ridges which were developed on the upper and under surfaces of the beds along the plane of their contact. The movement was N. 65° W. but the actual displacement was probably small in amount,

There are many other evidences of westerly thrust such as nearly horizontal fissures cutting across bedding planes, examples of bythrust along some of the transverse faults; examples of rotational movements on these fault planes; and also the examples of occasional reversal of movement as in the Rockwell Bay and Beauty Bay faults. The surface evidences which establish the fact that such faulting did here exist do not, indicate however, any great extent of movement. From the evidence near Burlington we should expect and look for a more deep-seated westerly movement involving the New York State shore or at least portions of it. We think we have such evidence in the westerly bend given the faults of the meridional system but we find it also in the rounded cobbles of Grenville age which were brought up by the dike fillings of the monchiquite invasion of our sediments. Some of these inclusions will be illustrated in a following chapter.

## SUGGESTIONS CONCERNING THE HISTORY OF THE FAULTS SYSTEMS

Cushing (1905, p. 403-5) finds indications of Pre-Cambric faulting in the Adirondack region. The paleogeographic maps of Bailey Willis and Schuchert show a remarkably straight, long and comparatively narrow valley, in Waucobian time, which ran from eastern Labrador to the Gulf of Mexico. If this natural trough possessed near-by lands on its eastern side it was then doubtless a graben; although at a still earlier date, perhaps Azoic, it may have been a faulted monocline, itself due to sediments carried easterly and deposited in a more primitive ocean basin. With age the ocean basins have grown deeper and the continental margins have been extended in consequence. We might therefore entertain the idea, as an hypothesis, that this line once represented the approximate eastern shore line of an older North America. It is also possible that the subparallel meridional faults of the Champlain valley were in their origin due to a very ancient anticline of which the Adirondack mass is a small remnant. Such a view would account for the great width of this system and yet in no manner be antagonistic to the idea that in still earlier times there existed here a great foreland which was being depressed or changed into a monoclinal fold through the weight of sediment brought to an eastern sea. Thrusts from the east have caused folding in near-by regions more than once since Cambric times and many times may have formed such in Pre-Cambric times. The long line of valley we have noted may then be in part due to age-long erosion of the weaker portion of an Azoic anticline. The development of a graben along this line of multiple faulting could easily have accompanied or followed the eroded anticline stage.

The Pre-Cambric history of this marked line of weakness may some day be better known. Our purpose here is to show the probability of its existence, in some form, at a date many times earlier than the beginning of Paleozoic time. During the infalling of planetesimals in the earlier stages of accretion and before the gathering of the waters of the earth into more permanent basins, faulting, or adjustments by flow must have taken place in response to greater equatorial accumulation, as well as to rotational stresses. With ocean basins established the development of the latter would give a new cause for the upsetting of isostatic balance through shifting of load transported by wind and water. In other words, if we realize that the earth has possibly grown, by the infalling of planetesimals, from a globe of "between 2000 and 3000 miles" in diameter (Pierson and Schuchert 1915, p. 531) it is easy to see that during the addition of the last 500 miles' thickness of crust there must have been some adjustments involving faulting.

We have long since come to look upon certain features of the earth's crust such as continental platforms and ocean basins as "fixed." To these fixed features we have lately added the conception of positive and negative elements. Certain major fault lines then must also be considered as fixed so far as general location is concerned. We have a period of earth history some thousands of millions of years long during which the earth most certainly formed true "habits" in faulting. We feel justified in claiming for the eastern rift which was occupied by oceanic waters in Waucobian time—an age at least ten times as long as the time which has elapsed since the beginning of the deposition of sediments of that age.

Leaving now this postulate of a very long Pre-Archeozoic history for Logan's Line we have a problem before us which involves the following questions. During what periods or epochs since the beginning of the Archeozoic era do we find evidence for continued (intermittent) activity on any portion of this multiple fault line, or on parallel lines in its immediate vicinity? In other words may we find recorded evidence enough to enable us to supplement our postulated period of youth of Logan's Line with a more detailed and accurate history of its periods of maturity and old age?

We have already referred to Cushing's evidence for faulting in this region in Pre-Cambric times. To this we have little to add save that the oldest areas of diabase and bostonite dikes in northeastern New York have concave margins next the Adirondackian mass and suggest, as we shall see in a following chapter, that these areas were invaded at two widely different periods by molten rock injected into fissures produced by tension in under-portions of basins depressed by load. These dikes were probably injected in Early Proterozoic time and before the elevated Adirondackian mass was worn down to nearly sea level, or peneplained.

Much later in geologic time, or some 500,000,000 years ago, this peneplain was again depressed and Eopaleozoic sediments began to accumulate over Logan's line. What can these deposits now tell us as to fault movements which occurred during this deposition? We could be very positive as to certain evidence there to be found if only we could tell whether or not any of these sediments were faulted while yet they were in a soft or nonlithified condition. It will be proper therefore to briefly discuss this aspect of the question.

Where slipping occurs along a fissure in lithified rocks we find that the beds near the fissure face are likely to have their edges dragged up or down; their bed edges broken; the fissure filled with broken and pulverized material, its walls slickensided; and sometimes so parted, because of unequaled hardness of the beds, as to leave cavities which might be subsequently filled with crystalline matter. Where nonlithified beds are fissured and a small slip occurs none of the characters enumerated above should be present. Their absence then in several minor faults on Valcour island may be taken to indicate faulting in soft sediments. In many cases soft sediments would be faulted through settling due to earthquake shock and the fissure never afterward be disturbed. In other cases the slipping of an old fissure in the solid rock below would cut and displace the new sediments above. In these minor Valcour Island faults but one slip occurred and the displacement amounted to only a few centimeters. Could we but follow such slips upward to the ancient sea bottom we should there find the edge of the fissure covered by new and undisturbed deposits and so be able to determine the approximate date of the cessation from slip. Being able to date the minor faults would give us some assurance that one or more major faults were active at that time.

Surely the effects of a slip along a fresh fissure in lithified sediments must differ from the effects of such a slip in nonlithified sediments and in either case the differences should be clearly registered in the faults themselves. In minor faults showing but a single slip the fissure and its walls could if necessary be studied in cross section, using a microscope and noting changes, if any, in the direction of the major axes or flat surfaces of the individual particles of the original sediments. Such particles ought to be able to reveal whether or not they were cemented or free when they were disturbed. Then too the effect of any small buried object held in one wall and left free to score the other would engrave a nonlithified wall in a manner differing markedly from such a scoring made on a lithified wall. Minor faults in mantle rock are abundant but have not yet received the careful study they deserve.

If, however, faulting occurred at various intervals during Eopaleozoic time there would be still other evidences of its presence. A movement with a downthrow on the east side of any northerly running fault plane which cut the accumulating (Champlain valley) sediments of this sub-era would at first form fault scarps in soft bottom sediments. Such fault scarps could not stand but the material on the high side would slump and be carried over to the low side. Possible evidences for such transfer of deposits will be described in a future paper. If many slips occurred and the accompanying flow of water from the elevated to the depressed side carried out and redistributed bottom sediments it would follow that the *local* (eastern New York) Eopaleozoic sediments on the east sides of old step faults would be thicker than on west sides. Now the Valcour Island beds lie on a faulted strip running four miles or more east of the exposures at Chazy, N. Y., and at least two major step faults lie between. It is therefore possible that part of the difference in thickness of the Chazy beds in the two localities (732 feet at Chazy, N. Y., and nearly 1000 feet on Valcour island) is due to a series of slips occurring in Chazy time with resultant wash and transfer of sediments from the elevated to the depressed side. Such shifted sediments have their own peculiar characteristics and the local Chazy beds contain many samples.

We have also possible evidences in the Chazy beds of Valcour island for bottoms strongly shaken up by earthquake shock or modified by tsunamis. These evidences will be discussed in a forthcoming chapter on some Diagentic features of the Valcour Island sediments.

There seems to be evidence then for faulting in the Champlain basin in Eopaleozoic times.

In the chapter "On the dike invasions of the Champlain valley" we shall present evidence tending to show that the invasions which cut the Eopaleozoic rocks occurred late in Eopaleozoic time and before the greater fault displacements now recorded in these sediments. Faulting became increasingly active in the earlier portions of Neopaleozoic time and very considerable displacement seems to have occurred between the time of the last dike invasions and the beginning of the overthrust movements inaugurated by the Appalachian Revolution.

There can be but little doubt that the marked westerly convexity of the fault lines of the meridional system is due to a bodily shifting of upper portions of an older faulted mass.

Here too may be a cause for a number of the parallel members of this system—minor or major. We may suppose that at intervals during the westward movement of the mass over the great thrust-fault plane, the buried older portions of the meridional fault planes renewed their activity, which they would be induced to do because of increase of load. In such cases a new fault would appear directly over the old plane. A fault with a single fissure below might then give rise to a parallel series of surface faults. Thus a multiple fault above might be due to the consecutive movements of a single fault lying below the mass moving over it.

Professor George H. Chadwick, in an unpublished paper read before the Geological Society of America at Albany (1916), pointed out that the local increase of load due to an overthrust would be likely to develop parallel faults in the platform over which it moved.

During the development of an approximately horizontal overthrust fault, any new slip in an older vertical fault of the basal platform or any new break in this platform due to increased load would dislocate the plane or planes of the overthrust; and if the throw became considerable before the overthrust continued its movement, the latter would be compelled to develop new planes and thus in part to become multiple in a vertical series. We have seen that this condition is present in the Champlain valley, but there are not enough of these nearly horizontal parallels in evidence to lend much weight to the latter interpretation. The regular spacing of the great meridional faults and the increase in number of the minor members of the series in areas close to the major fault planes are not to be wholly explained in this manner. Evidently an older and straighter system was bent bodily westerly.

As yet we know but little concerning the later history of Logan's Line. Cushing (1905, p. 406) has stated that the topography of the

Adirondack region seems to indicate that some of the faulting has taken place in Mesozoic time, "certain prominent fault scarps being difficult of explanation except on this assumption," and Woodworth (1907, p. 5–28) presents evidence concerning "Postglacial Faults of Eastern New York" which lie along Logan's Line. Berkey (1910, ch. XX) brings together the little knowledge we now possess of recent faulting along the Hudson River valley.

Logan's line is very evidently a fault line of great age and at the same time one that was doubtless active in Mesozoic times and possibly also in comparatively recent times. A long period of rest near the surface is not always to be interpreted as evidence of extinction of deeper seated activities productive of volcanic eruptions or earthquake shock. Vesuvius was for a long time thought to be extinct before the eruption of 79 A. D., and the periods between severe earthquake shocks may likewise be very long. Seismology is a very recent science and its data are not yet either detailed enough or of sufficient volume to yield results which shall be as valuable as those to be achieved during the next fifty years.

A very considerable earthquake shock was recorded for Canada in the winter of 1663. Palmer, in his History of Lake Champlain, p. 7, quotes as follows from Jesuit's Journal, Quebec, 1663: "Lakes appeared where none ever existed before; mountains were overthrown; rivers sought other beds or totally disappeared. The earth and the mountains entirely split and rent in innumerable places, creating chasms and precipices, whose depths have never been ascertained." This earthquake seems to have been caused by a slip on Logan's line.

The great disaster which befell San Francisco because it was built over a great fault line, should show us the very great importance of a study of all such lines whether old or new. We will here briefly outline the probable major stages through which Logan's Line has passed.

This fault is one that has long been active in a region receiving deposit. The fault line on the east of Valcour island cuts Grenville sediments. That these sediments extend easterly so far as this is shown by rock fragments of this age (identified by the late H. P. Cushing) which have been brought up by the monchiquite dikes. The idea that these Grenville beds were cut by normal faults long prior to the deposit of any Paleozoic rocks, may be entertained without shadow of doubt. The writer postulates a still greater age for this multiple fault and would have it cut the Pre-Grenville platform before the Grenville deposits themselves begin to accumulate. In any case it is very easy to comprehend that if a slip should now occur on this fault line and so displace the Pleistocene or Champlain deposits of recent years it might show near the present surface a throw of but six inches. Deeper in the same fissure, or in Paleozoic deposits, the accumulated slips of Post-Cambric time might measure 600 feet; still below this and in Grenville sediments the total throw might amount to several thousand feet; and in the Grenville platform, where we would reach still older portions of the same fault, the total throw of the last thousand million years might reach many miles.

The extreme old age portions of this fault plane are now buried at such depth that they have been long since destroyed by flow which has carried them far westerly. Early old age portions of this same plane, where it cut through the Grenville series, are still preserved in highly metamorphic rocks. Mature portions of this plane are to be found in the very slightly metamorphic or but little changed sediments of the Paleozoic era and the slips cutting Mesozoic and recent deposits might be considered as youthful. In other words, the life history of a fault may parallel that of a river. The latter may be old near the mouth and young in its upper reaches and it may also have been drowned near its mouth and beheaded near its source. Weathering may "behead" a fault plane and, with cessation of movement, a very large portion of the younger history of the fault may have been thus removed.

When we come to realize how long the life of a fault may be, we shall be less likely to consider it dead because it has apparently been asleep for a thousand years, or for one single millionth of the period of its activity. Whether or not a new slip of Logan's Line is likely to cut the great siphon of the New York City aqueduct which crosses the Hudson river near Storm King mountain is a question well worth asking. It may be that the old fault genii have been imprisoned with the seal of Solomon, but it would be an act of wisdom to undertake a very detailed and extensive study of this question.

A more exact knowledge of the length of Paleozoic time and of the eras which have passed since taken in connection with a more exact knowledge of the total displacement made by Logan's line in any one era would enable us to draw a graph which would show how near Logan's line was to its final rest. These items are then really of the utmost economic importance. Estimates of age which were at first dreaded by the theologian and used only in controversy are thus seen to be of very great importance to the actual safety of millions of our population. That such estimates reach as closely as possible to the truth should be the desire of all civilized peoples and this department of earth study should therefore be encouraged and liberally supported.

Turning now to the transverse system of faults we shall find that evidence for an age equal to that of the meridional system seems to be wanting. We have already noted that these faults do not seem to have attained such length, such parallelism, such uniformity of spacing, such regularity in direction of downthrow, nor on the whole so great a displacement as those of the system just discussed.

Chamberlain (1916, figures 32 and 35) gives evidence to show that, for our region, the meridional faults were in all probability the first to be developed. In paleogeographic maps representing the earliest stages of the development of North America in Paleozoic time we find distinct evidence for a long and narrow line of sea of which the Champlain and Hudson River valleys now represent but a small portion, but we fail to find in these maps any such distinct line of weakness crossing northern New York in the direction of the Lake Ontario axis. Take for instance the first of Schuchert's (1910) series of maps. That for Georgic time shows no evidence for such a line. In Upper Acadic time, however, a line of depression runs easterly across Siouxia near 45° north latitude, but this does not reach Logan's Line until Lower Ozarkic time. This depression apparently was not occupied by any seas in Canadic time but later the Chazy sea had here an arm which bounded Adirondackia on the north and this reached nearly to the Dakotas in Lowville time. Doubtless there were a number of easterly running faults near this line of 45° north in Pre-Cambric times but they do not seem to have formed so definite a line nor so pronounced a graben as that which paralleled the eastern edge of North America.

All of the evidence we have been able to find in the study of the northern Champlain valley seems to point to the development of its cross faults, or the major portion of them, in late Paleozoic time. Take for instance the great thrust plane which evidently cut through the buried Grenville sediments just before the invasion of the monchiquite dikes. The angular and rounded Grenville cobbles which these dikes have brought us from this plane must have been picked up at nearly the same depth. This means that the Cumberland Head and Valcour Island fault blocks had not at that time been markedly displaced with reference to each other. At the present time the dike at Martin's bay is exposed in the Cumberland Head shales while the dikes (monchiquite) of Valcour island are exposed in Middle Chazy beds. Since this dike invasion then the Cumberland Head block has possibly gone down nearly a thousand feet.

We may note also the present condition of the fault strip just west of the Woodruff Pond fault. The displacement of this fault is not large. We have the overthrust Cumberland Head shales on its east side near Plattsburg and at Plattsburg itself the beds of Trenton age. Farther to the south we have at Valcour island a large area of exposed Middle Chazy and at Bluff Point a mass of beds of the same age. At Plattsburg the buried plane of the great overthrust fault still cuts the Grenville series. Since the monchiquite invasion the Plattsburg block, Trenton at present surface, has possibly gone down some 600 feet below the Chazy block at Bluff Point. At Cliff Haven we have already seen that the fault there shows evidence of torsion, of thrust westerly, and of a true reversal in movement. It would seem that the break across this fault strip was due to that same westerly thrust which cut the Grenville and which also twisted and otherwise displaced these and many other blocks formed by cutting across the strips of the meridional system.

If we will again refer to figure 1 we will see that south of the Valcour Cove fault we have Beekmantown on the New York State shore, at the south end of Valcour island, and on the southern part of Providence island. Here is a Beekmantown formation horst which was probably supported by the Trembleau Mountain shelf. There is a little sag in this horst represented by the lowest Chazy beds on Garden island. On the cross strip north of this we find again Beekmantown on the New York side, but no farther inland, and an outcrop of the same rock on South Hero. The sag on this strip is more pronounced. North of the Rockwell Bay fault the Beekmantown is found one block farther westerly on the New York shore while on Grand Isle the oldest rocks are of Chazy age; the sag here is still more pronounced.

In east Beekmantown we find again a horst of rocks of Beekmantown age which rests doubtless on a buried spur of Lyon mountain and reaches easterly to the south end of Isle La Motte. To the north of this horst another depressed basin is found in which Chazy is followed by Trenton and then by Canajoharie. These horsts are no doubt due in part to the direction of hade of the cross faults bounding them, giving them broad bases. The basins are, however, due in part to greater loading in early Paleozoic times and in part to additions to this load due to the unequal weight of masses thrust over them. The effects of this thrust over the northern basin are well shown by the extra bend given the Tracy Brook and Little Chazy faults and by the shove given the cross faults of this region. This shove doubtless made breaks in the meridional lines though

Cushing does not show this in his map and we have left it for future examination. His faults near Chazy village are given in figure 1 practically as he drew them.

During the early stages of the Appalachian revolution there were molten masses underlying the described basins and while none of this matter reached the Champlain valley surface it probably did flow westerly under the Adirondack mass or under those fault blocks whose bases had the greater areas in proportion to this mass.

We should also note that in passing southerly over the area shown in figure 1 the meridional line of greatest displacement is constantly shifted easterly. At Chazy the greatest displacement is on line 2. Near southern Isle La Motte it is on line 7 or 8. In southern South Hero it is on line 10. May we take this to indicate in part the extent of the movement which has carried the present surface lines far to the west of the position of their origin and thus buried the old line or lines of greatest displacement with the comparatively little disturbed sediments of Canajoharie time? When the amount of overthrust is better known our meridional lines will have to be redrawn to show more accurately the amount of horizontal thrust where each cross fault cuts these lines.

If now we return to the Valcour Cove fault where it crosses the southern end of Valcour island we shall find further evidence which tends to show that the transverse faults had their origin during the Appalachian revolution. Because of the special interest of this first fault which we found to cross the northern Champlain valley, we made a model of its Valcour Island portion and now present views of this in figure 12.

The base of this model, which is in two parts, represents an area at present lake level which would measure 1200 by 350 meters and this is longitudinally divided by the fault plane. The hade of the faults of the region is not easily measured but in most cases is low and we have used a zero hade in our model. Believing that the auxiliary at Sandstone Point was once on the fissure of the Pebble Beach auxiliary and that its present more easterly position is due to a horizontal component of the fault movement, we have indicated the position which the fissures of the other northern auxiliaries would have occupied had they also crossed the main fault line before faulting had occurred and before the northern wall had moved westerly. These other extensions are therefore hypothetical. The position of the front block of figure 12 is intentionally so placed as to indicate the shove as well as the vertical displacement. The upper surface of these blocks represents the topmost Chazy bed as it would appear if nothing had been lost by erosion.

In viewing upper half of figure 12 we are supposed to be looking southerly. On the restored southern wall of the fault the Chazy "zones," which we shall recognize in a future paper, have been drawn to scale and a part of them designated. The nearer vertical face of the upper figure shows the restored beds as they would appear above the present level of the lake on a vertical section parallel with the fault and 175 meters north of it. On the restored upper surface the present southern shore line of the island has been indicated. In only two places, or at I and J, does it occupy any portion of the block on the south of the Valcour Cove fault line.

In figure 12 (lower half) we are supposed to be looking northerly and viewing only the restored north wall of the same fault. The broken line near water level indicates the approximate height of the remaining beds.

The mass represented by the rear block of the model has been almost wholly removed by erosion, the only portions now showing above water being the projecting cliff at Sandstone Point and the very small area exposed, only at low water, just off Fault Point.

If now we try to translate the story told by this fault we must recognize the diagonal fissures, so pronounced at Valcour and Providence islands, as older than the faulting itself but due probably to some torsion of the meridional fault strips. Such torsion would arise through westerly thrust and be still more effective if some slips of the meridional faults cut across the series of thrust planes and so gave effective edges for resistance to thrust as figure 13 (1). Resultant torsion and brecciation is shown in figure 13 (2).

The main fissure of the Valcour Cove fault seems to have developed from the east and the first sinking of the north side took place near and perhaps west of Providence island. There was thus developed a rotational stress which induced a progressive westerly movement of the newly formed northern trough. The nature of the movement was like that of the trough of a wave but with a slowness of motion almost inconceivable. For a time the blocks C and D, (see figure 12, lower diagram), clung to the face near J and dragged it down. At this time the eastern edge of block B was being pulled down but its western edge was still supported by the bridge across the fault at J though this also was bending. When this bridge finally broke across, the block B had already accommodated itself to the rotational stress, but C and D, not so accommodated, moved down more nearly at the rate of the western portions of the north wall. In other words the Valcour Bay fault once had its westerly end at J and there it remained for a period long enough to allow for a large displacement easterly. Later the fissure was extended westerly and the fault given new life in this direction. During this period of increased activity the Valcour island part of the northern wall was thrust westerly.

Brainerd and Seely (1896), and Raymond (1906), began their local Chazy section between L and M on the rear block (figure 12), and on reaching the main fault at Pebble beach crossed over to the remaining edge of the wedge B and calculated the thickness of the hiatus as if no fault existed. It looks as if Brainerd and Seely had a suspicion of a fault here which they did not dare express, for mental processes that do not lead to definite results are, by common usage, suppressed in most scientific reports. Sometimes the processes and the rejected conceptions would have a value greater than the conclusions themselves and it is a pity that trails, which at one time seemed to be promising, might not be noted, if only in an addendum, for the benefit of students who later should pass over the same ground. Now on using the distance between the nearest exposures and the average inclination of the beds on the Pebble Beach line, as determined to fractions of a degree over well-placed bed surfaces, one would get a thickness of but 107 feet for the lost beds—if he neglected the fault. Brainerd and Seely however made the loss here "about 200 feet." Why the "about" and why does this hiatus contain just the A3 (110 feet) and A4 (90 feet) of the B and S section which was not made through study of the island but by the aid of exposures on the mainland from Valcour bay to Bluff Point? Although following Brainerd and Seely, Raymond could not believe the hiatus so great and, allowing a very liberal dip, he cut it down to "about 133 feet."

Because of the Valcour Cove fault, the Brainard and Seely determination is probably nearer the truth, and a study of our figure 8 will convince anyone that the expression "about 200 feet" was one that was not used without due and careful consideration. That the hiatus can not be measured by passing from K to B, as if no fault existed, will be apparent to anyone who studies these figures, for the upper surface of the model everywhere shows the general dip of the beds save where they were covered by water. It is however remarkable that at the edge of the wedge B the displacement is so small. The model might be so adjusted that one would find zero displacement at this edge while displacements of 600 feet could be found at comparatively short distances either easterly or westerly, for the model shows the bottom of Z.46, on the rear block, to have rested nearly at the upper level of the topmost Chazy on the front block.

In figure 12 (lower diagram) we are viewing the southern face of the northern half of the model. The line of dashes along the lower edge represents the general surface some distance back of the water's edge. The lowest beds here brought to view are our Z.21 or the B1 (Middle Chazy) of Brainerd and Seely. The present fault faces of the segments C and D are practically covered by the mass K, L on the south side of the fault. From E to H one may collect from our zones .52 to .61. Here nearly half the Chazy is below the water line.

The Valcour Cove fault presents us with a remarkable example showing the possibility in field work of measuring a section crossed by a major fault and, *without noticing the latter,* obtaining a correct section of the beds measured.

To enable us the better to comprehend the movements and flexures involved in this interesting region we here present figure 14 (sections 1–4) representing a flexible model made by cutting through a pad of several sheets of paper. The sinuous line on each section represents the shore line of Valcour island from Cystid Point "K" to the cove "f" which lies just west of Sandstone Point. In viewing these models we are looking southerly and the surface is supposed to represent only the top of the Beekmantown formation as it might appear were the Chazy cover removed. One major fault (the Valcour Cove fault) crosses each figure from left to right. Two short diagonal cross faults or auxiliaries are also shown; the right hand one of these enters the island at Pebble beach.

In section 1 the central, unbroken, diagonal strip or monocline represents a belt of territory 104 meters wide and some 300 m. or more in length. This is supposed to be one of an east-west parallel series of such trips bounded on their sides by fissures running N. 49° E. We are to imagine that the area north of this fissure belt began to sink and at the same time move slightly westerly, thus causing the beginning of a series of more or less central displacements on the diagonal fissures. Imagine now that a new fissure (that of the Valcour Bay fault) begins to develop along the weakened belt of diagonal fissures and succeeds in cutting them all save the one represented as unbroken in our figure, and that this remains a bridge over which one may pass the Valcour Bay fault without being aware of it. Now near "a," or at Fault Point, the Beekmantown formation lies very near the present surface, while just north of the fault the same Beekmantown top is still covered by more than 600 feet of Chazy beds, yet if the conditions are as represented one could pass along the line k, h, i, d, and encounter no fault. If also the fissure cutting Sandstone Point between "d" and "f" were not extended so far southwesterly one might pass from "f" to "k" and find nothing but a few minor displacements. Under these conditions Raymond's measurement of the local section would have been much more accurate than that of Brainerd and Seely for there could be no hiatus of about 200 feet at Pebble beach or between "i" and "e."

An examination of the region, however, will convince anyone that the conditions shown in figure 14, section 1, are not those which exist today, although they may represent an earlier stage of these conditions. Fault Point itself is at "h" and the beds of Z.05 which show just south of it are at the right of "a" and on the belt itself, near "b." The Valcour Bay fault has then actually entered this belt on the east side and there produced a displacement of about 600 feet. Neither is Sandstone Point cut across between "d" and "e." Figure 11 also fails to show any reason for the varying direction of the strike which we shall notice in passing from "f" along the coast to "k."

Section 2 shows the conditions that would have arisen had there been a still greater westerly movement of the north block without any breaking across of the belt. Under these conditions we should find that in passing from "d" to "c" we would be going down from the Beekmantown top to lower beds and not up to higher beds.

In section 3, however, we have the same increased westerly movement of the northern block but the belt has here been completely cut across by the Valcour Bay fault. It will be of interest to note now that we may again have conditions that would allow one to measure the section from "f" to "k," calculate the loss at the Pebble Beach hiatus between "e" and "i," and although still *passing unknowingly over a major fault,* yet introduce no error in the thickness of the section. We have only to suppose that the westerly movement of the edge of the wedge at "i" has brought its upper Beekmantown surface flush with the surface of the same bed at "e" on the opposite wedge. In figure 13, however, the edge at "i" is a little above that at "e" and if this condition really existed in the field the loss at Pebble beach might be so low as 50 feet or, in fact, be reduced to zero. If one in the field will uncover a bit at the base of section C and compare the rock here with the topmost layers of section A he will certainly, from a lithologic standpoint, see no reason for believing these beds to be widely separated in the section. They consist of the same thin muddy limestones and the same thin interstratified sheets of "tough slate" which Brainerd and Seely found characteristic of their A2.

In section 4 we have allowed the end of the wedge at "i" to fall below the surface at "e." If this should represent the true condition at Pebble beach the "hiatus" might reach 400 feet or more.

While we have stated that the displacement at "h" is about 600 feet it must be remembered that in determining this we accepted the measurement of the Pebble Beach hiatus as given by Brainerd and Seely. We have seen however that their determination of the loss there was by inference and not through measurement. If their estimate exceeds the true loss the displacement at Fault Point is not so great as we have indicated it; if their estimate was under the truth our figures for the Fault Point displacement are too small.

If we could show that the inner auxiliary off Sandstone Point was once continuous with the Pebble Beach auxiliary (see figure 20) we should be able to measure the amount of westerly movement of the north wall of the Valcour Cove fault. The horizontal displacement thus indicated would be close to 200 feet. To obtain the vertical displacement at the end of the wedge formed by this auxiliary would necessitate the identification of some one or more horizons to be found on both sides of the fault, and this for the present is a hopeless task for no portions of Brainerd and Seely's A3 and A4 are to be found on Valcour island. On the nearest mainland these divisions were measured by their authors as reaching respectively 110 feet and 90 feet. The two together thus indicated that the loss of the section on Valcour island was 200 feet. As the A3–A4 divisions were measured more than a mile westerly from Pebble beach and so nearer the ancient shore line, we should hardly expect these beds to be as thick in the Pebble Beach region. This might well be, however, in a filling basin in which sediments under shallow waters were continually being shifted to deeper waters (and these sediments show evidence of such shifting); it also might well be if faulting dropped the Valcour Island meridional strip one or more times during the deposit of these beds and by creating a scouring eastern rush of waters thus reduced the thickness of deposit on the western and more shallow sea margin and at the same time increased the depth of deposit over the fallen strip.

There is another way, however, of getting an approximate estimate of the amount of this loss. We reproduce here (figure 15), a graph made in 1915 to ascertain if there were any paleontological evidences for breaking up the local Chazy formation. This graph was based mainly on the excellent lists furnished by Raymond (1906) and Ruedemann (1906). The long axis of this figure represents the thickness of the zones of the Chazy deposits of Valcour island drawn to scale. The Pebble Beach hiatus is here accepted as 200 feet. The verticals represent the number of resident Champlain valley species at the end of each zone, also drawn to scale.

The increase in number of resident species up to the end of Z.61 is remarkably orderly. At the end of Z.05 we have 17 such species described and an accumulation on Valcour island of 96 feet of sediments. The rate of increase (so far discovered) seems to be one new resident species for every 5.64 feet of deposit. At the end of Z.12 we have records for 12 new species and the additional deposits measure 57 feet in thickness. The rate of appearance of new species has increased and in the zone it seems to have been one for every 4.76 feet of deposit. Averaging the two rates we have an increase of 29 species during the accumulation of 153 feet of deposit or a rate of one new resident species every 5.27 feet. Taking now a nearly equal thickness of deposit (Z.36 + Z.38 + Z.46) or 162 feet of beds (on Valcour island) next above the lower Chazy of Brainerd and Seely we have at its upper limit an addition of 19 new species to the known fauna, or additions at the rate of one every 8.53 feet of deposit. Averaging the rates above and below the hiatus we would get the probable rate of increase at Pebble beach to be one new resident member for every 6.9 feet of deposit. Now at the end of lower Chazy times we find 35 species not represented in the first two zones. To gain these species at the rate of one every 6.9 feet would require a section measuring 241.5 feet. If, however, allowance be made for the falling off in Z.46 of the rate of increase as measured by deposit, we should get a figure very like that of Brainerd and Seely's estimate and a graph like that here presented.

The graph may not be based on enough "finds" to make it as definite as might be desired but it seems to have a message that certifies to the oneness of the local Chazy formation and to indicate also that the Brainerd and Seely estimate of the loss at Pebble beach was not far out of the way.

The author is far from believing that the sedimentation rate of advent of species is a good criterion to use in measuring the thickness of a break in the record, but when we come to estimate the thickness of sediments lost in a great unconformity such use is permissible. It is of interest, however, to note that where conditions changed very regularly, as they did during the formation of the Chazy of the Champlain valley, an estimate so made of loss in the section is a fairly accurate one.

It has been the aim of the author in the present paper to present some of the unsolved fault problems of a very interesting area for field work. It is hoped that the new material presented and the classification offered may make it easier for future students in this field. The author no doubt has laid himself open to criticism, which he will welcome, but he hopes that in addition to this he has, in a way, laid the region open in such a manner that it shall demand and receive the attention of more experienced workers in this special department of geology.

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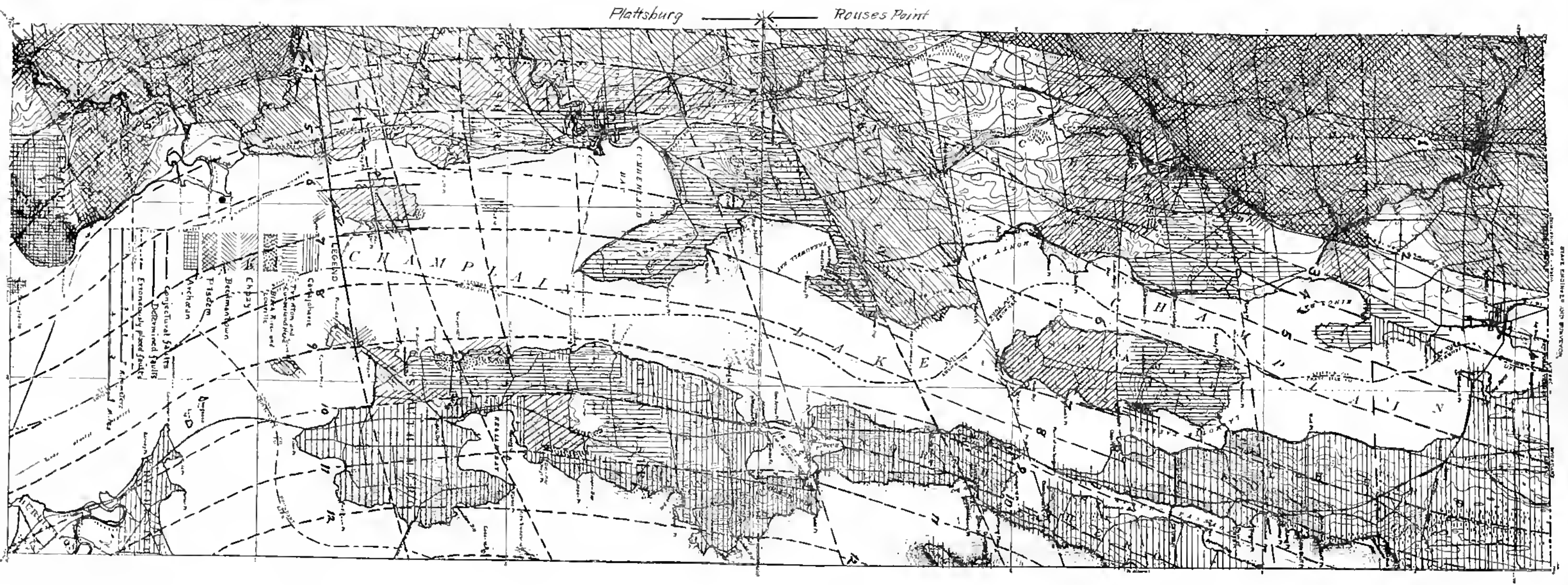


Figure 1 Faults and conjectural faults of the Rouses Point and Plattsburg quadrangles

Figure 2 Step faults at Treadwell's Mills, three miles southwest of Plattsburg, on the Saranac river

Figure 3 Spoon island. Cut from Valcour island by erosion along a north-south fault plane. (from a photograph taken in 1898)

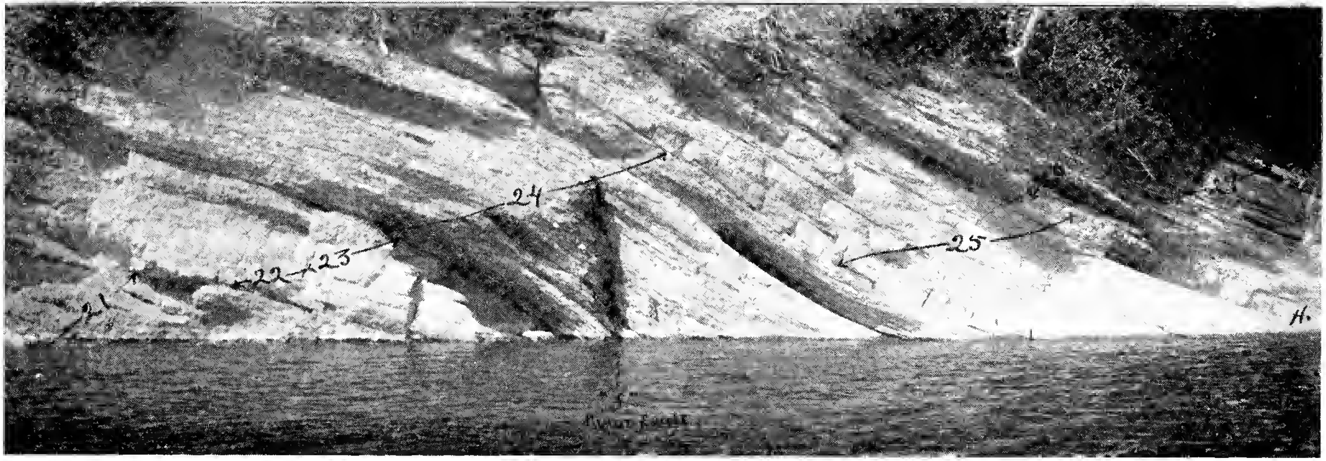


Figure 4 The remaining exposed portion of a fault block at the south end of Valcour island which yields exposures of the lowest Chazy beds, or those of section A

Figure 5 A portion of the cliff in figure 4, showing detail of beds 21 to 27 inclusive

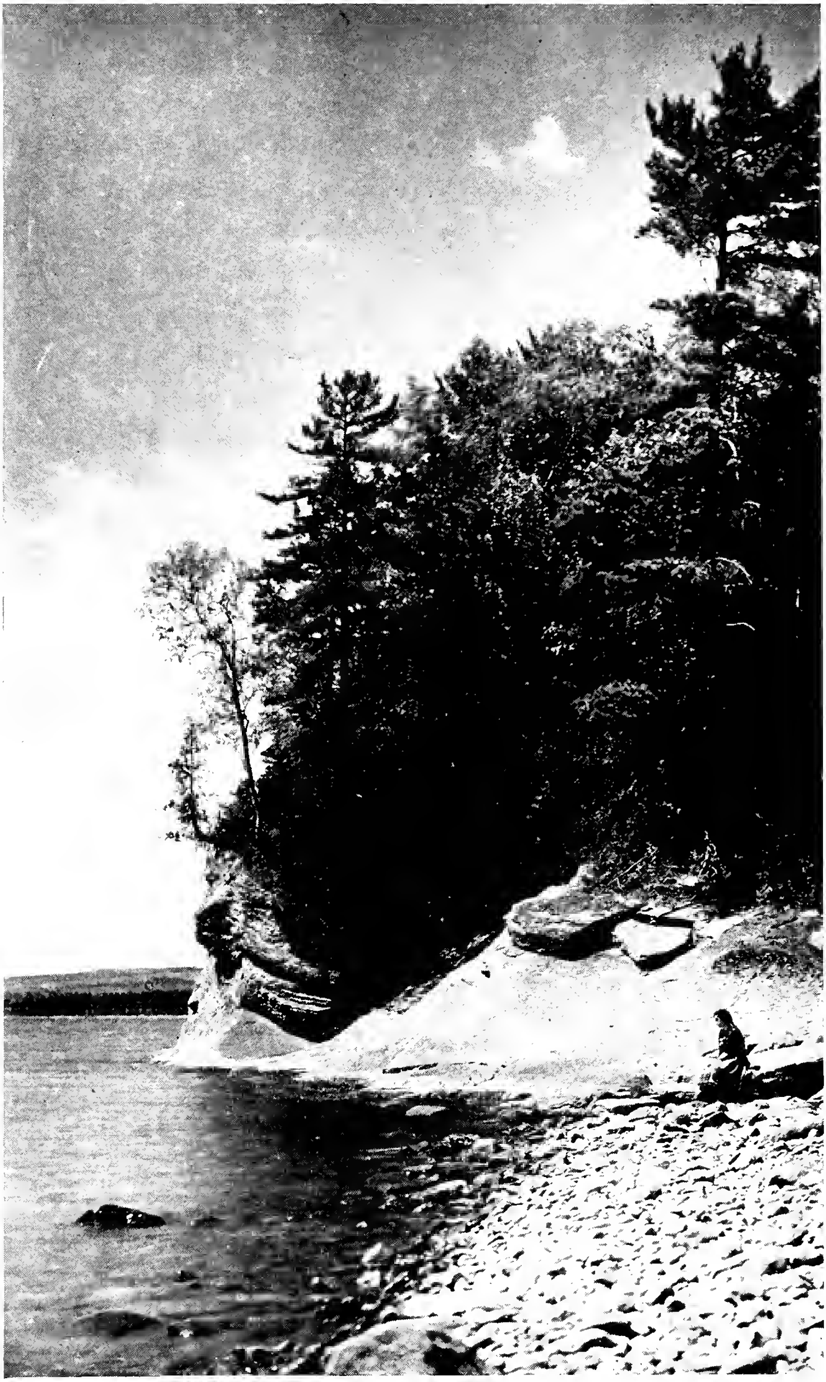
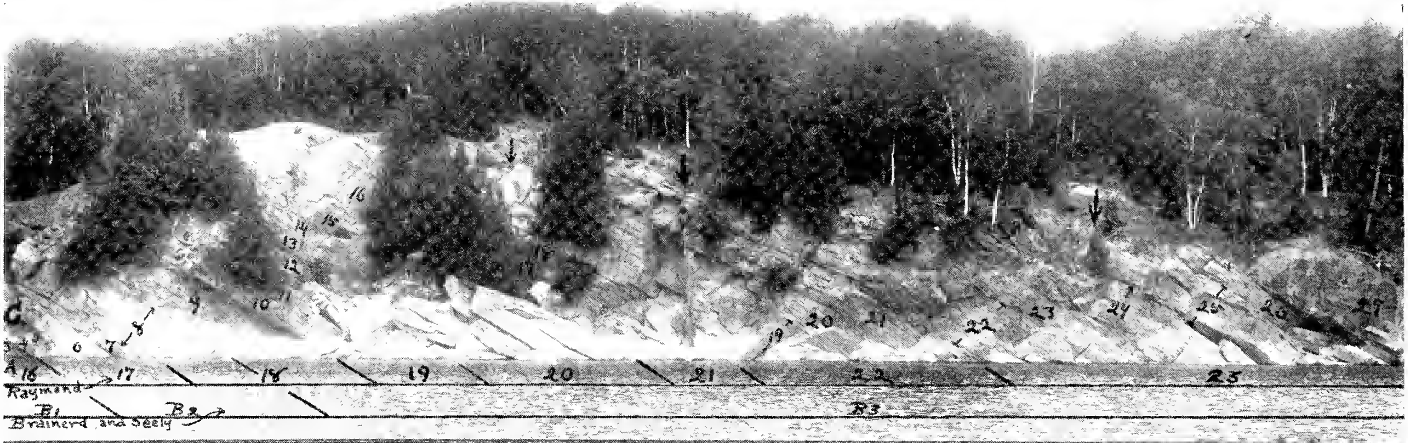


Figure 6 Looking westerly at eroded edge of Sandstone Point fault wedge, Valcour island (From a photograph taken in 1900)



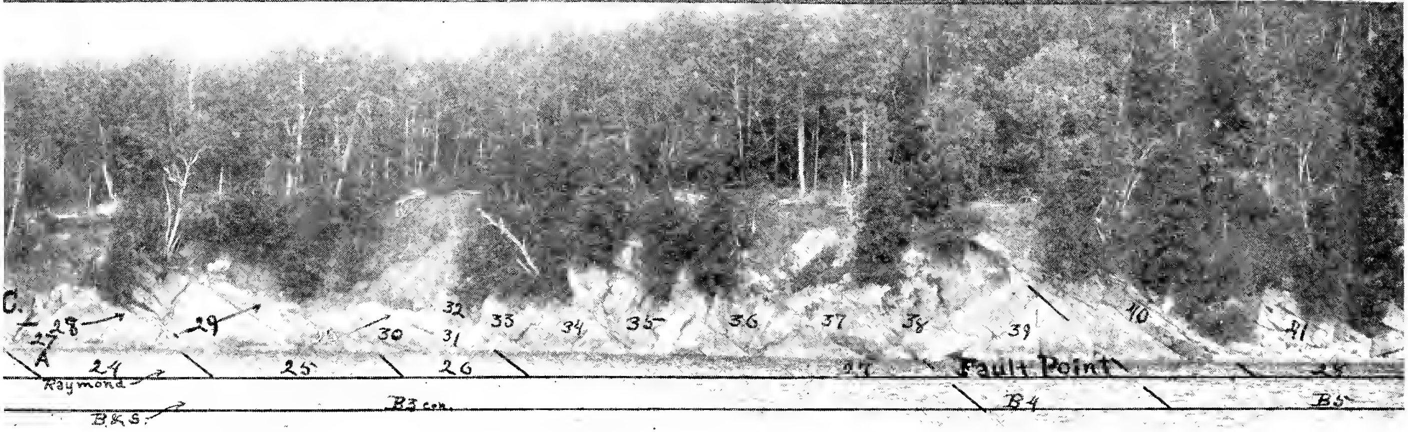


Figure 7 Eastern continuation of the fault scarp, Valcour Cove fault. Total thickness is about 300 feet
Figure 8 Continuation of the fault scarp shown in figure 7

Figure 9 Auxiliary fault at K-32, Valcour Island

Figure 10 Pebble Beach auxiliary fault. Its displacement where it makes its exit on the beach is nearly 250 feet. (From a photograph taken in 1917)

Figure 11 South side of Valcour Cove fault, near Pebble beach, showing two auxiliary faults (From a photograph taken October 24, 1908)

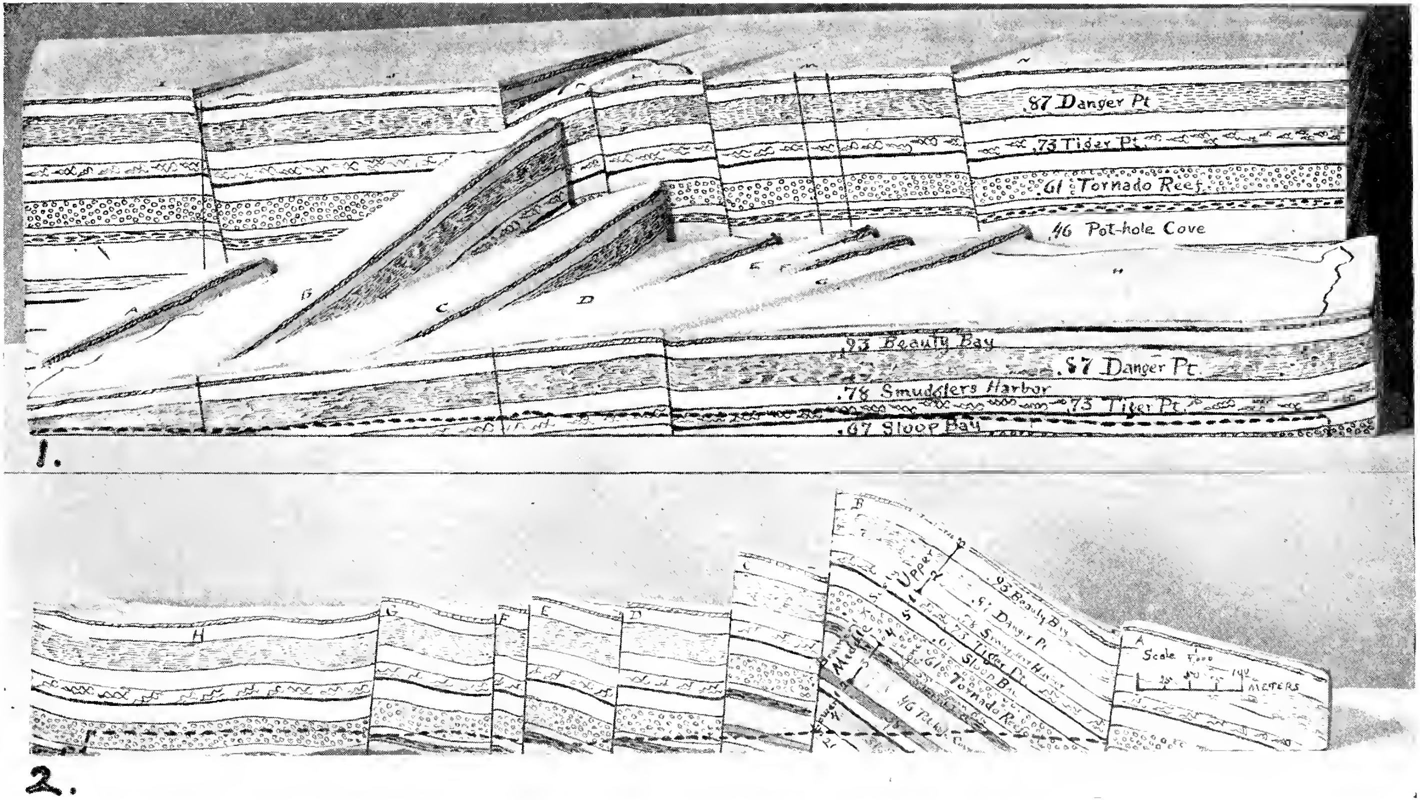


Figure 12 Two views of restored Chazy formation at south end of Valcour island

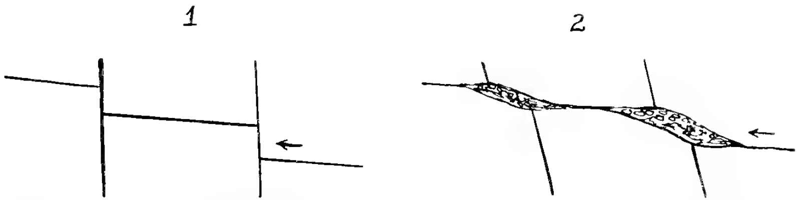


Figure 13 (1) Overthrust fault plane, dislocated by normal faulting. (2) The same fault plane after continued movement of overthrust.

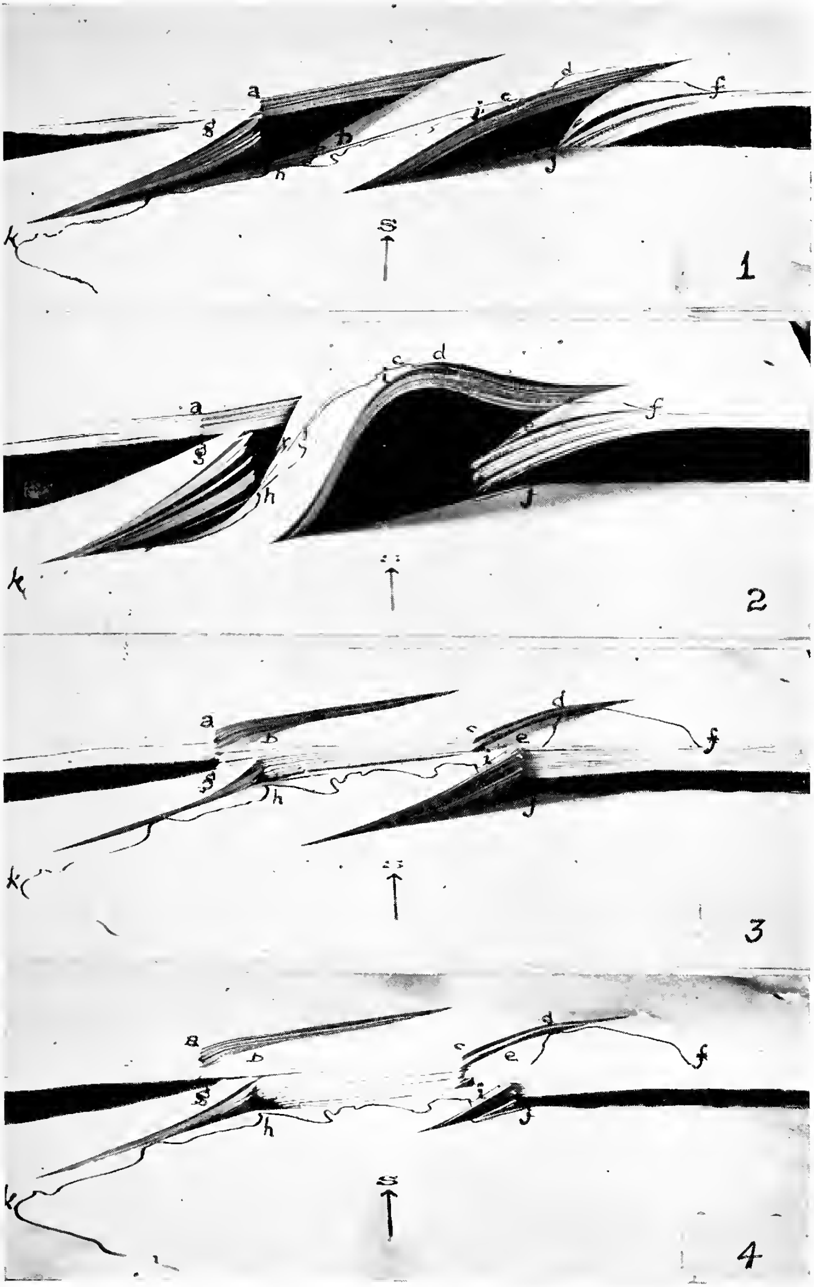
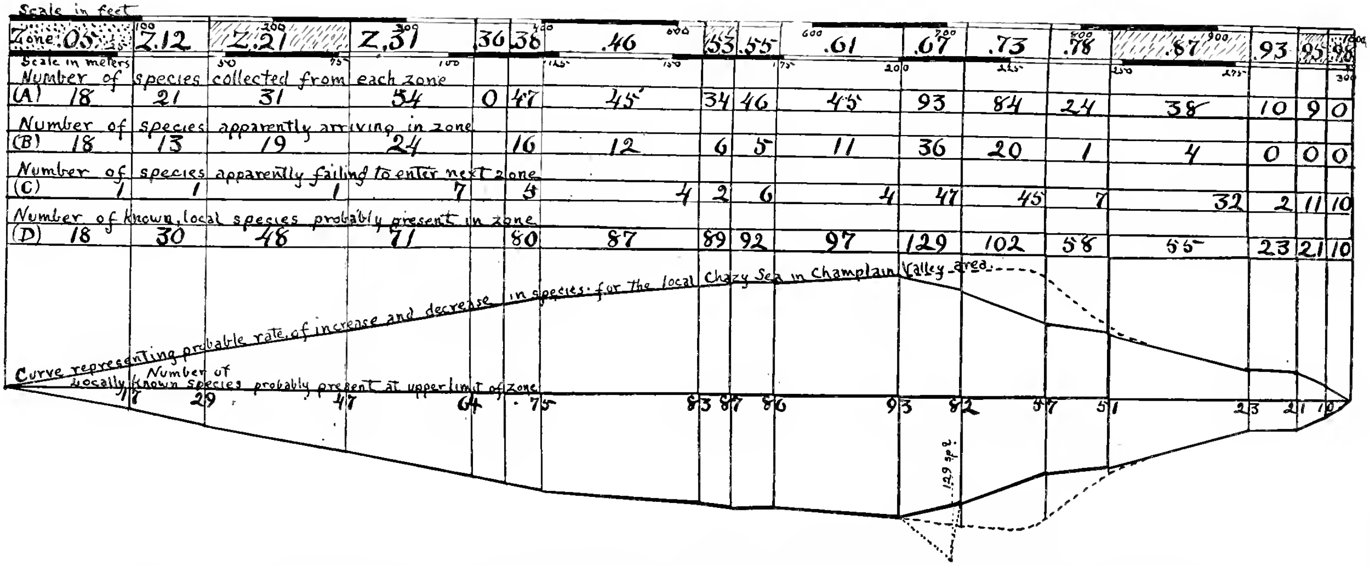


Figure 14 The movements and flexures involved in Valcour Cove fault, as illustrated by a flexible paper model



| Zone | .05 | Z.12 | Z.21 | Z.31 | .36 | .38 | .46 | .53 | .55 | .61 | .67 | .73 | .78 | .87 | .93 | .95 | .98 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of species collected from each zone (A) | 18 | 21 | 31 | 54 | 0 | 47 | 45 | 34 | 46 | 45 | 93 | 84 | 24 | 38 | 10 | 9 | 0 |
| Number of species apparently arriving in zone (B) | 18 | 13 | 19 | 24 | | 16 | 12 | 6 | 5 | 11 | 36 | 20 | 1 | 4 | 0 | 0 | 0 |
| Number of species apparently failing to enter next zone (C) | 1 | 1 | 1 | 7 | | 5 | 4 | 2 | 6 | 4 | 47 | 45 | 7 | 32 | 2 | 11 | 10 |
| Number of known, local species probably present in zone (D) | 18 | 30 | 48 | 71 | | 80 | 87 | 89 | 92 | 97 | 129 | 102 | 58 | 55 | 23 | 21 | 10 |

Figure 15 Paleontologic data covering zones of the Chazy formation in the northern Champlain valley

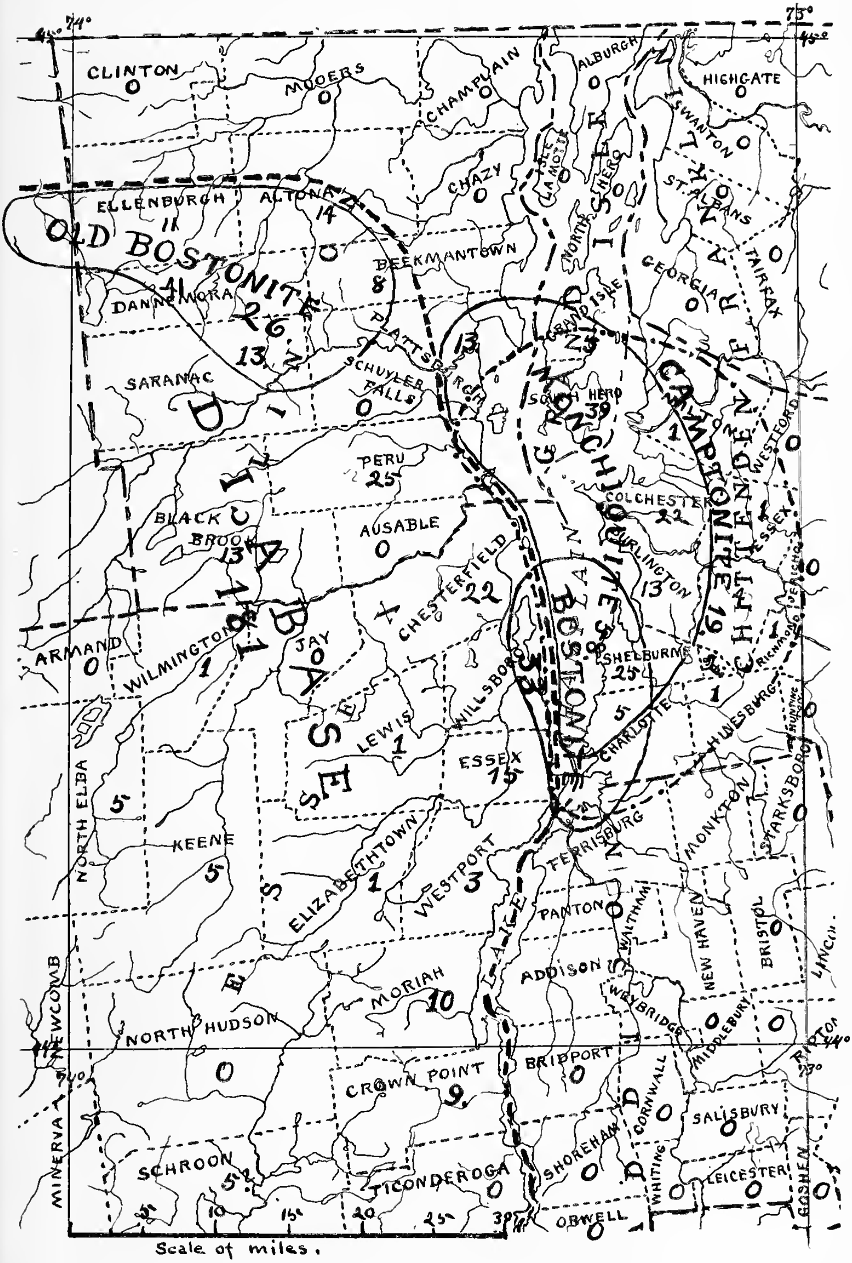


Figure 16 Lake Champlain dike regions

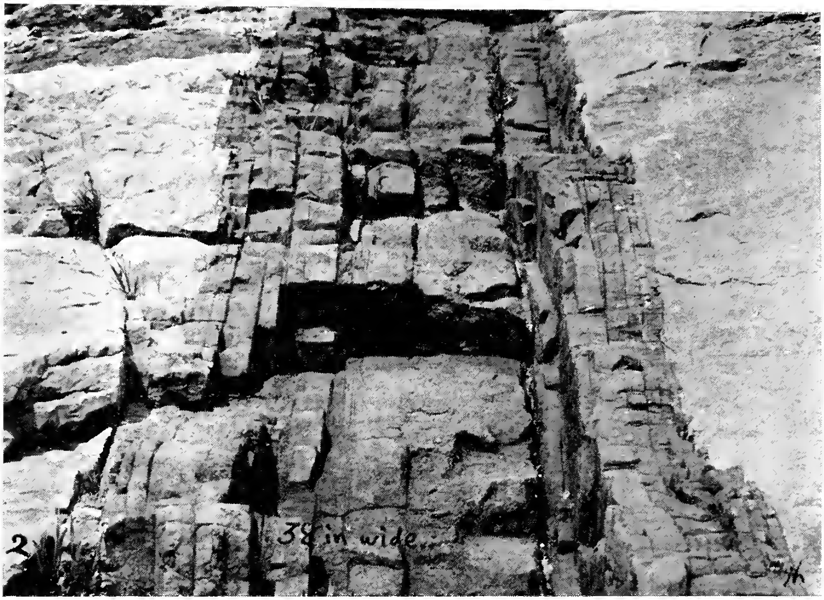


Figure 17 Fourchite dike at steamboat landing, Cliff Haven, N. Y. Dike 32 inches wide. (From a photograph taken in 1915)

Figure 18 Augite camptonite dike at T-19, Valcour island. Dike 38 inches wide. (From a photograph taken in 1915)

Figure 19 A dike (42 inches wide) inclosing rounded pebbles or angular fragments

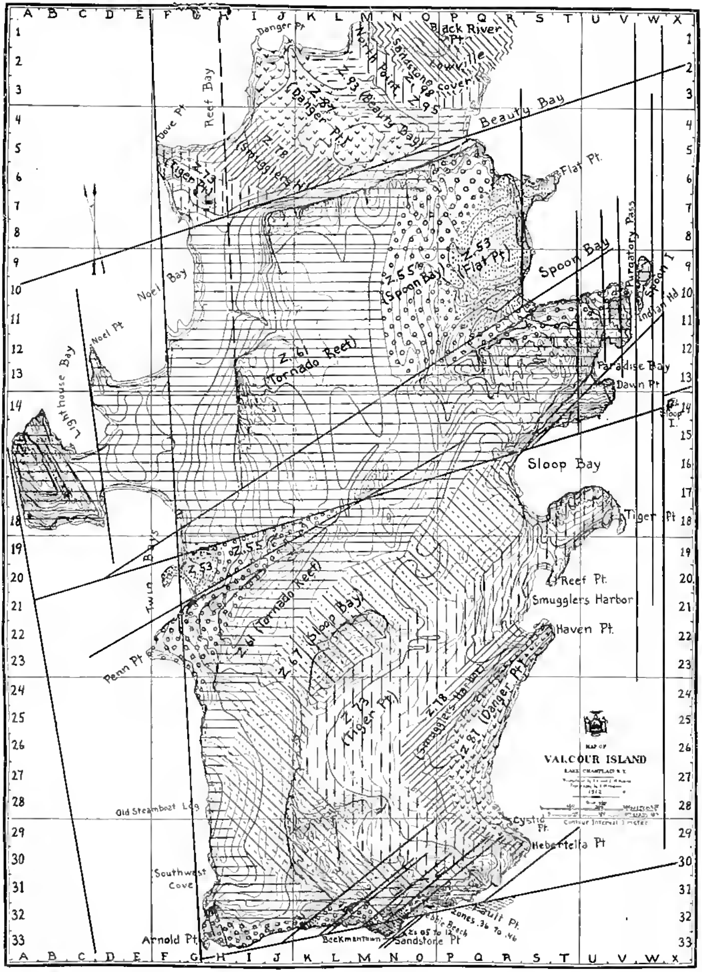


Figure 20 Map of Valcour island, Lake Champlain, showing known faults and the zones of the Chazy limestone beds

# THE DIKE INVASIONS OF THE CHAMPLAIN VALLEY, NEW YORK

BY

George H. Hudson

No special or detailed study was given to the dikes of the Champlain valley until Kemp and Marsters undertook this work in the summers of 1889 and 1890. They visited most of the known dike localities of this region and collected specimens for petrographical examination. The result of their studies was published by the United States Geological Survey in 1893 as Bulletin 107.

Plate 1 of their bulletin presents a map of the territory visited and shows an area which includes all or nearly all of the four counties bordering Lake Champlain on the New York State side and the same for four counties on the Vermont side. The area shown is 65 miles across from east to west and 115 miles from north to south. Outside of this they listed a few scattered dikes. Of these they said (loc. cit., p. 15): "The most southerly one described in this paper is from Dorset mountain (called also Mount Eolus) in the town of Dorset, Vt., and lies just below the southeastern corner of the map. A dike is also recorded in the Vermont Reports (Vol. 11, p. 588) from South Vernon which is in the extreme southern township of the state, and others are mentioned from Mount Holly which lies east of the limits of the map. South of Vermont, in western Massachusetts, but one dike has been mentioned. This is in the Hoosac Mountain near the Vermont State line." The most southerly mentioned for New York State are one near Glens Falls and one in Saratoga. On page 17 they say: "The records of the west side of the Adirondacks are less complete, and our reading has discovered no mention of dikes."

If we take the strip of territory lying between 73 and 74 degrees west longitude and 43 and 45 degrees north latitude it will include all the dikes mentioned by Kemp and Marsters except those at South Vernon and Mount Holly, Vt., and the one of Hoosac mountain, Mass. In this area 126 of their dikes lie north of 44 degrees and some 30 dikes south of it. More recent study of the region by Perkins, Cushing and others have largely increased the number known in the northern half and these now outnumber those in the southern half in the ratio of 10 to 1. As this northern area is one of exceptional interest we present a map of it here (figure 16).

In each township of this map will be found a figure representing the number of local dikes so far known. An attempt has also been made to show the distribution of special kinds by outlining the areas in which they are found. South and west of the curved line of dashes but still within the limits of the region mapped there have been found 181 diabase dikes. The field extends into Franklin county on the northwest where 40 additional diabase dikes are known (Cushing, 1905, p. 346) but most of these are in the eastern part of the county. At the eastern border of Hamilton county they practically disappear. Our map does not allow us to complete the boundary of this field but its western border would be concave. Occupying a relatively small area in the northern part of this field is a region which also contains a distinct and interesting group of 26 bostonites (syenite porphyries) only one of which lies outside of the county limits. Twelve of these were recorded by Cushing in his paper on the Geology of Clinton county (1897, p. 518–26), but he subsequently added to the number discovered. The 19 known camptonite dikes occurring in the mapped region all lie in the territory outlined by alternating dots and dashes. It is possible that the camptonite dikes of the South Granville and Whitehall region were connected with this field but as no dikes of this character have yet been found in the interval between that region and the one here outlined it has been deemed best to treat this as a separate field. The 33 bostonites of Kemp and Marsters tabulation (*loc. cit.*, p. 55–59) lie close to or within the southwestern portion of this camptonite territory, and the area which includes 58 monchiquite dikes lies also almost wholly within the local camptonite field and encroaches on that of the bostonites.

There is much that is significant in this distribution. We must note, first of all, that the northern and eastern boundary of the area of diabase dikes lies very near the old margin of the Precambrian Adirondackian land and that these dikes are most numerous along this margin. We should next note that the more circumscribed dike areas lie along this same border; slightly concave toward it, and strongly convex away from it. While some of the undetermined dikes may necessitate a change in these borders, the large number on which these studies are based will hardly allow such change to mask the essential characters here presented.

The position and form of these areas strongly suggest along-shore conditions as controlling factors of several successive igneous invasions and this suggestion becomes still more emphatic when we realize that the more eastern crescent-shaped areas are precisely where the Eopaleozoic sediments attained their greatest thickness. This thickness must have reached over 8000 feet, and the pressure at the base must have been as high as a million tons per square foot or some 18,000,000,000 tons per square mile. The old Adirondackian sea floor was depressed to a distance practically equal to the thickness of the sediments which covered it. As these deposits were thicker near the margin of the old continent and thinner farther out at sea, and as the thick and heavy portions must have been wider off river mouths and narrower on either side along the convex coast, it follows that the depressed areas, or local sagging basins, would have to be more or less crescent shaped, and with their convex margins next the ancient shore line. The three eastern fields suggest also the presence of an old Adirondackian river, perhaps an ancestor of the present Ausable, which on the whole discharged its sediments off the town of Chesterfield, N. Y., and built a delta reaching toward Burlington, Vt.

To realize the local effect of this load, let us imagine a great area of crystalline or granitic rock say ten thousand feet or more thick and being bent downward in a restricted portion to a depth of 8000 feet. It must readily be seen that so thick a mass of rock could not be thus bent without subjecting its lower portions to an immense stress which would there tend to produce fissures whose walls would spring apart to form mouths whose openings from wall to wall would widen downwards. Should fissures be developed by this cause they would tend to run parallel with the main axis of the trough, but as the central portions of the crescent are also bent down farther than its ends there would be, in addition, a tendency to develop transverse fissures. Does the actual direction taken by the monchiquite dikes give any evidence that the forces mentioned above were factors in their formation?

If the 29 monchiquites whose direction is known should be plotted on figure 1 we should find that in the northern part of the area they would markedly follow the direction of either the borders or the main axis, depending on their location. In the southern portion of the field, however, transverse fissures seem to predominate. These suggest an additional force and we know from other sources that in past time there was present here a stress greater than the one due simply to local increase of sediments. This new stress was a thrust from the east so great as to pass both the limits of elasticity of the local rock and any compensating molecular movement tending to reduce stress. This thrust culminated in the uplift and folding of the whole Appalachian system. It was strongly resisted by the solid crystalline mass of Adirondackia and particularly so off the northeast corner of Essex county, N. Y. The gigantic stresses produced here not only caused innumerable fissures but gave rise to deep seated crushing and the development of great heat.

If under the conditions now presented any fissure should be started well within the mass of the sinking basis the sudden relief from the great tension due to weight of mass above would cause the walls to quickly spring apart. If for any reason the rock mass below the horizon of fracture should have been heated nearly to its temperature of hydrothermal fusion at this tremendous pressure, the sudden relief of pressure along the line of the opening fissure would allow the rock below to liquify and rapidly fill the fissure. Upper portions of the ascending lava sheet would be frothy, for relief from pressure would allow imprisoned gasses to expand. Lava when cooled in this condition would have its rounded cavities subsequently filled by mineral matter carried in solution. The geologist usually interprets this amygdaloidal condition as evidence that the lava cooled near the surface of the land where it would be comparatively free from the pressure supposed to be always present at great depth. For our dikes such an interpretation would certainly be in error for many are amygdaloidal in middle Chazy beds, a position which at the time of the invasion was some 4000 feet below the surface. We must therefore seek a cause which would not only produce but which would for a time maintain a relief from great pressure at these depths.

We have seen that the downward bending of a mass of crystalline rock would produce a tension in its lower portion that would compel the walls of a fissure to spring apart, as soon as the limit of elasticity was passed and a break occurred. At the same time the thrust present in the upper portions of the bending block would keep the fissure walls tightly pressed together and perhaps even prevent the fissure itself from reaching the surface. The deep wedgelike cavities so formed would thus at first approach the conditions of a vacuum. Such a condition could not long exist because of ascending gasses and rapid filling with molten matter. Should complete filling take place before cooling the restoration of pressure would destroy all temporarily formed gas bubbles. Anything tending to offer resistance to the filling, such as the rapid cooling of the advanced portion of the invading mass, due to its fluid movement for long distances over cool walls or increased friction due to narrowing walls, would tend to prevent loss of bubbles through compression.

Then again let us suppose a sudden widening of a filled fissure, due to its lineal and lateral extension, to take place after partial cooling of its contents; the relief of pressure along the middle or unsolidified portion of the formerly filled portion would make it amygdaloidal from top to bottom and with the largest bubbles along the central zone where the mass was least viscous. The fourchite dike at Cliff Haven was apparently sprung wider apart soon after the first filling and had its new central cavity refilled, but not before the relief from pressure had allowed of gas expansion in the softer parts of its former filling. The chilling due to this gas expansion rapidly solidified the inner portions of the older walls and the second invasion did not destroy the two separated bands of bubbles already formed. The present appearance of this dike is shown in figure 17. The Reef Point dike (augite camptonite) of Valcour island presents an instance of a series of fillings which occurred rapidly one after the other as the result of sudden extensions and consequent widenings of the fissure (figure 18). This dike shows also a conspicuous flattening of many bubbles along its middle central portion which was apparently due to lateral compression before solidification of the last injected mass. Some of our dikes, such as the McMartin quarry monchiquite at Plattsburg, are solid and resistant in one portion, but in another, and at the same level, so amygdaloidal as to weather rapidly to a condition in which they may be crumbled to pieces by the hand. We also find dikes which are very amygdaloidal in a branch but not so in the main body. These conditions may be easily accounted for if we accept the hypothesis offered above.

If this hypothesis as to the origin of the local dike fissures is correct we should find them wider in their deeper portions and narrowing upward to complete closure before reaching the ancient surface of the land. There is evidence that they had this form but in order to understand it we must bring to mind certain changes which the Champlain valley has undergone since the periods of dike formation.

In this valley the fault blocks along its axis sank the deeper and those on its western edge were to a lesser degree elevated. The rising or sinking of certain blocks was very marked and at the completion of adjustment a bed of Canajoharie age sometimes found itself left in the same horizon as the Chazy bed of a neighboring block. Subsequent erosion planed down the upper portions of these blocks until their exposed surfaces were brought to nearly the same level.

The result was to give the valley floor the appearance of having been inlaid in a curious mosaic or checker-board pattern, with blocks varying greatly in kind and age. If the later dike invasions occurred before any great vertical displacement along fault planes had taken place, it would follow that on the present surface we could find cross sections of the dike-built endoskeleton of the valley which would show the variation in width all the way from horizons originally below the old Adirondackian rock floor to those as high as the remaining portions of the Canajoharie shales. We will here compare some of these cross sections as to width and see if they bear out our suggestion of a wedge-shaped fissure with its edge uppermost.

In the lists of Kemp and Marsters (1893) and Cushing (1897) measurements are given for 133 basic dikes now exposed at different geological horizons in the old Adirondackian land. Their average width is 4.7 feet. In the same lists together with those of Perkins (1902, p. 176–83) and those to be described in this paper, measurements are given for 101 basic dikes exposed at different geological horizons in the Eopaleozoic rocks of the region. Their average width is but 2.4 feet. If we may consider the former average as fairly expressing the probable mean width of the latter group where they cut through the Pre-Cambric floor, we must conclude that in rising some 400 feet they have narrowed down 2.3 feet or at the rate of 6.7 inches per 1000 feet. In the next comparison we shall limit our data to one particular kind of dike and to a still more limited field: that presented by southern Grand Isle township and South Hero, Vt. In the western side of this field we find 14 monchiquite dikes which cut Chazy and Black River beds at the surface and average 23.7 inches in width. In the eastern side of this field are 13 monchiquites, many of which are doubtless extensions of the dikes already averaged. Here, however, they cut Canajoharie beds and their average width at this horizon is but 14.3 inches. The mean vertical distance between the original horizons of the compared cross sections is not far from 1000 feet and the rate of closure is therefore about 9.4 inches in that distance. The narrowing here is along lines parallel with the field margin and is more certainly due to difference in original horizon. The last average should thus be worthy of the greater confidence.

That the two averages (6.7 in. and 9.4) should vary but 2.7 inches among themselves, although obtained through the comparison of such different groups, is significant. The greater rate of closure where sections in Chazy and Canajoharie beds were compared may simply mean that all fissures did not rise to the same height and that the greater number of fissures cutting the deeper beds reduced the rate of recession in individual fissures. In any case it seems best to use the 9.4-inch rate in attempting to answer the question as to whether or not any of the Grand Isle dikes ever reached the old surface of the sediments into which they were injected and there produced local outflows of lava.

The greatest width of the 13 monchiquites and three camptonites cutting the Grand Isle Canajoharie beds is 30 inches. At the rate of closure of 9.4 inches a 1000 feet it would take but the restoration of 3192 feet of removed sediments to bring this fissure to its horizon of closure and thus completely hide the dike endoskeleton of this township. That the fissures were actually closed above the Canajoharie is indicated negatively by the fact that the Champlain valley shows no trace of any surface outflow. The evidence here presented as to the form of the fissures and their closure above is decidedly in favor of the hypothesis advanced to account for the formation of the dikes of the Champlain valley. Fissures which do not reach the surface but which widen below and increase in number with depth must be due, in part at least, to a deep seated tension produced by downward bending in response to increase of load.

The conclusions here drawn must be subjected to review when still more of our Champlain valley dikes are known and when branching fissures have been determined and properly considered. The results obtained from present available data, however, are suggestive,

When more of our dikes become known; when more accurate measurements are made of the dike widths, and these are given for both ends of an exposure; when small and closely set branches of a dike are added to the major fissure of which they form really a part; and when additional examples of the faulting of dikes are made to show still more clearly how much of the faults movements occurred after the dike injections; then we shall be in a better position to show the rate of fissure widening with descent.

The problem may also be approached in a different manner. If when the dike fillings took place there were a number of fissures that did not reach so near the surface as did others it would follow that in equal and contiguous areas there should be more dikes cutting Chazy deposits than those cutting Trenton.

Beginning with the Southwest Cliff dike of Valcour Island, and following the order given in Appendix I we cross 17 dikes cutting Chazy deposits. Of these, five at least should be considered as dike branches, thus leaving an average of six dikes to the mile which must be crossed on passing along a line leading to Cumberland Head. Crab island has but one dike, a fourchite, and for nearly three miles of the east coast of Cumberland Head no dikes are in evidence.

There is, however, one large dike cutting Cumberland Head shales at Martin's bay. Starting southerly from this dike and following the shore to Cliff Haven we find but two narrow dikes cutting the Canajoharie on west shore of Cumberland Head and two cutting the Trenton, the Plattsburg barracks and Cliff Haven dock dikes. From here southerly, in about half the distance already passed over, we cross six dikes cutting Chazy exposures. One of these, the golf links middle dike, should be considered as a dike branch. In eastern Plattsburg and Peru townships, not including Valcour and Crab islands, there have been found so far three dikes cutting Trenton and six cutting Chazy, for in this grouping we may add the Martin's quarry monchiquite to our list. If the two omitted islands be added it will not increase the number of dikes cutting Trenton, but it will add very considerably to those cutting the Chazy exposures.

On southern Grand Isle a similar condition seems to exist. On Perkins' map (1902, opposite p. 102) we find between Rockwell bay and Phelps Point two exposures of Chazy beds along the coast that are cut by 6 and 8 dikes respectively, a total of 14. The sum of the length of these two coast lines would be contained two and a half times in the distance from Allen to Kibbie Points, and if dikes were equally numerous on the southeast shore of Grand Isle we should find there 35 dikes cutting the Canajoharie shales. Perkins' map shows but 19 or but little more than half of 35.

If long enough lines of bare areas could be compared and dike directions and width noted it would not be a difficult problem to measure the extension per mile in which the dike fissures cut the Eopaleozoic rocks in different regions of the present exposed surfaces. In contiguous areas, as in Southern Grand Isle or the eastern portion of Plattsburg and Peru townships, we believe that this extension would be found to be least for the highest geological horizons and greatest for the lowest.

We have stated that the starting of lines of fracture and the formation of local molten magmas were without doubt largely due to thrusts from the east. The tabulation then of fissure directions may lead to important conclusions and we here present such a table, grouping dikes of a kind together, but subdividing such groups to bring out differences due to locality.

**Average strike of dikes arranged in groups showing differences in kind and location**

| AUTHORITY | KIND | LOCATION | NUMBER FOR WHICH STRIKE IS RECORDED | MEAN STRIKE IN DEGREES WEST OF NORTH |
|---|---|---|---|---|
| Kemp and Marsters | Camptonite | South Granville, N. Y.<br>Fairhaven, Vt.<br>Summit, Vt. | 4 | 130 |
| Kemp and Marsters | Diabase | Essex co., N. Y. | 18 | 105 |
| Cushing | Diabase | Clinton co., N. Y. | 78 | 103 |
| Kemp and Marsters | Camptonite | Northeastern Essex co., N. Y., and opposite Vt. shore | 9 | 93 |
| Cushing | Bostonite | Clinton co., N. Y. | 11 | 92 |
| Kemp and Marsters | Bostonite | Northeastern Essex co., N. Y., and opposite Vt. shore | 21<br>21 | 81<br>81 |
| Kemp and Marsters | Monchiquite | Southern part of field | 10 | 77 |
| Hudson | Camptonite | Peru, N. Y. | 6 | 76 |
| Kemp and Marsters, Cushing, Hudson | Monchiquite | Northern part of field | 24 | 74 |

Near the close of Eopaleozoic time the eastern shore of the old Adirondackian crystalline mass ran practically due north from Fort Ann to Port Kent, a distance of over 150 miles. The most eastern extension of this great barrier was at Split Rock on Lake Champlain, but the extension of the Trembleau Mountain headland as indicated by Schuyler island and the reef to the southeast must have nearly equaled it. Any thrust from the east (or from a little north of east) during the middle or late Paleozoic sub-eras would here have met greatest resistance. Between these two points and in the region immediately east the Post-Cambric dikes are most abundant, most varied in character, and reach their greatest observed width. Here too occur true laccolites or intruded lava sheets which we shall refer to later, and the Eopaleozoic sediments which were locally metamorphosed by heat and pressure. The excessive heating in this locality must have been due largely to deep-seated crushing of rock, although undoubtedly intensified by the chemical action of surface waters admitted through the great faults of the region. As the resistance must have been greatest at the headlands mentioned and not so great between them, the dike-filled fissures of this locality ought to indicate the direction of any thrust producing them. If from the above table we take the diabase and bostonite dikes of this region we shall have a total of 39 whose average strike is N. 92° W. The nine camptonites are in remarkable accord with this figure, their mean strike being N. 93° W., and we can not be greatly in error if we accept this direction as that of the thrust producing these camptonite-filled fissures.

If on either side of our 150-mile front the shores of the Adirondackian mass receded markedly toward the west the relief from pressure thus afforded should find its expression in a very noticeable change in fissure direction. Along the northeastern border they should run more northerly and along the southeastern border more southerly, in each case tending to approach parallelism with these borders.

East of the line from Fort Ann to Saratoga Springs the old Adirondackian shore probably ran about N. 145° W. for some 60 miles. On the Saratoga quadrangle (Cushing and Ruedemann, 1914) are 5 diabase dikes whose mean strike is N. 151° W. or 46 degrees more toward the south than the 12 diabase dikes of Essex county. In table I we have the mean strike of four camptonite dikes near Whitehall. These run N. 130° W. or 37 degrees more toward the south than the nine camptonites previously given. The change in trend due to relief from pressure is here very evident.

Taking the northeastern border of Adirondackia we find the trend northwesterly from Port Kent for some 60 miles to be about N. 35° W. That this border extends southeasterly into Lake Champlain is shown by a partly buried river channel which lies near the Vermont shore in the vicinity of Shelburne Point and crosses over toward Valcour island. The trend of this bend in the old river runs N. 35° W. for nearly nine miles as is shown by the long axis of the area of soundings of over 200 feet in this part of the lake. In two places soundings of over 300 feet are reached: at one mile west-southwest of Juniper island is one of 335 feet and just to the left of Colchester Shoal is one of 332 feet. This bend in the old buried river undoubtedly follows the line of contact between Proterozoic and Paleozoic rocks and indicates a now buried southeastward extension of the Trembleau Mountain mass. Its trend is also subparallel with a line extending from Trembleau Point to Schuyler Reef. If we consider the Lyon Mountain outlier, however, we must make our trend more nearly N. 25° W. In any case the turn to the west here would not give so much relief from a N. 93° W. thrust as did the turn in the southeastern border near Fort Ann. The influence on the Post-Cambric dikes is therefore not so marked, yet the strike of the six camptonites of Peru, N. Y., averages N. 76° W., showing a swing of 17 degrees to the north of the trend of their near neighbors on the south. Table I also shows that the monchiquites followed the new lines of least resistance, for 22 of them, in the northern part of their field, average N. 74° W.

We have already recognized a sinking borderland or downfall as an influence tending to produce fissures widening downward, and have pointed out that fissures so influenced should tend to run parallel with the long axis of the sinking basin, although if this sinking was more rapid in certain areas along this axis cross fissures would tend to form. In the known westward thrust which folded the Appalachian system we may recognize a force which not only assisted in fissure formation in the sinking areas but which to a large extent influenced their direction.

There is an alternative hypothesis that we may use and that is that our dikes represent the outer zone of some ancient volcanic center. If we plot the mean strikes of the camptonites as given in table 3 we shall find a provisional radiant for these dikes at a point some 80 miles easterly or near South Lancaster, Vt., and not far from Mount Star King and Mount Waumbek. Kemp and Marsters, however, referred the local activity to a focus some 80 miles northerly or in the neighborhood of Montreal, Can. They say (1893, p. 36, 37): "The fact that the camptonite, monchiquite and fourchite dikes are almost invariably associated in other localities with eleolite-syenite, has often been referred to in the preceding pages. It is our belief that their presence in the Lake Champlain valley indicates that eleolite-syenite is somewhere in the region. . . . Near Montreal eleolite-syenite does occur and is associated with rocks such as we have described . . .. It is within the bounds of reason that the Lake Champlain dikes are the extreme southern manifestation of the eruptive action chiefly shown across the national boundary forty to one hundred miles from their principal outcrop." Cushing on the other hand, says of Rand Hill, N. Y. (1905, p. 346): "The display of dikes there is the most impressive known in the Adirondack region. If any volcanoes were built at the time, surely the roots of one gigantic one are here," but he at the same time follows this statement with a paragraph in which he gives evidence which tends to show that these dikes did not reach the ancient surface.

We may point out that our data for half the known dikes of the region under study is as yet incomplete or lacking in desired accuracy and that other fields must be made to contribute more fully before a decided answer can be given as to ancient causes. We should admit, however, that the causes which give rise to any deep seated reservoirs of molten rock need not necessarily continue until actual outpour occurs. It should be a reasonable assumption that more subterranean magmas are formed than the number that reach the surface and that such magmas may produce locally circumscribed areas of dikes which become revealed only by long continued erosion. If the birth of the Green Mountain range could be celebrated by "fireworks" at Montreal why might not Plattsburg and Whitehall prepare for independent displays? We shall turn now to evidence that two or more distinct periods of igneous activity are represented by our dikes, and the data to be presented will help to clarify our problem.

Kemp and Marsters noticed the peculiarity of the distribution of diabase and camptonite dikes but attributed it to local influences. They wrote (1893, p. 27): "The true diabase dikes are principally if not entirely found in the crystalline Archean areas"; and again (p. 27): "It is notable that in the dikes of the Lake Champlain region the diabases are in the areas of crystalline rocks of Archean age, while the camptonites are in the later stratified rocks. This would necessitate the passage of the refused magma of the latter through a much greater thickness of rock before it reached the surface or at least before it solidified;[1] while the diabase has chilled nearer its parent mass.[2] It may be that the wall rock has exerted some influence; certainly the camptonites must have remained molten longer."

To Cushing we owe the first recognition of the fact that the diabase and bostonite dikes now exposed in surfaces of Proterozoic age are millions of years older than the dikes cutting Paleozoic sediments. The "peculiarity of distribution" and the fact that "All along the northern line of contact between the Potsdam and the older rocks in the county (Clinton) the diabase dikes are found numerously on one side of the line and not at all on the other" (1897, p. 516) led him to express the opinion that these dikes had been injected and worn down nearly to their present horizon before the Potsdam sandstone had been deposited and that the northern and eastern limits of their field were now hidden from view by the remaining portion of the Eopaleozoic cover. The resemblance of these rocks to those of the igneous outflows of Keweenawan time led Cushing (1905, p. 347–48) to conclude that they probably were of the same age.

Of the Clinton county bostonites he says (1896, p. 13): "The writer has heretofore classed these with the trachytes (bostonites) but they present constant differences when compared with the Lake Champlain bostonites, and evidence is accumulating that they are distinct in age. They are quite numerous in Clinton county and in the eastern part of Franklin, and have not been seen cutting any but

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[1] This is equivalent to stating that the source of the molten magma was farther below the surface where the latter was of stratified rock.

[2] And therefore should have remained the longer molten.

the Pre-Cambric rocks." That this bostonite invasion really occurred before that of the diabase is indicated by an observation of Cushing's. He says (1905, p. 348): "Near the summit of Rand Hill a 15-inch dike of the syenite porphyry, bearing N. 65° E., is cut by a diabase dike of the same width bearing east and west. In this case the diabase is indisputably the younger."

Some of the diabase or the syenite porphyry dikes will yet be traced to the edge of the remaining Potsdam cover and if they pass under but not through the latter the evidence of a separate age will be rendered absolute. Further studies on Valcour island may also reveal testimony fully as decisive in its character. In the Chazy bed of blown sand pebbles there occasionally occur dark grains reaching some three or more millimeters in diameter and resisting the action of hydrochloric acid. If the dikes here under discussion were really present in the old Adirondackian or other near-by land at the time when the great wind storm brought its layer of pebbles to Valcour island, then it ought also to have borne some pebbles made of diabase or syenite porphyry, and if but a single pebble of such character be found in this bed it also would positively affirm the presence of these dikes in the region before Chazy time.

That the Adirondackian bostonite and diabase invasions occurred late in Proterozoic time is shown by the fact that although both cut through rocks already rendered highly metamorphic yet they themselves were subjected to no such change save possibly next to the western border of the last bostonite invasion. In other words the Archaeozoic and Proterozoic sediments and lava outpours had already been buried, crushed and heated until little resemblance to their former condition remained and after this they had been lifted from the sea and profoundly eroded before the first bostonite invasion occurred. This invasion thus dates back to a period some 500,000,000 years ago and only the acidic or lighter portions of the magma reached the horizon now exposed. Later a more extended invasion of basic lava occurred.

If the earlier bostonite area was due in part to the sinking of an off-shore basin of Proterozoic sediments it indicates a very great age for the northwestern Adirondackian borderland and a persistence of geographical features due to some still more ancient and profound cause. It is interesting also to note that the fissure problem is simplified by referring the diabase-filled fissures of Clinton and Essex counties, with their trend of 103 and 105 degrees west of north, to a period antedating the later dikes by possibly 200 million years. If the mean strike of the dikes of any restricted area is due in part to lateral thrust, a marked change in direction of any set of dikes of the same area must be due to a change in direction of thrust and such marked change would indicate a marked lapse of time between the different invasions. On this principle we should say that the early bostonite and diabase invasions were separated by a considerable interval of time during which the direction of thrust moved from N. 92° W. to N. 103° W. or through some 11 or more degrees of azimuth, but before we can be sure of the 11 degrees' difference we need to have the direction of more of the bostonites and need also to exclude what may be short branches or dike portions crossing from one fissure to another.

Of the Post-Cambric dikes we know that the monchiquites preceded the bostonites for as we shall see the latter cut through the former at Nash's Point, Vt. Sixty monchiquites have been found in the area outlined on map I and although this number doubtless includes some cases in which two distant portions of the same dike have been listed, further study will reveal a still greater number of these monchiquite-filled fissures. There is a marked tendency in these dikes to run parallel to each other in any restricted area but the more northern dikes seem to begin and end in more advanced positions, that is, farther west-northwesterly along the general fissure direction. This herringbone pattern taken together with the widening of the fissures near the middle of their exposed sections seems to speak also of a more northerly component of the thrust acting on the field; a thrust meeting greater resistance nearer the old Adirondackian border and less resistance farther to the northeast of that border.

The later bostonites are easily recognized in the field by their "prevailing light tint which is usually a creamy or brownish white, but which is also in instances a light chocolate" (Kemp and Marsters, 1893, p. 18). During the invasion of this acidic rock the pressure was so great that the lava was squeezed in between certain beds of Canajoharie age and there formed lens-shaped masses or *laccolites.* These grew in size like blisters under the skin and gradually lifted the beds above, two thousand or more feet thick, into low domes. One of these laccolites occurs at Cannon's Point on the New York State shore. Another occurs at Nash's Point, Vt., and its spreading intercalary sheet cut across two older dikes one of which (Kemp and Marsters, 1893, p. 52) may "still be traced in the thin cap of overlying shale." Still another occurs at Charlotte, Vt. (loc. cit. p. 53) "covers about 20 acres and rises 150 feet above the plain." These three laccolites show conclusively that during their formation the fissure feeding them did not open on the surface, for any outflow would have given relief to the pressure that here actually lifted and bent at least two thousand feet thickness of the Ordovician cover. Dike no. 113 of Kemp and Marsters' list (1893, p. 59) is not far south of Nash's Point and is 40 or more feet wide. It is hard to believe that this dike did not produce a true overflow yet it also may have simply fed a higher laccolite, since worn away.

The camptonites are basic dikes some of which are so like diabase as to be with difficulty distinguished from the latter. Dike no. 587 of Kemp and Marsters (1893, p. 57) is listed by them as diabase but as it cuts Canajoharie shale it can not possibly belong to the first diabase injection. The Spoon Island dike of our present paper was analyzed by Cushing as a diabase but its Spoon Bay extension is at the same time designated as a camptonite. We have already seen that Kemp and Marsters attribute the difference in character of these dikes in part to relative speed in cooling though it is not clear why they suggested that the diabase "nearer the parent mass" cooled more quickly. That the monchiquites and later bostonites reached near the Adirondackian Pre-Cambrics without cutting their present exposed margins is a fact of unusual significance but we can not assert that the camptonite-filled fissures of the region show in Post-Cambric beds only. The diabase dikes which are now exposed on Pre-Cambric surfaces but which yet grade toward camptonites may be Post-Cambric in age. In tabulating strike we have avoided most dikes of this intergrading character. As the camptonite field was more extended than that of the monchiquites we might expect to find a complex of diabase and camptonite in the uncovered Adirondackian border, and the dikes of this locality should have more careful study.

In this connection we should note that a single hornblende-fourchite is listed by Kemp and Marsters (1893, p. 56) as cutting the norite of Bouquet mountain west of Essex, N. Y., while a single fourchite also cuts the Trenton at Cliff Haven and Crab island.

The relative age of the camptonites is as yet unknown. Though there must be many places in the region presented by our map where camptonites either cut or are cut by monchiquites or bostonites, such intersections have not yet been seen. Kemp and Marsters credit the Willard's Ledge dike near Burlington, Vt., with Pre-Cambric inclusions but they are not abundant and no other camptonites seem to show them. In any dike a few fragments of its own wall might occur; it is the abundance of fragments brought up from the deeply seated Grenville series in dike localities miles apart that leads us to postulate for the monchiquites an outflow cutting across a comparatively young horizontal thrust fault whose broken Grenville walls had formed an enormous quantity of rounded cobbles which were in a relatively free or uncemented condition. We would suggest then that the camptonites were injected either before this deep-seated fault movement took place and therefore before the monchiquite invasion or at a period after the bostonite invasion. As the more widely spread Pre-Cambric diabase invasion followed that of the early bostonite it may be that the more widely spread camptonite followed the late bostonite and at a period when the fragments filling the deep-seated thrust fault had been, in part at least, re-cemented. When the strikes of these dikes are better known and when we can deal with a greater number of examples it may be that a real change in direction of the fissures will lead to a more profitable discussion of age. We have endeavored to show that a series of local molten magmas were formed in large part by crushing due to gigantic thrusts from the east. Such thrusts occurred at the birth of the Taconic mountains and again during the Appalachian revolution. Kemp and Marsters have suggested the earlier of these periods as the time of invasion of all the dikes. They say (1893, p. 36): "The Montreal syenite and related rocks are shown to have been intruded after the Trenton period, whose limestones they cut, and before the Lower Helderberg, to whose conglomerates they have furnished rolled bowlders. This would place them at the close of the Lower Silurian or in the early part of the Upper Silurian. It will at once occur to one familiar with the Green mountains that they were elevated at the close of the Lower Silurian and were formed in one of the great upheavals of New England. We think it probable that the intrusion of the dikes was caused by this disturbance. Outpourings or intrusions of igneous rocks almost always attend mountain-making action, and it is reasonable to suppose that the Green mountains have been no exception."

Cushing on the other hand was inclined to accept a later date for the Post-Cambric invasions for in 1905, p. 397, he said that he had "recently come to the belief that a Carboniferous age must be assigned to them, though this is not possible of demonstration at the present time."

We will hold, subject to revision, that of the Post-Cambric dikes the monchiquites and bostonites are the earlier and were injected some 200 million years ago or during the development of the Taconic mountains. The camptonites and fourchites we shall, for the present, refer to a date as late as 150 million years ago. That the camptonites fall into a class by themselves is indicated by the large territory they occupy, their small number in any limited area in this territory, their great variation in strike, their penetration of the margin of the Pre-Cambrics, and their practical freedom from crushed and ground inclusions of older rocks.

This chapter has gone into detail rather freely, not because of a desire to have its conclusions accepted but to impress on observers the need for more complete and accurate data. In other words, we have tried to exemplify the old adage "many a straw will show the way the wind blows." The difficulty with our conclusions lies in the fact that so many observers thought the straws (strikes, length exposed, dip, width, exact location, kind of dike, extent of wall metamorphism and whether or not the walls showed any vertical displacement) not important enough in all cases for record or at least for exactness in record. As a result of this imperfection we have been able to use the testimony of but *about half of the dikes now known to exist in the region* and the other half may yet modify or upset some of our conclusions.

It has also been our desire to show that nature has probably left a very definite and clear record of the causes and sequence of her igneous activity along the northeastern Adirondackian border. If we do not yet present it properly and in a convincing manner it is because we have tried to interpret before seeing all the evidence. The time is certainly ripe for the study of more minute details and for greater accuracy in field work.

Let us briefly summarize the contents of this chapter. We found the upper Champlain basin particularly rich in dikes, the different kinds occupying crescentic areas bordering the old Adirondackian shore and with their concave sides toward it, thus suggesting long continued and heavy along-shore deposits as an important contributing cause of their formation. This idea we found to be further strengthened by the study of the dikes themselves. The comparison of dike width in greatly eroded areas with that in the least eroded indicated a downward widening of all fissures at a rate of between eight and ten inches in a thousand feet and this thin wedge shape with edge uppermost was also corroborated by comparisons between cross sections of the same kinds of dikes in Chazy and in Canajoharie beds. Allowing for subsequent erosion of surface, the gradual upward closing of the fissures led us to conclude that no dikes reached the ancient Paleozoic surface of the country, a conclusion supported by the formation of laccolites in more fissile strata and by the fact that continued flow could not have taken place through the fissures without subjecting the dike walls to a long continued and higher temperature which would have made them more or less metamorphic in character. That the filling was made by the suddenly ejected uppermost portion of the magma, semifluid until released of stress, is shown by the upward sweep of Grenville rocks for some 6000 feet and the sudden cooling and stiffening of the mass before these could fall back, as they might have done had the filling remained fluid. These inclusions were heated enough to crack them open but not enough to render them metamorphic save to a very slight extent. In this connection the Grand Isle monchiquites should be examined on their eastern and western ends to see if the up-rush carried these fragments into Utica beds. The suddenly injected material was rapidly cooled in places by contact with colder walls and, as soon as relief from greater pressure was secured, by gas expansion. The duplicated amygdaloid zones also show that filling occurred before certain extensions or adjustments of the fissure walls could take place and these widenings or closings either produced twin zones of gas bubbles or flattened out those already formed. The marked amygdaloidal character of certain dikes was seen to be no indication of near surface conditions and therefore of late filling. Fissures and fillings of the character described speak of deep-seated yieldings to stress in loaded and local sagging basins. In addition, however, to this stress from load there was another stress which was doubtless associated with great rock foldings in more easterly regions. Such were specially manifested at the time of the Taconic and Appalachian uplifts. These thrusts from the east appear to have differed somewhat in direction in different ages and to have been further modified by the form and resistance of the old Adirondackian headland. This was shown by the tendency to become deflected towards parallelism with receding shore lines and by the herringbone pattern of the more northern dikes of the region.

We have seen evidence showing that the dark bostonites antedated the diabase and that both invasions occurred long before the deposition of the Potsdam sandstone. The lighter bostonites, the monchiquites, camptonites and fourchites all occurred after the deposition of the Canajoharie beds, for the latter are cut by them. That the dikes differing in chemical composition, or in the character and arrangement of their glassy or crystalline contents, also differed in age is shown by the restricted yet often overlapping areas which each kind occupied; by the restriction of certain kinds to Pre-Cambric rocks and the addition of their worn fragments to later deposits; by average difference in direction of strike; by intersection of dikes of different kinds; and, in the monchiquites, by the fact that they alone brought up a profusion of rounded Grenville fragments, thus showing that their invasion occurred soon after the formation or renewed movement of a deep-seated thrust fault and before the fragmented zone was re-cemented. The monchiquites thus also tell us something of crushed and nearly horizontal fault planes which formed some 8000 feet or more below the old Siluric surface of the country and whose fragments were rolled and rounded by movement in the crushed zone. Some of these rounded cobbles are shown in figure 19. See those marked "a," "b," and "c." Many sharply angular fragments, such as "d," were probably from larger cobbles cracked by heating.

The sequences and approximate dates of these igneous invasions are in part determined by evidences enumerated above. The fact that certain faults cut the dikes show that in these instances the dike invasion preceded the faulting and the fact that average dike cross sections, now at practically the same level, have markedly smaller diameters in what were formerly the highest beds indicates also that the greater displacements of the faulted blocks of Post-Cambric rocks occurred after the last dike invasion. Additional evidence for this conclusion is also to be found on Valcour island where all dikes cut the bedding planes at nearly right angles. The strongly dragged-up beds east of Pebble beach show two monchiquites markedly tipped from the position they held at the time of their injection. In only one instance on Valcour island did faulting occur during the filling of the fissure. Just north of Beauty bay is a monchiquite which approaches ouachitite. Of this dike Raymond (1906, p. 520) says: "There is a fault of 1 foot 11 inches between the two walls enclosing the dike, with the downthrow to the north."

## SUMMARY

Evidence is given to show that the fissures of the Champlain Valley dikes were due in part to basins sinking under load and in part to horizontal thrust; that these fissures were widest in deepest portions and closed near the surface; and that invasions occurred at several distinct periods separated by wide intervals of time.

In Appendix I, many heretofore unknown dikes of Peru and Plattsburg townships are listed and analyses, by H. P. Cushing, of 23 of these are given.

In Appendix II, analyses by Cushing of some of the inclusions of the Grenville rocks (brought up by the monchiquites) and his discussion of same are given.

# APPENDIX I

## THE DIKES OF VALCOUR ISLAND AND OF THE PERU AND PLATTSBURG COAST LINE

BY

G. H. Hudson and H. P. Cushing

In this appendix the known dikes are arranged in series depending on location. On Valcour island the list starts with the westernmost dike at the south end, and the series runs thence counter-clockwise around the island. The list for the mainland begins with the southernmost dike of the Peru shore and gives the order going northerly. Each dike is identified and located by marginal numbers and letters on accompanying map (figure 20).

The order of entry is name, kind, locality, strike, width, beds cut, characteristics. Except in two instances all dikes are remarkably vertical. These two are the second and third of the first list and these were very evidently tipped by drag due to major fault movement which occurred after their formation.

From the dikes heretofore unrecorded, specimens were collected and sent to the late Prof. H. P. Cushing. He very kindly determined these and his analyses, here given, are from his letter of February 1, 1909, unless otherwise stated. Those heretofore known were listed in Cushing (1897, p. 518–26). All determinations then are his, unless followed by a question mark. The numbers in parenthesis were numbers given him with specimens.

### THE VALCOUR ISLAND DIKES

**Southwest Cliff dike (1).** Augite camptonite or diabase, K–32 (see figure 20), N. 55° W., 11 in., Middle Chazy dike a little sinuous vertically. Apparently faulted across by a northern auxiliary of the Valcour fault, and slickensided. Northern portion 4 in. west of southern portion.

"Abundant large phenocrysts of augite, which is nearly colorless in thin section, but with lilac-colored borders and crammed full of inclusions, in part arranged zonally. A few small, rotted olivines. Groundmass of feldspar laths, small augites and magnetites and some apparently devitrified glass base. Small calcite-filled amygdules. Feldspar labradorite to bytownite."

**Garden Island dike (4).** Augite camptonite or diabase, N. 55° W., about 2 feet, lowest Chazy. Contains "horst" from its own walls.

"Big augite phenocrysts, often crammed with inclusions, and with more colorless than lilac augite as in dike 1; smaller olivines badly altered, some calcite amygdules. Feldspar laths, augite and magnetite in the fine-grained groundmass, glass base uncertain but probable."

Cushing's likening of specimen 4 to specimen 1 is significant. They are on very nearly the same line though the exposures are about half a mile apart and crossed by the Valcour Cove fault with a displacement of over 500 feet. These conditions speak for verticality of the dike, for a straight course, and for but a small westerly movement of the Valcour Island fault block. The greater width on Garden island would indicate a longer extension southeasterly. In his letter of March 19, 1909, Cushing wrote: "I have no question that it is the same as dike 1. The big colorless augites, crammed with inclusions are the same in each, and the remainder alike except for the finer grain of Garden island, owing to the specimen being nearer the dike margin."

**Southeast Cliff west dike (2).** Monchiquite, Q–31, N. 48° W., 16 in., Middle Chazy (B and S, B5).

"Augite phenocrysts, often large, smaller olivines, badly altered, some calcite-filled amygdules. Big augites, colorless with lilac-colored rim, as in previous, and crammed with inclusions; smaller augites lilac colored. Groundmass of augite and magnetite, a few apatites and some considerable apparent glass base."

**Southeast Cliff east dike (3).** Monchiquite, Q–31, N. 51° W., 17 in., Chazy (B and S, B5).

"Medium sized olivine and augite phenocrysts, latter lilac colored, the larger ones with colorless centers, and inclusions not prominent. Olivine quite fresh, groundmass of augite, brown hornblende and magnetite with considerable apparent glass base."

These Southeast Cliff dikes which are near each other were evidently injected before the formation of the Valcour Cove fault. Their present southwesterly dip is very evidently due to drag which has treated both alike. These dikes could probably be found farther inland, in or near P 29, where the soil is very shallow and where the faulting could not have so markedly disturbed them.

**Southeast Shore dike A (5).** Monchiquite, R–25, N. 80° W., 15 in., Upper Chazy.

"I did not send No. 5 as it appeared too rotten . . . No. 5 then I have not reported upon, and it may well be the same as 6. With the lens many augite and olivine crystals are to be made out so that it is more likely a monchiquite than a camptonite." (March 19, 1909).

**Southeast Shore dike B (6).** Monchiquite, R–25, N. 86° W., 3 in., Upper Chazy.

"Big augites, all with lilac borders, some with colorless, and some with green, pleochroic aegerine-augite centers, many inclusions. Less frequent, very fresh olivines. Fine-grained groundmass of augite and magnetite, with a little brown hornblende, and much dark-colored glass base."

This little dike is not far north of A and can be followed but a short distance. It is probably but a branch from no. 6 and can be found only at low water as it does not cross the present wave cut bench.

**Smugglers Harbor dike (7).** Monchiquite, S–20, N. 83° W., 24 in., Upper Chazy.

"Small phenocrysts of olivine and lilac augite, former badly altered. Coarse groundmass of augite, much brown hornblende and magnetite with a little glass base."

**Reef Point dike (8).** Augite camptonite, T–19, N. 95° W., 38 in., Middle Chazy.

"Abundant and good-sized augite phenocrysts, mostly lilac color, crammed with inclusions. Olivine sparse. Coarse groundmass of feldspar laths, augite, magnetite and some brown hornblende. Feldspar show beautiful flow structure around the porphyritic augites. Augite somewhat gone to chlorite."

A view of this dike is shown in figure 18. A few pieces of an undetermined dike outcrop near an inland cliff. They probably belong to this or the preceding. Could the crossing point of these dikes be found, their relative age could be determined.

**Paradise Bay south dike (9).** Typical hornblende camptonite, U-12, N. 58° W., ?, 29 in. and narrowing somewhat in ascent, Middle Chazy.

"Only slightly porphyritic. A few olivines, badly altered. Rock nearly half brown hornblende, in characteristic laths. Feldspar next in abundance, with much less augite and a little magnetite."

**Paradise Bay largest dike (10).** Monchiquite, U–12, N. 58° W., 41 in., Middle Chazy. Many Grenville inclusions.

"This is a beautiful and quite fresh monchiquite, and likely the same dike mentioned by Kemp from the island (Bul. 107, p. 46). It has abundant phenocrysts of augite and olivine, with a groundmass of sharply idiomorphic augites and brown hornblendes, usually of lath shape and a multitude of small magnetites, set in a base approaching glass in character. Some of the olivines are quite fresh. The larger part of the augite is of a paler gray-lilac color but some of the phenocrysts have a core of green augite of varying depth of color, with an outer border of the lilac augite, and are pronouncedly zonal in character.

"Throughout the rock are occasional roundish patches of colorless material, either isotropic or with very weak and irregular double refraction. Wherever they appear they are accompanied by hornblende, to the exclusion of the other rock constituents; the hornblende increases in grain and the whole colorless area is shot through with its long slender prisms. The colorless material is thought to be analcite." (February 24, 1908)

This dike can be followed inland along practically a straight line for about 600 yards though covered for portions of this distance. It appears again nearly two-thirds across the island at 1–7 and there, shows great numbers of its Grenville inclusions. Its position here, however, seems to be a little west of its line running in from Paradise bay.

**Sloop Island south dike (11).** Monchiquite, N. 58° W., 54 in., Middle Chazy. Many Grenville inclusions.

Cushing included sample of this dike and made his analysis of (10) cover this also saying "The description of the rock of the one will, however, serve for both." (October 24, 1908)

The trend of the Paradise Bay dike would carry it close to the position of this Sloop Island dike and though they are separated by about 320 yards, they must be considered as one and the same dike. Here again is marked evidence for the verticality of this dike as in this distance it crosses two north and south faults.

Cushing's identification and petrographic analyses of Grenville inclusions from this dike and from its Paradise Bay continuation will be given in Appendix II.

**Sloop Island north dike (12).** Monchiquite ?, 2 in. Not far north of the larger dike and probably injected from it.

"Dike 12 I judged too rotten to be worth sending. Judging from the piece that dike must show good, columnar jointing." (March 18, 1909)

**Paradise Bay middle dike (13).** Monchiquite, 18 in. Leans in to join the largest dike and is but 4 meters north of it. Widens above. Very amygdaloidal.

"Lot of big amygdules filled with calcite and analcite? A few rotted olivines, otherwise no phenocrysts. Augite, brown hornblende and magnetite, in dark-colored glass base, make up groundmass.

**Paradise Bay fourth dike (14).** Monchiquite ?, 1 in. A narrow, sinuous, ribbonlike dike about 12 meters north of last. Width about one inch. No doubt an irregular injection from the large monchiquite. Cushing made no analysis of the fragment sent him.

**Paradise Bay fifth dike (15).** Monchiquite, 3 meters north of last, 8 in., ribbonlike and probably also injected from the large monchiquite.

"Olivine phenocrysts, some of large size and fairly fresh, and medium-sized lilac-colored augites, some zonal with green centers, and few inclusions. An augite, magnetite groundmass in light-colored glass base."

**Spoon Island dike (16).** Diabase, N. 74° W., 34 in., Middle Chazy. Much eroded because of lying within zone between low and high water. Exposed south wall with thin calcite seam and slickensided and thus slightly faulted since filling; probably because it here crossed a very narrow faulted strip.

"A labradorite, augite, magnetite rock with ophitic structure. No certain olivine to be detected."

**Spoon Bay dike (17).** Camptonite, S–9, N. 74° W., 34 in. In Middle Chazy, lower than above dike. The middle 22 inches is bordered on either side by a narrow zone which weathers away rapidly because of its amygdaloidal character. It is suggestive of a second filling.

"This comes nearest to an ordinary diabase of any of the camptonite dikes of the region that I have seen, though Kemp [1893] has described one diabase dike from South Hero (Bul. 107, p. 48). The dike is essentially a feldspar-augite-magnetite rock, with a good ophitic structure. The camptonite relationship is shown by the presence of a trifle of the characteristic brown hornblende, but it is only a trifle. Extinction angles up to 25° indicate labradorite as the feldspar. Big augite phenocrysts occur and what apparently was olivine, now wholly gone to chlorite and calcite. There are small, calcite-filled amygdules. My material is not fresh and the main interest attaching to the rock is its diabasic character, exceptional in this group of dikes.' (February 24, 1908.)

This dike is very closely on the line of the one last mentioned and but about 330 yards (across the bay) from it. It can be traced inland by a low mound which is practically destitute of tree growth for some 300 yards. Its characteristics all show it to be but another portion of the Spoon Island dike, and we have here another example of straightness for at least 2000 feet and, because of only slight displacement by the Purgatory Pass fault, for verticality. This dike should cross the Paradise Bay monchiquite farther inland near L–7, unless its fissure closes before reaching it.

**M-6 dike.** At base of north cliff of island. In this locality a few dike fragments have been found near each other but they may have been transported to this position. They have not been analyzed.

**North Pasture dike, 0-4.** N. 76° W., 72 in., Upper Chazy.

This dike has not been seen on the shore line. It forms a low mound on which no trees grow but which can be easily traced for a hundred meters or more though soil covered save for a very short portion near the eastern end of its visible portion. Because of its covered character it long escaped detection, although it is the widest dike of the island. It has some inclusions from its walls. It has not been analyzed.

**Beauty Bay dike A (18).** Monchiquite, approaching ouachitite, Q–3, N. 84° W., 34 in., Upper Chazy. Amygdaloidal; walls slightly faulted.

"Occasional lilac augite phenocrysts; olivine uncertain and sparse at best. Abundant plates of a light brown mica, probably phlogopite, irregular in outline and poikilitically enclosing the other constituents. Augite, phlogopite, magnetite and a lot of apatite constitute a coarse groundmass with no glass.

"Monchiquite, approaching ouachitite, and recalling some of the Grand Isle dikes described by Shimer."

**Beauty Bay dike B (19).** Monchiquite, 16 meters north of A, N. 85° W., 3 in., dip 60° or more southerly.

"Many olivine and augite phenocrysts, augite lilac; no zonal ones seen. Groundmass very fine grained, augite and magnetite with much glass; specimen probably from near edge."

**Beauty Bay dike C (20).** Three and three-fourths meters north of B, N. 83° W., 2 in., not analyzed.

**Twin Bay dike.** Augite camptonite, G–21, close to diabase, N. 97° W., 12 in., Middle Chazy.

"Big augites, with green centers, heavily packed with inclusions, and smaller lilac ones. Groundmass of feldspar laths, augite and magnetite; no glass."

**Old Steamboat Landing dike (21).** Monchiquite, G–28, N. 86° W., 22 in., dip about 80° southerly, Middle Chazy. Packed with Grenville inclusions, usually with long axes in line of flow.

"Much porphyritic augite, often large, these of the colorless, inclusion-filled type, with lilac border. A few olivines. Coarse groundmass with much brown hornblende along with the augite and magnetite. Glass uncertain; some amygdules."

**Southwest Cove dike (22).** Monchiquite, H–31, N. 60° W., 10 in., Middle Chazy, some Grenville inclusions.

"Abundant fresh olivine and augite phenocrysts, some of the latter having green and some colorless centers, with inclusions. Augite, magnetite and considerable brown hornblende in the groundmass. Glass base uncertain."

Concerning the Valcour Island dikes Cushing wrote (March 18, 1909): "Your dikes run straighter than I should have believed possible. I think, however, that your identifications are all right. It might be worth while if you could trace a camptonite and a monchiquite to a point of intersection. So far as I know their relative age has not been determined in the Champlain region. I question if they are very far apart in age.

## PERU SHORE DIKES

**South dike.** These are given in order passing northerly. In field about a half mile north of Valcour dock. Monchiquite, N. 90° W., 36 in., Lower Chazy.

**Day's Quarry dike.** About 80 rods north of last, "Camptonite not fresh," N. 71° W., 74 in., near lake. Can be followed inland in nearly straight line to highway. It narrows down to 48 inches.

## PLATTSBURG SHORE DIKES

**Golf Links south dike.** Lake shore, a little over a half mile southerly from Bluff Point dock. Monchiquite, N. 77° W., 10 in., Middle Chazy.

"Many small olivine and some augite phenocrysts. Augite, magnetite groundmass with some brown hornblende. Extra long laths of this and of augite flock in certain, roundish, light-colored spots, which are probably analcite."

Fissure shows decided curves passing rapidly from N. 83° W. to N. 72° W. Dike also breaks up here in passing from one fissure to another. Seems to have been broken at bend after solidifying and cavities subsequently filled by crystalline matter.

**Golf Links middle dike.** A narrow ribbonlike dike, about 15 meters north of above, N. 80° W., 2 in., running out to one inch easterly. Not analyzed.

**Golf Links north dike.** About 25 meters north of last. Monchiquite, near ouachitite, N. 83° W., 26 in. Not much of dike exposed. Amygdaloidal strip between 2 and 6 inches of southern edge.

"Medium sized augite and olivine phenocrysts and coarse phlogopite which encloses the others as well as magnetites and augites which seem to belong to the groundmass, indicating that it was the last mineral to form. It seems, however, primary; at least the freshness of the rock precludes any possibility of alteration. Groundmass of augite, magnetite, phlogopite and a lot of apatite. In this last respect also it is like dike 18.

"Dike 18 and the hornblende camptonite are the most unusual and the easiest to compare from character."

The North Golf Links dike and the largest Beauty Bay dike (18) seem to lie on the same line and though distant nearly one and one-half miles from each other are probably parts of the same dike.

Believing that these dikes continued west-northwesterly we examined the region where, if extended, they would cut the outcrops just west of the highway and there found two dikes, one in the edge of a lane just back of the farmhouse and the other on the same elevation at the north of the house. These have not been analyzed but are doubtless monchiquites. The distance from the farmhouse to the Beauty Bay dike (18) is nearly two miles and the trend of the group of dikes, as thus determined, lies between N. 81° and 82° W. In this connection it will be of interest to note that the similar dikes (monchiquite near ouachitite) of Shimer (1902, p. 177, no. 7; and p. 179, no. 28) lie on opposite sides of South Hero and are over four miles apart, yet the line connecting them runs also between N. 81° and 82° W. and though one and three-tenths miles north of the line of the similar Valcour Island and Plattsburg shore dikes is practically parallel with them.

**Cliff Haven south dike.** About one-half mile north of Bluff Point dock, monchiquite, N. 93° W., 21 in., Middle Chazy. To be seen only in face of cliff, covered above.

**Bluff Point Schoolhouse dike.** An inland continuation of the latter, monchiquite, N. 80° W., 5 in., Middle Chazy.

**Cliff Haven Dock dike.** Fourchite, N. 93° W., 32 in., Trenton.

A few feet only of dike exposed. Later, 4 in. wide, injection through center. In places very magnetic. See plate I, figure 1. Cushing found several pieces of this dike on the south end of Crab island, and in line of its strike at Cliff Haven. The dike can be seen just off the south shore of Crab island and at about five feet depth at low water. It gives another instance of the straightness of these dikes for long distances.

**Plattsburg Barracks shore dike.** About two-thirds of a mile south of breakwater, monchiquite, N. 67° W., 24 in., Trenton.

"Lot of augite phenocrysts, some with green centers, and some wholly altered olivines. Groundmass of augite, magnetite and considerable brown hornblende, with some glass."

**Saranac River dike.** Just south of Catherine street bridge, monchiquite, N. 67° W., 20 in., Trenton.

"Many phenocrysts of augite and olivine. Groundmass of augite and magnetite with a little brown hornblende."

This is probably a part of the Plattsburg Barracks dike. On the river bank near this is a transported boulder from some dike which is filled with cobbles and fragments from the Grenville.

**McMartin's Quarry east dike.** A little over a mile north of the State Normal School in quarry on west of road, monchiquite. Very amygdaloidal and rotted, about N. 78° W., about one foot wide, Middle Chazy. Not analyzed.

**McMartin's Quarry west dike.** In first field west of above, monchiquite, about N. 78° W., 3 in.

"Many small, rotted olivines and a few augite phenocrysts. Specimen from near edge and groundmass largely glass, with minute augite, brown hornblende and magnetite crystals."

**Martin's Bay dike.** About N. 45° W., about three feet. Crammed with Grenville inclusions carried up, not alone to the Middle Chazy, as at Valcour island, but to (and cutting) the Cumberland Head shales. D. H. Newland, state geologist, has kindly analyzed the rock of this dike, and his report is given herewith.

"The specimen here described consists of a tabular block about four inches thick, bounded by parallel surfaces. The specimen measures about 20 by 12 inches in the other dimension.

"The most striking feature of the specimen inheres in the occurrence of many foreign inclusions, set off from the dike material by color and textural differences. In the aggregate these inclusions compose nearly as much of the specimen as the dike rock itself. They belong to two contrasting types. One kind of inclusion, and much the more common, consists of a grayish, granular, medium-textured rock of the appearance of some of the Adirondack granites or granite gneisses. It seems to be composed largely of feldspar and a dark silicate like hornblende or pyroxene. The individual inclusions are subangular to round or oval in outline and measure from a fraction of an inch to two inches in diameter. They are sharply differentiated from the dike material, having clean-cut boundaries with no intermixtures of dike magma with their substance. The other kind consists of a dense, homogeneous, hard material, darker than the granite, with a vitreous look. Its hardness is that of quartz, and in fact it is a cherty variety of that material.

"Crushed fragments of the granitic type of inclusions, when examined under the microscope are found to consist of microcline and microperthite as feldspars, of greenish pyroxene badly decomposed and iron-stained grains that may be hornblende or biotite, or both, small amounts of quartz, and occasional garnet crystals. It has, thus, the make-up of much of the country gneiss of the northern Adirondacks, which in composition ranges from granite to syenite among the igneous class of rocks.

"Samples of the dike were prepared for sectioning so as to include some of each kind of material, but in cutting the parts representative of the foreign inclusions were lost, probably owing to the difference in hardness and toughness of the rocks. The sections returned by the preparator (State Museum slides nos. 52 and 53) contain only the dike substance which is a fine-grained diabase, with small porphyritic crystals of augite and olivine. The groundmass is wholly crystalline, with no unresolved glassy base. It consists mostly of lath-shaped plagioclase in felted arrangement and small irregular grains of augite and iron oxides filling the interspaces. There is a close resemblance to some of the small Pre-Cambrian diabase intrusions of the Adirondacks proper."

Doctor Newland's recent analysis of this specimen as a diabase will require some modification of views expressed by the author which were based on data known in 1910. New dikes still appear. The west shore of Cumberland Head shows three not yet analyzed. The largest of these, 38½ inches wide, does not appear to carry any Grenville inclusions. Careful study of other portions of the large field shown in figure 16 will certainly yield still more evidence for or against the hypotheses presented in the body of this paper, and for the present these may be allowed to stand. New work in the field and the development of more accurate conclusions must now be left to others.

# APPENDIX II

## ANALYSIS OF GRENVILLE INCLUSIONS AND DISCUSSION

BY

H. P. CUSHING

(Feb. 24, 1908)

### INCLUSIONS IN DIKE 2[1]

**Inclusion collected by H. P. Cushing** (slide 45). Coarsely granular rock of feldspar, quartz and augite with accessory magnetite, apatite, titanite, pyrite and graphite. Titanite and pyrite are sparse, but there is a lot of apatite and minute graphite scales are of frequent occurrence. The augite is of light green color and with the accessory minerals constitutes 7 to 8 per cent of the rock. There is from 10 to 12 per cent of quartz with a tendency to appear in foliae. The feldspar constitutes from 75 to 80 per cent of the rock. About half of it is microperhite and is fairly fresh; the remainder is badly altered and wholly lacking observable twinning or intergrowth structures. It may be either orthoclase or untwinned plagioclase, more probably the former.

The rock is a common one of Grenville association everywhere in the Adirondack region. It is one of the dubious rocks in respect to origin, and is very possibly igneous, in spite of the disseminated graphite scales. I have never met with it, however, except in association with unmistakable Grenville sediments.

**Inclusion (G. H. Hudson's specimen 1, slide 46).**[2] The slide is practically all feldspar and quartz, with the merest trifle of minute magnetite, and a little of some ferromagnesian mineral wholly gone to calcite and sericite. The rock is well foliated, the quartz being in distinct leaves. It forms 25 per cent of the slide, but seems to constitute a somewhat larger amount of the specimen. The feldspar is mostly microperthite of very fine mesh. The rock is an acid gneiss of uncertain relationships.

**Inclusion (Hudson's specimen 3, slide 47).** A coarsely and evenly granular rock composed of pyroxenes and plagioclase with a little magnetite. The pyroxene is mainly a light green augite which is perfectly fresh. Along with it are patches of badly altered material which was apparently an orthorhombic pyroxene. The plagioclase shows albite and pericline twinning but with no grains suitable for

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[1] This inclusion was from the Paradise Bay southern monchiquite. G. H. H.

[2] This and the two following inclusions were from the Sloop Island southern monchiquite.

extinction measurements, although the angles are plainly not high, and suggest oligoclase to andesine as the feldspar.

**Inclusion (Hudson's specimen 4, slide 48).** Similar to last but with garnet present, orthorhombic pyroxene absent, more magnetite, and the better cut feldspars showing angles up to 20° indicating andesine-labradorite as the feldspar. Slides 49 and 51 are of identical rocks. These garnet-holding, pyroxene gneisses are common Grenville rocks throughout the region.

## DISCUSSION

This dike holds more prolific inclusions than any known to me of the basic dikes of this general group. The inclusions seem to me to demonstrate the presence of the Grenville series here, underneath the Paleozoic cover. Since today the dike comes to daylight in lower Chazy rocks it follows that either these Pre-Cambrian fragments have been brought up a vertical distance whose minimum measures is the thickness of the Potsdam and Beekmantown formations combined, 3000 feet at least; or else that the dike below ground has cut across a fault plane, which it may have followed for a distance, and may have picked the fragments out of the fault breccia. Now while there are plenty of faults in the vicinity none of them, so far as known, bring to the surface rocks older than the uppermost Beekmantown, so that the amount of vertical rise of the fragments seems fairly well assured, and can safely be set down as not less than 3000 feet. The inclusions have not chilled the lava except in the case of very minute threads of it which have worked their way into them, and which seem to bespeak considerable fluidity in the mass, so that it does not seem likely that the inclusions were carried upward because of being pushed along by the pasty upper portion of the igneous mass, provided it had an upper portion of that character. The lava is very basic and there of high specific gravity, but the pyroxene gneiss inclusions are also quite basic. It is quite possible in the case of inclusions which have been borne upward in this fashion that they may actually have sunk in the lava, but at so slow a rate as to by no means have kept pace with the rate of upward movement of the lava, so that their upward movement has been relative merely.

## CONTACT EFFECTS

All the contacts shown in the slides are with the inclusions of the pyroxene gneisses. In slide 47 in a border zone one-quarter inch in width, the dike rock is full of separate feldspar and augite grains which have been frayed off from the margin of the loosely granular rock. In the case of the augites the material can be seen in actual process of being frayed off, giving way along the cleavage cracks. The lava has had no chemical action on the augite, the contacts being sharp, but in the case of the feldspars there has been slight corrosive action. All are rounded by this corrosion and there is developed about them a finely crystalline border of the usual minerals of the dike rock with, in addition, abundant small feldspar crystals, the material for which came evidently as a result of the corrosion.

In the case of the garnet-pyroxene gneisses (slides 48, 51), the gneiss is all penetrated by minute dikelets from the dike. The garnet alteration has been profound, a broad zone of kelyphite aspect having been developed around it and also within it along the fracture cracks, all connecting into a network with small interstitial portions of unchanged garnet alone remaining. Feldspar corrosion is widespread and the dikelets consist essentially of feldspar and brown hornblende. There is also a local development in them of fairly large, platy, brown hornblendes which are packed with minute opaque inclusions, often developed in great abundance along wavy lines. The dikelets have apparently worked their way around most of the feldspar grains, eating away their borders and replacing them by the fine-grained feldspar-hornblende magnetite aggregate. As before the augite is unaffected.

When it is remembered that these inclusions are very small and were inclosed in the molten lava for a considerable time, long enough to be brought up vertically more than half a mile, this contact action must be considered of very trifling amount, so much so as to afford basis for the conclusion that the temperature of the lava could not have greatly exceeded its point of solidification, and that mineralizers were present in but slight amount.

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# AN OCCURRENCE OF PERIDOTITE NEAR OGDENSBURG, NEW YORK

BY

D. H. NEWLAND

*State Geologist, New York State Museum*

Plentiful evidences of a volcanic episode in the geological record for central New York have been forthcoming with detailed study of that region, notably within the last two or three decades. These evidences consist of dikes of dark-colored igneous rocks cutting vertically across the flat Paleozoic sediments which underlie the whole region. There are no signs anywhere of volcanic cones or surface lavas and ash, if such were once present, for the reason that many thousands of feet have been eroded from the surface of the region since its uplift at the close of Paleozoic time, bringing to exposure the conduits of the old volcanic centers at varying depths from possible former outlets. The numbers and distribution of the dikes indicate a zone of some hundreds of square miles in which igneous activity must have been in progress sometime after the deposition of the Paleozoic strata.

The earliest published account of one of these dikes is contained in the reports of Lardner Vanuxem (1839) for the Natural History Survey of New York. It refers to the Green street locality in Syracuse, then in the eastern environs of the city, to which his attention had been called by Professor Oren Root sr, of Hamilton College, an early student of the geology of the district and a discriminating collector. Vanuxem noted that the traplike appearance of the rocks which he recognized were largely serpentine in composition, but did not contribute any definite explanation of their origin. In his final report (1843), however, he classed the rocks as metamorphic with the explanation "that they have not been caused by a dry heat or fire, no evidence of the kind existing." This statement may be regarded correct so far as it bears on the immediate derivation of the serpentine constituent, which is a secondary or metamorphic product, but falls short of a full interpretation of its history as indicated in the primary mineral intergrowths which have contributed the materials for the formation of the serpentine and of which unchanged remnants are usually to be seen in all the examples. In fact, methods for study of the microscopic constituents and textures of rocks had not been perfected at that time.

It was not until 1887 with the publication of the papers on the Syracuse occurrences by G. H. Williams that the origin and mineralogy of the rocks were precisely determined. Williams found that the microscopic evidences, together with the larger geological features, clearly established an igneous source and that in regard to mineral composition the dikes were to be classed with the peridotites, a group of igneous rocks composed largely of olivine. Comparisons were made between the Syracuse dikes and the peridotite of Elliott county, Kentucky, which occurs under very similar conditions.

Later on the list of dike occurrences was greatly extended by discoveries reported outside the environs of Syracuse. Many were found in the Cayuga lake region, particularly around Ludlowville, Ithaca, Taghanic and Glenwood. These have been studied by Kemp, Matson and others who reported close resemblances with the first-mentioned examples, and all were likewise classed as peridotites. Burnett Smith described dikes from Clintonville, 15 miles southwest of Syracuse. C. H. Smyth jr established relationship of occurrences at Manheim in the Mohawk valley below Utica with the Syracuse type. Other studies have appeared from time to time so that the present literature on the subject is quite extensive, as appears from the summary presented by T. C. Hopkins in the "Geology of the Syracuse Quadrangle" (1914). This report gives many interesting details of the Syracuse dikes.

A new discovery of these basic intrusions for which the record is here presented is a dike near Ogdensburg, found in the summer of 1928 in the course of excavations for a power dam. The locality is Eel Weir on the Oswegatchie river, four miles south of its outlet into the St Lawrence. This is more than 100 miles distant from any other described occurrence in the state and greatly widens the limits within which the volcanic rocks may be looked for in the future. There is every prospect that further examples will eventually be found in the St Lawrence valley, although the heavy glacial deposits of that region make their discovery more or less a matter of chance as in the present instance.

Eel Weir does not appear on the Ogdensburg topographic sheet of the United States Geological Survey, but has reference to the stretch of rapids in the Oswegatchie below its junction with the Black lake outlet. The river descends for a short distance over a series of steps developed in successive layers of sandstone which dip slightly northward with the stream. Above and below the rapids the current is sluggish and the stream bed is formed of glacial materials. It is a country of low relief with few outcrops.

The underlying rocks, according to the geological report of Cushing (1916), belong to the Tribes Hill formation of the Lower Ordovician, made up of calcareous sandstones and dolomites which grade downward into the siliceous Theresa formation, and these beds in turn into the hard quartzites of the Potsdam series. The strata exposed in contact with the dike may be described as hard limey sandstones in rather massive beds. They are extremely tough and resistant to abrasive wear, but apparently break down rather readily in contact with surface waters through solution of the carbonate bond, so that the stream bed shows deep channeling along the joint planes. In this way, also by undercutting along the bed joints, immense blocks are loosened from place.

The dike, at the time of my visit, was exposed only on the west side of the river for a distance of about 40 feet; it stood vertical, projecting as a wall slightly above the sandstone, with an average width of four feet. Its course, west-northwest and east-southeast, was diagonal to the river. The contact with the sandstone was tight or frozen and was marked by a slight sheeting of the latter parallel to the walls. There was little evidence of alteration effects upon the inclosing strata. On the weathered surface the dike was grayish or grayish green, changing rapidly to dark green and nearly black in the interior.

The rock has a fine groundmass in which appear brilliant specks of a micaceous mineral, but little else discernible by the eye alone. Amygdaloidal cavities filled with secondary carbonates and thread-like veinings of the same minerals stand out conspicuously against the green in some specimens. The relative weight of samples suggests a high percentage of iron in the composition.

Under the microscope the groundmass is resolved into a network of serpentine fibers in which lie embedded lath-shaped sections of brownish and yellow biotite, granular calcite, abundant black metallic grains of magnetite or ilmenite, and secondary iron oxides, red and yellow. Some rounded and irregular areas of nonpolarizing, non-pleochroic substance, with serpentine borders, suggest magmatic glass in process of alteration. Of the original silicate components only the biotite has shown definite resistance to the general alteration to serpentine and exists in sharply defined crystals which, however, have been somewhat bleached by removal of iron, now distributed as oxides on the borders.

There is no olivine discernible in thin sections but its former presence may be regarded as practically certain from textural evidences. The serpentine fibers show frequently the peculiar mesh structure that results from olivine alteration as distinguished from the parallel-banded structure which follows from the change of cleavable minerals of the pyroxene and amphibole families. Also, here and there the crystal outlines of olivine are indicated in a columar arrangement of the serpentine, with a beveled termination to the columns, the included angle of the end planes being somewhat less than 90°. Iron oxides and more or less carbonates accompany the alteration. The lack of any vestiges of pyroxene or amphibole is indicative that these minerals probably have taken little part in the composition of the parent rock, for as a rule they alter to serpentine less rapidly than does olivine under like conditions.

The abundance of magnetite, which seems to be the predominant iron mineral, calls for remark. In most of the New York dikes ilmenite has been mentioned as an ingredient that shares importance with or even exceeds magnetite in abundance; but in the present instance there appears to be very little titanium present in any form. The metallic particles have quadrilateral and trigonal outlines when they show any crystal forms at all, and are not bordered by reaction rims of leucoxene. Perofskite is also lacking. The particles when released from the silicates by crushing respond sharply to a weak magnet. It is estimated that the iron mineral constitutes 10 to 12 per cent of the mass, on the basis of the proportions found in thin sections.

Minerals of the garnet and spinel families, observed in some of the other peridotite dikes, are not represented in this occurrence.

Particular attention was given to the possible participation of melilite in the composition of the original rock, as this mineral was identified by C. H. Smyth jr, in the Manheim dikes, and used as criterion for classifying the latter with the alnoite group rather than with the peridotites. Melilite was found also by F. D. Adams in the dike at St Anne de Bellevue near Montreal. The latter, it would appear, may belong to the same series as the present occurrence, as it cuts Potsdam sandstone and like it is composed largely of olivine and biotite. No unaltered remnants of melilite could be identified in thin sections, and nothing in the microscopic structure of the alteration products would seem to suggest its former presence. The possibility of its occurrence, however, can not be said to be excluded on the evidences obtainable from so highly altered material. The mineral is susceptible to rapid decay and is rarely if ever found in rocks which have undergone so complete change as apparent in the present example.

Laying aside this element of uncertainty, the classification of the dike with the mica peridotites is proposed on the basis of the indicated presence of olivine in large amount and the known occurrence of biotite as the principal additional silicate ingredient. The mineralogical relationship to the dikes of central New York is so close as to constitute evidence of their development from a common primary magma.

The question of the age of the intrusion is thus bound up with that of the other occurrences, for which the most probable assumption is that they belong to the late Paleozoic, coincident in time, perhaps, with the crustal adjustments that accompanied the Appalachian revolution. The fact that the Ithaca dikes break through Upper Devonian strata shows that they can not be earlier than that period. Matson has found some indications that the Ithaca peridotites were intruded during the progress of Appalachian folding but antecedent to the culmination of the movement which was accompanied by thrust faulting.

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# NOTES ON THE CLINTONVILLE DIKES, ONONDAGA COUNTY, NEW YORK

BY

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Twenty years ago a short note was published announcing the discovery of two igneous dikes in the Hamilton shale of Clintonville, Onondaga county, N. Y. (Smith, 1909, p. 724). Several years later the presence of a small "stringer" just east of these dikes was noted (Hopkins, 1914, p. 52). Counting the "stringer" as a dike it may be said that these three intrusions have represented until now the known cases of igneous masses visibly cutting the Hamilton shale.

During 1929 torrential rains greatly increased the volume of water flowing through the Clintonville ravine. It is believed that this circumstance accounts for much recent erosion of the talus. On September 21, 1929, a hitherto unknown dike was discovered beneath root-matted talus which apparently had been freshly undercut. Search of the stream bed on the following day revealed another small dike a short distance east. On October 21st the excavation of a favorable looking mass of talus brought to light still another dike.

It is therefore possible to record six dikes associated with the Hamilton shale. All are in the Clintonville ravine and all run some risk of landslide burial. On this account it is deemed wise to fix their geographic positions more exactly and to give brief descriptions of their more important field features. Photographic illustrations of the larger dikes are presented. (See figures 21, 22, 23.)

The term "Clintonville ravine" is applied to the lower gorge excavated by the stream which originates near Shamrock west and south of Rose Hill and which flows first west and then north of Clintonville. All of the localities in question can be found on the United States Geological Survey topographic sheet of the Skaneateles quadrangle. Just before reaching Nine Mile Creek this stream is crossed by a road which has a general northwest-southeast direction. This intersection of stream and road makes a convenient reference point in fixing the position of the dikes. It was so employed for the dikes of 1909 but unfortunately the term "Marietta road" was used. The latter name has become particularly inappropriate with the development of improved highways. "Lower road" will therefore be substituted. This serves also to distinguish between the two roads which cross the stream near Clintonville. The "lower road" is furthermore the lowest and last road encountered by the stream in its course to Nine Mile creek.

For convenience the dikes will be numbered in the order of their discovery (see figure 21.) Dikes 1, 2 and 3 are closely associated and constitute a western group. Here the numbering corresponds with the west-east distribution. Dike 2 is two feet and five inches east of dike 1. Dike 3 is one foot and six inches east of dike 2. About 202 feet east of dike 1 is found the westernmost member of the three dikes of an eastern group. This is dike 6, the last to be discovered. Dike 4 is one foot and five or six inches east of dike 6. Dike 5 is about 32 feet and 8 inches east of dike 4.

In a general way each dike is vertical, or nearly so, and trends almost north and south, its boundaries apparently determined by preexisting joint planes having such attitude and direction. All are known from the south wall of the Clintonville ravine or from the stream bed at the foot of this wall. So far no intrusions have been detected in the north wall.

Size, position and condition of preservation combine to make dike number 1 the best for reference purposes. It is approximately 1250 feet west of the intersection of stream and lower road. Its outcrop meets the stream from 45 to 50 feet above the level of the bridge at this intersection.

It is now proposed to summarize briefly the more important field features for each of the known Clintonville intrusions.

**Dike number 1** (Smith, 1909, p. 724). See figure 22. Dull green in color. Darker on fresh surfaces. Porphyritic in texture, showing phenocrysts of a bronzy mica and olivine like grains. This dike is relatively hard and firm, seeming to resist disintegration better than does the adjoining shale.

Width (distance between walls): 6 to 8 inches.

Attitude: Walls nearly parallel and vertical.

Trend: approximately 2° west of north (magnetic).

One shale inclusion has been seen in this dike.

**Dike number 2** (Smith, 1909, p. 724). See figure 22. Green in color. When first discovered its surface was much weathered. Erosion and collecting have removed most of the weathered zone. Full of inclusions which are nearly all referable to the Hamilton shale. They are practically unaltered.

Width: 7 to 8 inches in lower part but diminishing to 5 or 6 inches above.

Attitude: approximately vertical.

Trend: about 2° to 3° east of north (magnetic).

This intrusion is somewhat irregular in its upper portion. Here the eastern dike wall moves west from one joint plane to another. There is a slight compensating bulge of the western dike wall but this is not sufficient to prevent the reduction in thickness noted above. Still higher, as the dike blends with the soil, there is an eastward projection of igneous material.

**Dike number 3** (Hopkins, 1914, p. 52). Dull brownish to dull greenish, compact and relatively hard.

Width: 1½ inch to nothing.

Attitude: approximately vertical.

Trend: about 2° east of north (magnetic).

The walls of this intrusion are irregular and there appears to be some transfer from one shale joint plane to another.

**Dike number 4.** Found September 21, 1929. See figure 23. Light brown, almost straw colored. Seemingly porphyritic with conspicuous mica phenocrysts. Soft and friable.

Width: 5 inches.

Attitude: almost vertical, but the walls, in common with neighboring joint planes, show a slight eastward lean.

Trend: about 7°–10° west of north (magnetic).

So far no fresh rock has been obtained from dike 4. Its easy weathering is partly responsible for the troughlike gash in the ravine wall at this point. This gash is cluttered with root-matted shale fragments which constitute a thin but resistant talus. Stream undercutting was just sufficient to permit this dike to be seen below the talus fringe. Excavation shows an intrusion making a striking color contrast with the dark gray shale.

**Dike number 5.** Found September 22, 1929. Light brown, almost straw colored. Seemingly porphyritic with conspicuous mica phenocrysts. Soft and friable yet less so in these respects than dike number 4.

Width: 1¼ to 1¾ inches.

Attitude: approximately vertical but not determinable exactly for the outcrop is mostly in plan.

Trend: about 6°–12° west of north (magnetic). This dike shows only below water in the stream bed. Like dike 4 it makes a decided color contrast with the shale. The projection of this dike above water level passes under slide so thick that excavation was not attempted.

**Dike number 6.** Found October 21, 1929. (See figure 23.) Light brown, almost straw colored. Seemingly prophyritic with conspicuous mica phenocrysts. Soft and friable.

Width: 1 foot and 1 or 2 inches.

Attitude: approximately vertical though the exposure is too short for a reliable reading.

Trend: about 6°–10° west of north (magnetic).

This dike makes a striking color contrast with the shale and is very like number 4 from which it is separated by only one foot and 5 or 6 inches. So far no fresh rock has been obtained. The talus-filled gash mentioned under dike 4 appeared too wide to have been produced by weathering of that intrusion solely. The presence of a concealed dike (number 6) was therefore deemed likely. Excavation confirmed the suspicion.

**Contact phenomena.** These intrusions have produced only feeble contact metamorphism. There appears to be some hardening of the country rock but it is very slight. The most notable effect of intrusion upon the shale is a multiplication of joint planes adjacent to dike walls. Most of such planes are therefore of later date than any which might have determined dike trend. An incipient jointing has also been seen within the mass of dike 2. It does not, however, extend to the inclusions present.

**Correlations.** In the absence of contrary evidence one seems justified in regarding the Clintonville intrusions as constituting a natural series having a common source and referable to the same period of igneous activity. The members of the western group are allied in color and in trend though dike 2 contrasts with its fellows in the presence of numerous shale inclusions. Similarly the three units of the eastern group are very like in color and also in trend. These facts suggest that the Clintonville series is divisible into two natural groups.

Exact synchroneity between the Clintonville and other igneous series is doubtless difficult to prove. There seems, however, to be no objection to a general correlation with the Ithaca and Syracuse intrusions.

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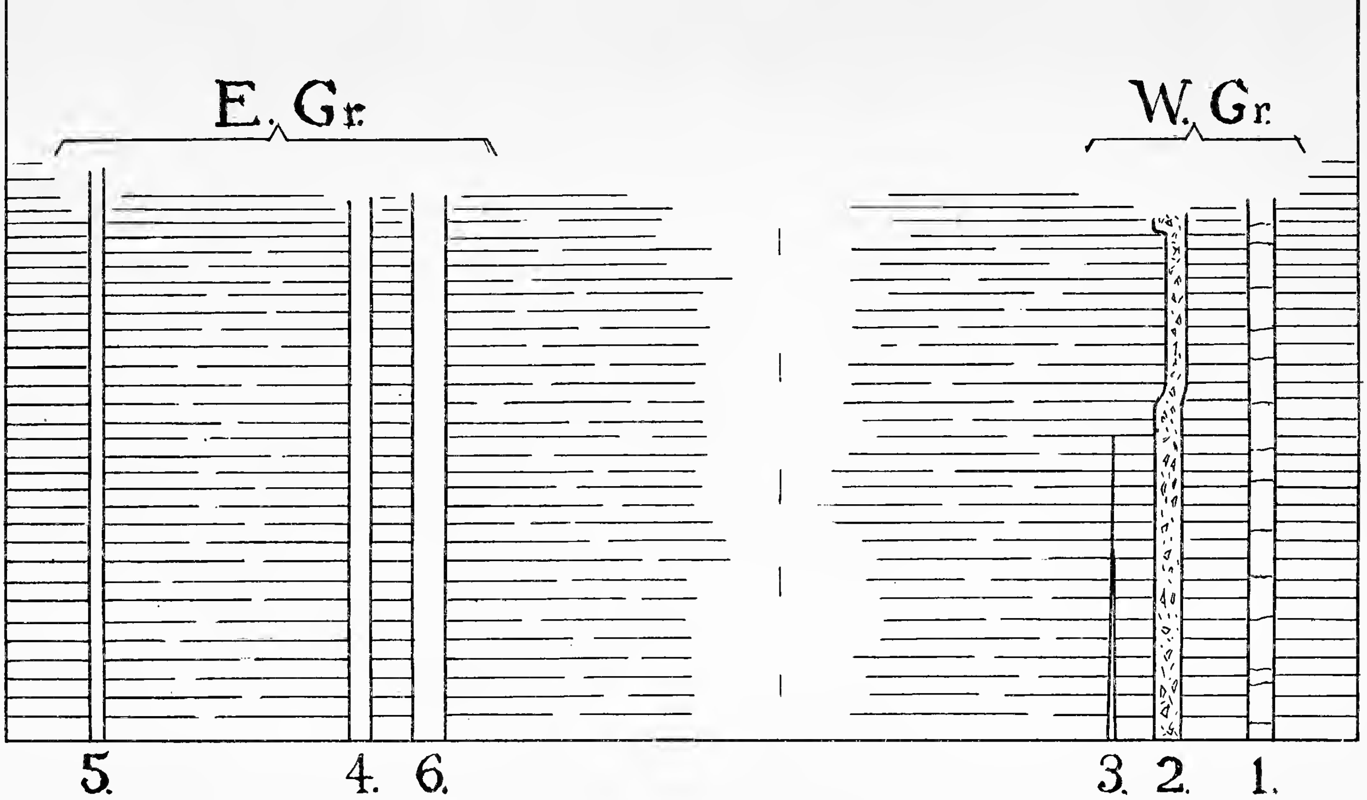

Figure 21 Clintonville ravine. Diagram showing distribution of known dikes. The numbers correspond to those given the dikes in the text, p. 120, 121. The distance between dikes 1 and 6 is about 202 feet; not drawn to scale in the diagram.
W. Gr.=Western group of greenish dikes.
E. Gr.=Eastern group of light brown dikes.

Figure 22. Clintonville ravine, south wall, showing dikes 1 and 2. Dike 1 is delimited by the numbers 1–1′. It may be further recognized by its division into massive and slightly rounded blocks. These are bounded by joint planes which are horizontal or nearly so. Dike 2 is delimited by the numbers 2–2′. It is without horizontal jointing. One inclusion shows plainly just above water level. Westward bulging of the west wall and a westward transfer of the east wall can be seen about two-thirds of the way up the outcrop. Eastward pushing of igneous material is visible, but less apparent, just as the dike blends with the soil.

The position of "stringer" is indicated by the number 3.

Figure 23 Clintonville ravine, south wall, showing dikes 4 and 6. Dike 4 is delimited by the numbers 4–4′ and shows two auger holes one above the other. Dike 6 is delimited by the numbers 6–6′ and shows three auger holes in a horizontal line.

These dikes are without joints and without inclusions. Their greatly weathered condition is emphasized by the auger holes. Multiplication of shale joint planes near dikes is shown. (From a photograph taken October, 1929)

# A PREGLACIAL OR INTERGLACIAL GORGE NEAR SENECA LAKE, NEW YORK

BY

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## INTRODUCTION

In a paper[1] presented before the Geological Society of America in December, 1928, I argued that a certain association of deposits in filled gorges in central New York might be regarded as indubitable evidence of at least two distinctly separated ice invasions of that region. I suggested that interested observers should give attention to sites where such an association might be present. In consequence of this suggestion E. W. Hard, a graduate student in the department of geology, Cornell University, reported a filled gorge near Bellona on Kashong creek, on the west side of Seneca Lake, N. Y., that seemed to be exactly of the type specified. This Bellona is on the Phelps quadrangle sheet of the U. S. G. S. topographic survey. Another Bellona, a railway station, is shown on the Penn Yan quadrangle sheet.

## SITE

At Bellona, bench mark elevation 731 feet A. T., Kashong creek enters a gorge about 100 feet deep at the head of which is a waterfall over the Tully limestone. Upstream about one-half mile south of Bellona the creek divides into two branches, one of which heads near Penn Yan and flows northeastward toward the site of the junction; the other branch has a general west to east course, but its headwaters are in a broad open valley with a northeast trend. It is quite obvious from inspection of the topographic maps that both branches of Kashong creek follow courses wholly unrelated to the pattern of the preglacial drainage of the region. It appears, however, that the existing stream courses in general antedate the last

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[1] Interglacial Deposit in Central New York, Bul. Geol. Soc. Amer. V. 40, 1929, p. 469–480.

glaciation. The valleys of the present drainage have been opened to a cross section of maturity by erosion of the bed rock of Genesee shale. However, the deposits of the last ice in the valley of the west branch, a mile upstream from Bellona, were sufficiently thick and irregular to divert the stream from its previous line of flow in the valley bottom and to cause it to cut downward and laterally into the bed rock, first on the one side of the channel then on the other. Accordingly, the course here is marked on alternate sides of the stream by rock walls, in places 30 to 40 feet high, and by a rock floor which disappears under drift on the side opposite the rock wall. There is no postglacial gorge with rock walls on both sides in this section. At one place the rock floor is interrupted by a cross-section cut which is filled with compact till abundantly studded with striated pebbles and boulders.

Downward erosion of the bed-rock floor is still in progress but only slowly as the gradients are all easy. It appears that postglacial down-cutting has proceeded to the local base level determined by the massive Tully beds at the site of the falls at Bellona. It may be inferred that the same relations existed interglacially except that the falls site may have receded slightly farther upstream and that the upstream sections of the valley in the weak Genesee beds were opened out more widely by weathering and lateral erosion. In other words interglacial time is indicated to have been considerably longer than post glacial time.

The particular occurrence herein described is located about one mile upstream from Bellona on the westerly branch of Kashong creek and at a point quite exactly three-eighths of a mile above the junction of the two branches. In this section the stream course winds within the valley walls sufficiently to produce a reach about one-eighth mile long with a trend N. 20° E. looking down stream. The east side of the stream in this reach is a nearly vertical, postglacial rock wall. This rock wall is interrupted by the cross section of a smaller valley entering the present valley, apparently at right angles, from the east. This smaller valley is completely filled with unconsolidated materials. The photograph (figure 24) shows the conditions of the site before completion of the work of clearing away trees and brush and excavating the face of the cut to expose a clean section.

## NATURE OF THE CHANNEL

Sufficient digging was done to make certain that the filled channel had its sides and floor on bed rock. Obviously the postglacial Kashong creek erosion has proceeded to a greater depth than did that of the filled channel in an earlier epoch, the difference in level of the rock floors of the two channels, however, is a matter of inches only. Hence this filled channel very probably marks the course of the Penn Yan branch of Kashong creek to a point of junction upstream from the present site and west of the line of the postglacial rock wall which now intersects the filled channel. Assuming a local base level for both erosions fixed by the elevation of the Tully limestone at the falls site the slight difference in depth of downcutting would be accounted for by the position farther east, at present, of what is herein termed the westerly branch of Kashong creek in postglacial time.

## FILLING OF THE CHANNEL

In figure 24 the outline of the cross section of the channel and its relation to the existing postglacial stream (in foreground) are clearly shown. In figure 25, a photograph made after much excavation had been done, the stratified structure of the fill is brought out distinctly. From the rock floor to the surface of the fill at the base of the tree above the center of the channel is approximately 16 feet. In contact with the bed rock on each side of the channel there is a layer about six inches thick of particles wholly derived from the weathering of the Genesee shale. Next above this layer is a bed about four feet thick in the center, black like the layer below, made up mostly of Genesee shale fragments but which has sandy streaks and rock fragments not Genesee shale. This mass appears to be a talus accumulation. Next above there is a layer of dark sand eight inches to ten inches thick. Above this is another sandy layer in which erratic pebbles of considerable variety, including igneous and metamorphic rocks, are fairly abundant. These pebbles do not have the fresh surfaces characteristic of the erratics in the morainic deposits of the region, but, on the other hand, are not rotted through. The next higher layer is four inches of fine sand weathered yellow. There follows approximately eight feet of water-laid, coarse sand containing shale fragments in abundance. At the top, completing the section, is the sandy, forest-soil layer in which scattered large erratics appear. This layer is unlike the average glacial till of the the region but is only obscurely stratified. It should probably be classified as till modified during or after deposit by water action.

## INTERPRETATION

The filled channel certainly antedates the present drainage development, and, in view of the fact that the topmost, or soil layer, contains large erratics, must antedate the latest ice advance. If erratics were present in the bottom layer in contact with the bed rock the erosion of the channel during interglacial time would be nearly certainly established. It is possible that further excavation along the bottom of the channel will lead to the discovery of such materials. Even without these the presence of the sandy layer with erratics in the middle of the filled section indicates an interglacial origin. When attention is given to the succession in kind of layers a plausible explanation of their deposit during an interglacial interval is possible. The alternative is to ascribe the erosion of the channel to revival of stream flow through uplift in time immediately preglacial. The channel may be a development of preglacial tributary drainage. Its small cross section would make it improbable that it could have carried the whole preglacial flow of Kashong creek. However, the cross channel (referred to above) filled with till extending across the bed-rock floor of Kashong creek is wider and was cut below the existing erosion level. Accordingly the tributary-drainage possibility with preglacial rejuvenation is not ruled out by evidence at hand. Such drainage could not have been governed by the local base level at the falls over the Tully limestone.

If, however, the filled channel is held to be due to a diversion in drainage occasioned by an earlier glaciation the deposits it contains may be accounted for as follows. The interglacial stream readily cut the gorge through the Genesee shale to the local base level gradient fixed by the Tully limestone outcrop. The cover of unconsolidated deposits left by the earlier glaciation was completely swept away along the course of the gorge. During the remainder of interglacial time the Genesee shales of the sides and bottom of the gorge were deeply weathered. Such weathering accounts for the bottom layer and the talus accumulation above it. Why, however, was the gorge not opened wider at the top? All the deposit superior to these bottom beds is ascribed to effects due to oncoming of the next ice invasion. Such advance of ice barred northward escape of all Seneca lake drainage. Consequently the level of Seneca lake rose eventually to the south overflow elevation at Horseheads, approximately 900 feet A. T. The elevation at the site of the filled channel is approximately 760 feet A. T. But the channel had a history before it was completely submerged under the lake waters. As the ice advanced it may be assumed that the volume of the Kashong area drainage was augmented and that the accompanying refrigeration led to an increase also in the sediment supply. In consequence the lower sandy layer and the layer with the weathered erratic pebbles were deposited. As the rising lake waters slacked the current the fine weathered sand was deposited. Then during an interval of essentially shore line conditions the thick mass of coarse sand with shale fragments collected in the hollow of the channel cut. Finally after the channel site was covered by the ice and perhaps eroded at the top by glacial scour the melting away of the glacier brought the deposition of the topmost layer with its included large erratics.

It is planned to make further excavation of the filling of the channel particularly to dig back at the bottom level. If the interpretation outlined above is correct, and the channel was eroded in interglacial time, scattered erratic boulders and gravel should be present in the weathering and talus layers at the bottom of the cut and may be discovered. Another possibility is that the site is actually a pothole of glacial origin excavated during the first ice advance; interglacially weathered and filled, and bisected by postglacial stream erosion. Opposed to such interpretation is the till-filled cross channel. Excavation of this cross channel may give more decisive evidence in regard to the interglacial relations. Meanwhile this description may lead to the discovery and investigation of similar sites.

Figure 24 Filled gorge cut into Genesee shale at Bellona, N. Y., before clearing and excavating the site (June 6, 1929)

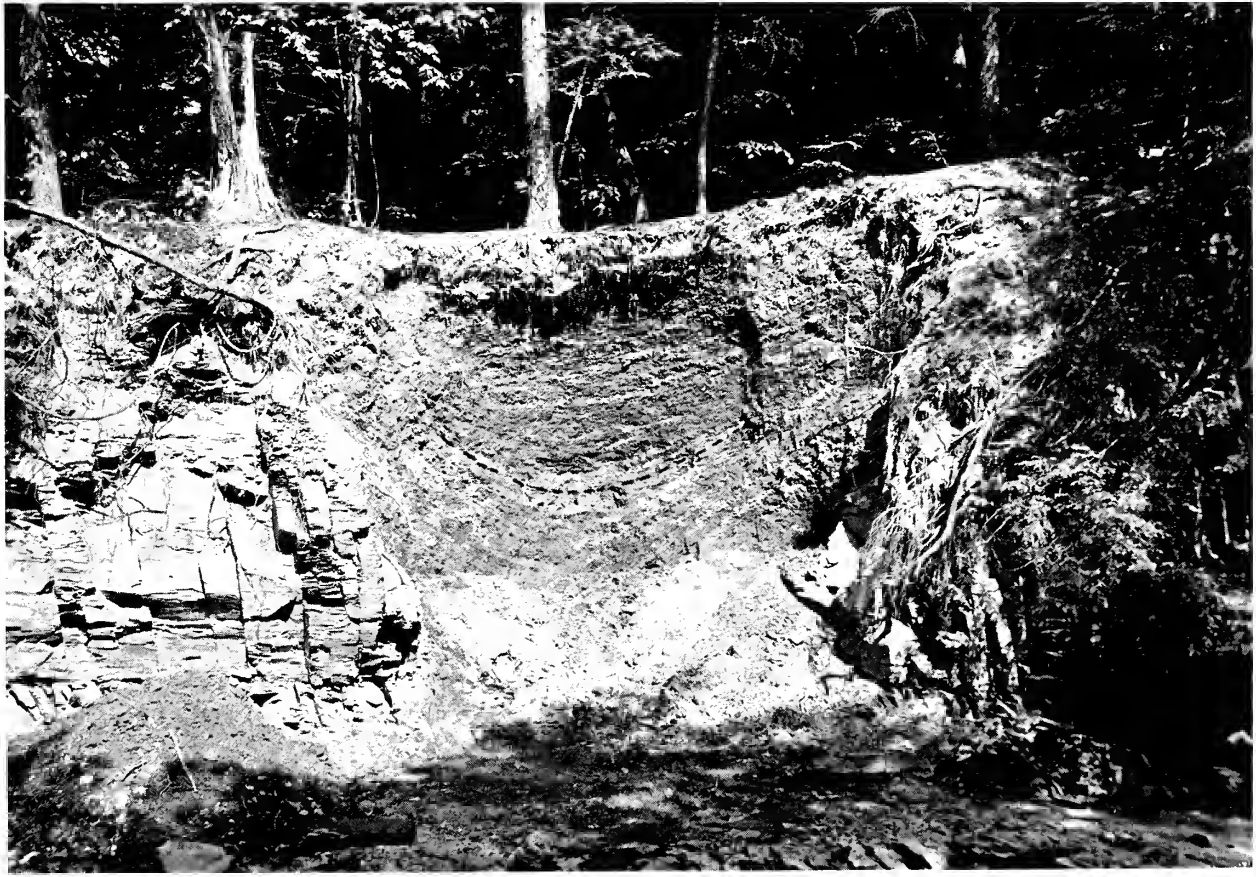

Figure 25 Filled gorge near Bellona, N. Y., showing stratification of unconsolidated material. Dashes mark the bottom of the layer containing weathered erratic pebbles. (June 11, 1929).

# AGE AND ORIGIN OF THE SIDERITE AND LIMONITE OF THE BURDEN IRON MINES NEAR HUDSON, NEW YORK.

BY

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## INTRODUCTION

The mapping of the Cambrian and Ordovician rocks of the Catskill quadrangle has led the writer to become interested in the Burden mines near Hudson, N. Y., which are noted among economic geologists for the composition of the ore which is carbonate of iron or siderite.

The siderite mines form a belt near the crest of a range of hills one to two miles east of the Hudson river in the towns of Greenport and Livingston in Columbia county. The hills are known as Plass hill (now Church hill on Catskill quadrangle) in the north, Cedar hill in the middle, and Mount Thomas (popularly known as Mount Tom, the name given on the topographic map) in the south. Cedar hill and Mount Tom make up one ridge sometimes known as Long hill.

The ore occurs in beds forming a belt four miles long and trending north-northwest on the crest or steep western flanks of the hills, 300 to 500 feet above tidewater.

According to Smock (1889, p. 63) the Plass hill openings expose the iron ore bed 300 feet above the river close to the top line of the ridge. The dip of the bed is 25°–30° N. 80° E. and the thickness of the ore ranges between 10 and 16 feet, but in it there are thin layers of shale. The footwall is a drab colored shale; the hanging wall, a gray sandstone.

On Cedar hill (Smock *ibid.*) the outcrop is on the crest, and is 400 to 450 feet above tidewater. The dip of the beds is on an average 40° N. 80° to 85° E. The thickness of the ore varies from

8 to 30 feet, including in places some interbedded sandstone and also some slaty rock in the ore. A mine (Livingston mine) east of the Cedar hill openings is near the top of the ridge with a vertical shaft 40 feet deep. The ore is here 18 feet thick and dips 35° east-northeast.

The Burden mines (Smock *ibid.*) are in the southern slope and southeast of Mount Tom (mines no. 3 and no. 2) and there is a long open cut on the west slope of Mount Tom 460 feet above the river. The ore at the south end is 41 feet thick including a thin bed of sandstone near the hanging wall. In the Mount Tom and no. 3 mines the ore dips eastward at a moderate angle and in no. 2 the ore lies in a small syncline with slight offsets through cross-faults. (See figure 26.)

The Burden mines were worked between 1875 and 1901 and furnished, according to Smock, an output of 450,000 tons of roasted ore up to 1889. The other mines were worked intermittently in the eighties.

Kimball (1890, p. 157) distinguishes four separate basins, separated by barren rock. They are now represented by lenticular bodies of ore, broken by faults and involved in anticlinal and synclinal folds. The original "basins" form a chain that, as well as the individual basins, runs parallel to the trend of the Taconic range. The basins are connected by red iron-stained rock.

## AGE OF THE ORE BEDS

The ore beds are cited in the literature as being probably of the age of the Hudson river shales (Smock, p. 14). The writer has found graptolitiferous beds both east and west of the ore belt which have yielded Normanskill graptolite faunas. These as well as the character of the rocks surrounding the ore beds, which are of typical Normanskill aspect, leave no doubt of the Normanskill (Chazy) age of the beds containing the ore. The Normanskill shale is a division of the Hudson River shales, the latter term having been discarded. As a matter of fact the entire belt of rocks at the latitude of the ore belt between the Helderberg Silurian and Devonian rocks west of the Hudson and the Berkshire schists at the eastern margin (of as yet unknown age and probably overthrust on the unmetamorphosed beds) consists of Normanskill rocks with the exception of the narrow inlier of Deep Kill shale (of Beekmantown age) on the eastern flank of Mount Merino just north of Church hill; the thick mass of Normanskill rocks thus forming a closely folded belt that is eight miles wide, and near the middle of which appears the belt of iron ore. As we shall see later the ore beds themselves belong to the Normanskill grit.

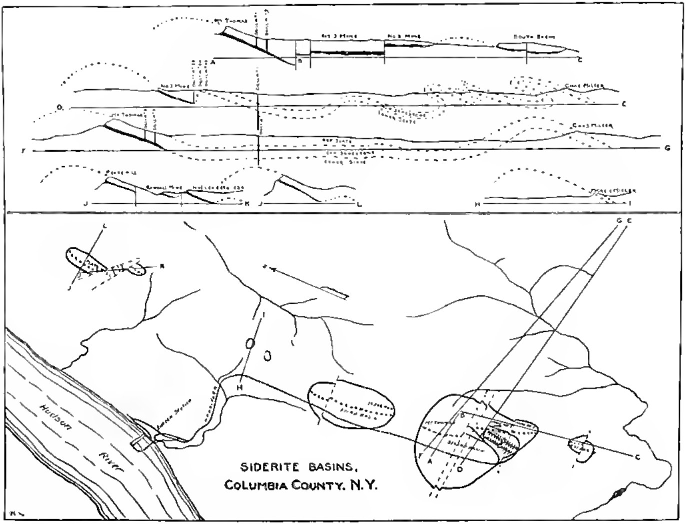

Figure 26 Chart showing location and vertical sections of the siderite mines near Hudson, N. Y. (From J. P. Kimball)

## ORIGIN OF THE SIDERITE

**Current views.** The ore consists of siderite and limonite, but it is generally understood that the limonite is an alteration product of the siderite, as the latter alone is found in the deeper and fresher portions of the ore beds.

The origin of these remarkable ore deposits has been the subject of varying opinions.

The first who seems to have expressed an opinion, if not on the origin of the siderite mines of Columbia county, at least on the numerous limonite mines of the eastern slate belt of New York (some of which also contain siderite in deeper levels) was J. D. Dana.

Dana (1884) from his general study of the geologic features of the slate belt arrived at the view that the siderite and limonite lie in interbedded seams with the other rocks and are hence original deposits in basins. He says (p. 400): "During the transition from one to the other [limestone-making seas to mud-distributing seas], iron was washed down from not distant land in the state of bicarbonate or a salt of an organic acid over limited areas of the calcareous deposits. These areas so invaded by the iron solution during the transition epoch, were within interior seas or basins or marshes, half shut off from the ocean. The calcareous material wherever receiving the iron-bearing waters became changed more or less completely to ferriferous limestone or ferriferous dolomite, or received pure iron-carbonate."

Putnam (1886) in his report for the Tenth Census accepts Dana's view of the origin of the limonite in the entire mine-belt of eastern New York from iron carbonate and describes the occurrence of the carbonate in some of the limonite mines, as the Gridley mine (p. 132), where the miners call it "white horse" or "dead head." He expresses no opinion on the origin of the siderite and he did not study the siderite mines.

Smock, with characteristic caution, has not committed himself on the origin of the carbonate ore, but has pointed out (p. 62) that "the ore is conformable in stratification with the underlying slates and the overlying sandstones and conglomerates" and "is apparently a part of the Hudson river slate formation."

J. P. Kimball (1890, 1891) was the first to advocate the derivation of siderite ore from pseudomorphous replacement of limestone. He describes the origin of the ore as follows: "This remarkable series of ore basins seem to owe their origin to depressions on an in-shore mud bottom fed by waters from decomposing basic rocks. From such waters ferric oxide was precipitated along with mechanical sediments from the land and calcareous sediments from the sea. Currents and occasional perturbations introduced detritus, while vegetable and animal life found conditions favorable for existence in degree inversely to the predominance of ferric precipitate. This is indicated by the presence in the ore of phosphoric acid in inverse ratio to the proportion of iron, the metamorphic or spathic ore of the southern part of the second basin alone being below the Bessemer limit in phosphorus and up to the shipping standard in units of iron. Submergence of the basins by rapid accumulation of sediments and probably also by subsidence below the range of atmospheric action was followed by decay of buried organic matter attended by reduction of ferric to ferrous oxide, whence ferrous carbonate in the presence of carbonic acid and absence of atmospheric oxidation. To some extent, also, carbonate of lime has probably been replaced by carbonate of iron."

Eckel (1905, p. 341 f.) concludes: "In the Burden mines, as well as at other points, the weight of evidence seems to favor the idea that the iron carbonate is not an original deposit but that it has been formed by the replacement of limestone. On page 342 he says: "The original iron carbonate was undoubtedly deposited from solution as a replacement of a limestone and not deposited in a basin contemporaneously with the inclosing rocks. To this extent the writer's explanation differs from that of Dana and certain other geologists. On the other hand, it is clear that the iron-bearing solutions did not pass freely everywhere through a mass of generally porous rock as seems to be required by the invariably accepted theory. In such a thoroughly porous mass bedding planes would not affect the shape of the deposit, the only restraining influence being the 'impervious pitching trough,' whose existence is so freely postulated and in the New York-New England district so rarely proved." This view prevails to the present time, as shown by Newland's (1921, p. 133) statement that "the explanation that the iron has been introduced in solution and as a replacement of the limestone seems more in conformity with the present known facts of the field occurrence."

F. W. Clarke's authoritative work, "The Data of Geochemistry," (1924), also supports this view for it (p. 581) considers siderite as formed either as "bog-ore deposited from a bicarbonate solution in presence of organic matter and out of contact with air," or "by replacement when iron solutions act upon limestone." To the first class belong the important deposits of "clay-ironstone," "ball-ore" and ferriferous limestone that are found associated with the coal beds.

They were undoubtedly formed in the presence of an abundance of carbonic acid set free under the swamp conditions that produced the coal. Also, "the great iron ore bodies of the Lake Superior region (limonite, hematite, magnetite, etc.) are now regarded as in great measure secondary bodies, derived from iron-carbonates of sedimentary origin. Leith holds that marine algae acted as organic agents in the deposition of these Precambrian iron ores."

To Clarke's second class of siderites, those formed by replacement of limestone, would belong those here under consideration from the Burden mines under the current view.

**Author's view of origin of siderite beds.** The author's study of the geologic conditions surrounding the Burden ore deposits has led him to doubt their origin from replacement of limestone by infiltration and rather to see their origin in the original deposition with the beds in which they are now found either as glauconite or magnetite which later were altered to siderite and limonite.

The ore belt is situated in the middle of the closely folded Normanskill shales and grits, the latter of which are in that region more strongly calcareous than farther north in Rensselaer and Albany counties. It is exposed now on the crest of ridges of preglacial age and the ore was found to bear glacial striae on Mount Tom (Smock, p. 62).

The ridges are not only of preglacial age but reach undoubtedly far back into Mesozoic time and are the result of the slow differential weathering of the Normanskill shale belt in which all the ridges owe their prominence either to beds of Normanskill grit or white-weathering chert (as Mount Merino). The hills containing the ore belt are mostly stiffened by the presence of abundant beds of Normanskill grit. As the ore belt is now on top of the ridge it must have been formed before the hills were chiselled out by erosion. If we then go farther back to the time after the overlying Devonian beds were eroded away and the Normanskill belt first exposed as a more or less level plain, some time in the Mesozoic age, the region of the iron belt was in the middle of the Normanskill shale and grit belt. If the belt itself had to furnish the iron for the solution it might have been derived from the red and green shales which form a part of the Normanskill formation or from the pyrite scattered through the darker shales. Very little red shale has been seen in the exposures of Normanskill in Columbia county and the pyrite would appear to be too scattered and practically sealed up in the impervious clayshales. Of the underlying formations (Deep Kill and Lower Cambrian rocks) the red and green shales would appear to have been in a position to yield iron to percolating waters, but again these shales are strongly impervious to water and therefore little able to yield large quantities of iron. The Snake Hill shales of Trenton age which once covered the Normanskill beds are of like lithic character and not competent to yield iron solutions.

In the early part of the Mesozoic age and during the later Paleozoic age the region of the mines was blanketed by the Helderberg limestones of Devonian age, now exposed only three miles to the northeast in the well-known Becraft mountain outlier and five miles to the west in the Helderberg escarpment. This great mass of limestones, several hundred feet thick, would have taken up all iron-solutions before they could have reached the much less calcareous Normanskill grit that contains the ore.

The position of the ore beds that follow the strike of isoclinal or close folds and at the south end of Mount Tom enter both limbs of a syncline suggests that the ore either entered along a weak line after the folding, along a fault, or broken limb of a fold, or was present before the folding and was folded with the remaining beds. The fact, to be stated more fully further on, that the ore is strictly bound to a group of one or two strata of Normanskill grit, with beds of like composition, but without the ore in contact either above or below is to us sufficient proof that the ferriferous beds were present before the folding. Nor is there any evidence of a fault line along the strike of the ore bed that might have served as conductor to the ferriferous waters, although there are strike-faults present at Mount Merino which therefore also might be present on the iron-bearing ridges. There is likewise no evidence that the limb of the syncline bearing the iron had in any way been weakened or broken more than the other folds and thus facilitated the entrance of iron solutions. It thus seems that the ore bodies are of an age preceding the folding which is Taconic folding of late Ordovician age. The only younger formation of Ordovician age which is present in the Levis basin, of which the Normanskill beds are a deposit, is the Snake Hill shale of Trenton age and of like lithic character as the Normanskill shale, that is, composed of argillaceous shale and sandstone, and therefore not competent to yield iron solutions to the underlying shales.

## MACROSCOPIC CHARACTER OF SIDERITE-BEARING BEDS

The beds which carry the siderite and limonite are composed, besides the iron ore, of quartz sand with a calcareous and siliceous matrix (dark-gray siliceous limestone) and frequent pebbles of limestone and white weathering chert, sericite, etc. In other words the beds are Normanskill grit such as is found in the Normanskill shale belt in numerous localities in the neighborhood. As stated before, the Normanskill grit is frequently more calcareous in Columbia county and farther south than in the north. There are also more frequent intercalations of thin limestone beds and limestone breccia in the Normanskill grit than in the Albany region. A fine section showing many alternations of shale, limestone and breccia is exposed in a new road-cut on the state road to New York one-half mile from the south end of Becraft mountain and two and one-half miles east of the iron belt.

It is now a highly significant fact that not only the sand-grains in the grit are for the most part well rounded but that the siderite grains are also, proving their common origin from shore sand. Both in the rich ores of the Burden mines and in the leaner ones the siderite grains can be readily seen with a lens to be distributed together with the quartz-grains through a calcareous matrix. It is the presence of this calcareous matrix that makes the Burden ore self-fluxing. This distribution does not at all favor the view that the iron was brought into the rock by solution and that replacement of limestone took place, but rather that it is a primary constituent of the rock. We consider this as the original arrangement of the quartz, calcite and iron ore.

Still more significant seems to be the fact that the ferriferous bed of Normanskill grit is in contact with a like bed that now overlies it as seen at the entrance to the Mount Tom mine (see figure 27), and that is so calcareous that the mining engineers' diagrams have designated it directly as limestone.[1] This whitish bed carries no iron ore whatever; it is, however, densely packed with rounded quartz-grains and the calcareous matrix is so ready to accept iron that the writer picked up pebbles of the fresh calcareous grit around the mine that are covered by a secondary crust of limonite formed since mining operations ceased. This bed would surely have been invaded and altered by iron solutions if such had permeated the rocks and infiltrated and altered the adjoining bed of Normanskill grit that is now the ore producer.

The ore-bearing Normanskill grit bed is underlain by gray argillaceous shale that effectually seals it.

As Smock has mentioned already there appear one or two thin seams of shale between the ore-bearing beds. One of them is well

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[1] Also Raymond (p. 340) states that the overlying formation is calcareous, "a shale or limestone."

seen in the pit on Church hill separating the two ferriferous beds. This fact and the fact that the ore beds show great variations in thickness from 40 feet at the Burden mine to 8 feet, with a general decrease in thickness northward, indicate that the ore-bearing Normanskill grit bed is as irregular in thickness and distribution as naturally are all the Normanskill grit and conglomerate beds. The intercalation of shale (figure 28) at several places is further evidence of the shifting conditions that prevailed in the shallow sea when these beds were formed.

Smock not only observed that "the ore is conformable in stratification with the underlying shales and the overlying sandstones and conglomerates," but he also saw that at the Burden mine (p. 64) the ores are "stratified, and exhibit the slight variations in texture and composition, which are marks of bedded deposits."

The irregular distribution of the ore in the grit bed with richer ore of Bessemer grade at the Burden mine and leaner to very lean ore farther north, as well as the scattered distribution of the siderite in grains in the lean ore, and the restriction of the ore to one or two strata of Normanskill grit with ore-free beds of like composition adjoining, in the writer's view, are all facts pointing to an original deposition of the iron ore together with the inclosing rocks. This deposition, like that of the grit, took place in the shallow shore waters of the Levis basin. This basin extended, as the writer has recently set forth, in a north-south direction in eastern New York. Near shore accumulations of ore would therefore have a like direction, and the north-south extension of the ore beds and their but small east-west width is readily explained by the original extension of the iron accumulation parallel to the shore.

## PROBABLE NATURE OF ORIGINAL IRON DEPOSITS

While the writer believes he has brought forward in the preceding chapter irrefutable evidence to prove that the iron ore of the Burden mines is of contemporaneous origin with the Normanskill grit and is of Normanskill age, this fact does not solve the problem of the chemical nature of the original iron deposit. While we arrive in the following at a preliminary working hypothesis, we are aware not only of its contradiction to the prevailing views, but also of the difficulties still existing in the understanding of the chemical processes leading from the supposed original magnetite deposits to the siderite ore.

The iron deposited in the shallow shifting shore waters of the Levis trough, that we find now in the form of siderite and limonite, may have been originally in the form of (1) siderite, or (2) glauconite, or (3) pyrite or (4) magnetite.

*Siderite* is deposited from a bicarbonate solution under the influence of abundant carbonic acid and the exclusion of oxygen in the presence of organic matter and out of contact with air. It is possible that such conditions existed in the Levis basin, at least at times, for the rocks have proven utterly barren of fossils save graptolites and small brachiopods. These fossils are found in the rare intercalated black shales that derive their carbonaceous content from the decomposition of seaweeds which were also the carriers of the brachiopods and graptolites in so far as the latter were not free planktonic in habit. These organisms lived near the surface and the bottom waters of the long basin extending south from the Newfoundland region were undoubtedly fouled by the decomposing organic matter and sulphuretted hydrogen as set forth by Marr (1925) and Ruedemann (1926). Such conditions were undoubtedly as favorable for the formation of the pyrite which is found in both the black graptolite shales and the Normanskill grit as for that of siderite wherever sufficient carbonaceous matter was produced by seaweeds. That is the case, however, only in the black shales of the Normanskill formation, while the Normanskill grit is quite free of all organic matter and was as the rounded sand grains, pebbles and the brecciated condition of parts of the beds indicate so close to wave-action that the water there must have been freely aerated and supplied with oxygen. Siderite might therefore have readily formed in the black shale as it did in connection with the coal-beds of the Pennsylvanian, but not at the time and place where the Normanskill grit was deposited, for with free access of air limonite would have been formed.

The green, granular silicate of potassium and iron known as *glauconite* forms (see Clarke, p. 519 ff.) in the sea near the "mud-line" surrounding the continental shores. It occurs in rocks of nearly all geologic ages. "As an oceanic deposit glauconite is developed principally in the interior of shells, and organic matter is believed to play a part in its formation" (Clarke, p. 520). These conditions of its formation at the bottom of the sea preclude its presence in such quantities as to lead to the Burden iron ores for the same reasons that militate against the direct formation of siderite, namely, the absence of any signs of organic life in the grit, especially also remains of shells that would have served as starting points for the formation of glauconite.

H. Martyn Chance has published several papers (1908, 1909) which point to the possibility of the origin of most iron ore deposits from pyrite, and the siderite and brown hematite ores of eastern New York are especially mentioned among these. This view assumes some probability from the fact that the Normanskill grit and still more so some of the shale above and below it contain pyrite in small quantities, especially the graptolite shale. The formation of pyrite in large quantities such as would be necessary to furnish the basis of the iron ores requires the presence of large amounts of decaying organic material. Of such there is only evidence in the black graptolite shale, which indeed is the only portion of the Normanskill formation that contains pyrite in more than widely scattered particles.

A more serious difficulty arises when one asks himself what becomes of the sulphuric acid produced in the process. Chance (1908, p. 410) conceives "the formation of hematite and limonite from pyrite by oxidizing water containing free oxygen and the incidental formation of sulphuric acid, involving the oxidation of ferrous sulphate with precipitation of iron as ferric oxide and hydrate, and the de-oxidation by pyrite of the resulting ferric sulphate to ferrous sulphate . . . the ferric sulphate continuing to react upon the sulphide to produce ferrous sulphate and sulphuric acid and the ferrous sulphate being oxidized to ferric oxide or hydrate and ferric sulphate, resulting finally *in the complete oxidation of the pyrite to ferric oxide or hydrate and sulphuric acid.*"

This process involves the production of an amount of free sulphuric acid equal in volume to the iron ore. If this acid was produced at the bottom of the original shore deposits or in the Normanskill grit bed, it would have met in the first case the calcareous ooze at the bottom of the sea that now forms the matrix of the Normanskill grit, and in the case of later transformation of the ore, the calcareous matrix. In either case anhydrite would have been formed and we should now find gypsum instead of limestone beds in contact with the iron ore.

Chance considers the limonite and hematite ores as gossans of pyrite. As a matter of fact there has been found siderite in all mines as the original and deeper ore and there are no records of the occurrence of pyrite in still greater depths in the mines of eastern New York.

By exclusion, there would seem to be left only *magnetite* as the original iron deposit of the Burden ore. While the magnetites of the Lake Superior region as well as the limonites and hematites are now regarded as having been derived from iron carbonates of sedimentary origin, it is also well known (see Clarke, p. 350) that "by further oxidation magnetite can alter to hematite and limonite, and through the agency of carbonated waters it may be transformed into siderite again." If there was therefore an original deposit of magnetite present in the Normanskill grit, the strongly calcareous matrix of the grit in that region and the limestone beds and limestone-breccias of the adjacent strata would have been fully competent to furnish the required carbonated waters for the transformation.

Furthermore, it is obvious that under the well-known law of mass action in chemical reaction, which explains reversible reactions, it is possible that the much greater mass of calcium carbonate than magnetite in the rock, under favorable conditions of heat and pressure and the presence of solvents which were furnished when the ore beds were buried deeply under the Ordovician, Silurian and Devonian (probably also Mississippian) rocks now eroded, will lead to a direct alteration of the magnetite to siderite by the chemical mass action of the calcite matrix.

Let us now see whether there would have been circumstances favoring the accumulation of magnetite sands along the shore of the Levis trough in Normanskill time. As is generally known large accumulations of magnetite sands are found today along the coasts in various parts of the world, as the Ceylon, Florida shores etc. Smock (1889, p. 3) mentions the occurrence of iron sands along the coast of Long Island and Lindgren (1928, p. 279) states that magnetite placer deposits occur along the lower St Lawrence river and along Columbia river, Oregon, and that magnetite sands have been utilized rather extensively in Japan and New Zealand. These magnetite sands are derived from Precambrian rocks and brought down to the sea where they are sifted, owing to their greater specific gravity, from the quartz sand and accumulated in certain places by the shore currents. There is now not the least doubt that magnetite sands must have been carried plentifully by the rivers coming into the Levis trough from the east, for the Highlands of the Lower Hudson are still today studded with magnetite mines, some of which like the Tilly Foster mine in which the ore body is 160 feet wide in the middle, have become famous for the large amount of ore they have yielded.[1]

These Precambrian rocks continue without doubt northward under the Taconic and Green Mountain ranges along the eastern boundary of the state and they were undoubtedly exposed east of the Levis trough in Paleozoic time, furnishing not only the quartz, feldspar, lime and clay for the Normanskill beds, but also the mag-

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[1] The magnetite iron deposits have recently been fully described by R. J. Colony (1923).

netite that now comes to the surface in the Burden mine in the form of siderite and limonite. The long narrow Burden ore deposit was formed along a temporary shore line of the sea that shifted back and forth in the unstable trough. The present rapid alterations and changes of clays, grits, sandstones, breccias and limestones all testify to the frequent changes of shore lines, depth of water and direction of currents.

The feldspar content (plagioclase and orthoclase, see Dale, 1899, p. 187) of the Normanskill grit (an arkose) is of great importance in this connection in proving derivation of the grit from Precambrian rocks exposed not far away and pointing to a common source of the Normanskill grit and the magnetite.

There are many more mines, nearly all producing limonite ore, in the eastern shale belt of New York to the east and southeast of the Burden mines. Most of these are in metamorphosed rocks, mostly schists, possibly of the age of the Normanskill beds but as yet undetermined. It is possible that these ore bodies had the same origin as the Burden siderite and limonite. Dana, at least, considered them all as produced by original deposition of iron in shallow basins. It will, however, require close study of the geologic surroundings of all these ore bodies to answer that question. It may be mentioned that the scattered condition of the ore beds in the shale belt, in narrow zones, which is cited by Dana as evidence of the action of iron solutions in small swamps or basins on the limestones, may with more propriety be used to support the idea of long near-shore accumulations of some iron mineral, probably magnetite in all cases.

The writer is under obligation to Dr D. H. Newland and Mr C. A. Hartnagel for information and suggestions.

## SUMMARY

The writer has arrived at the following conclusions from a study of the geologic conditions surrounding the siderite and limonite ore deposits near Hudson, N. Y.:

1 The ore deposits are of Normanskill age, as graptolite beds carrying Normanskill graptolites are found above and below them.

2 The ore deposits are contemporaneous with the Normanskill grit and did not originate from later infiltration of iron solutions into limestone as is currently believed.

3 The nature of the original iron mineral is open to question. The writer believes that it was magnetite concentrated along the seashore by currents. This was altered to siderite by the including limestone, and the siderite to limonite.

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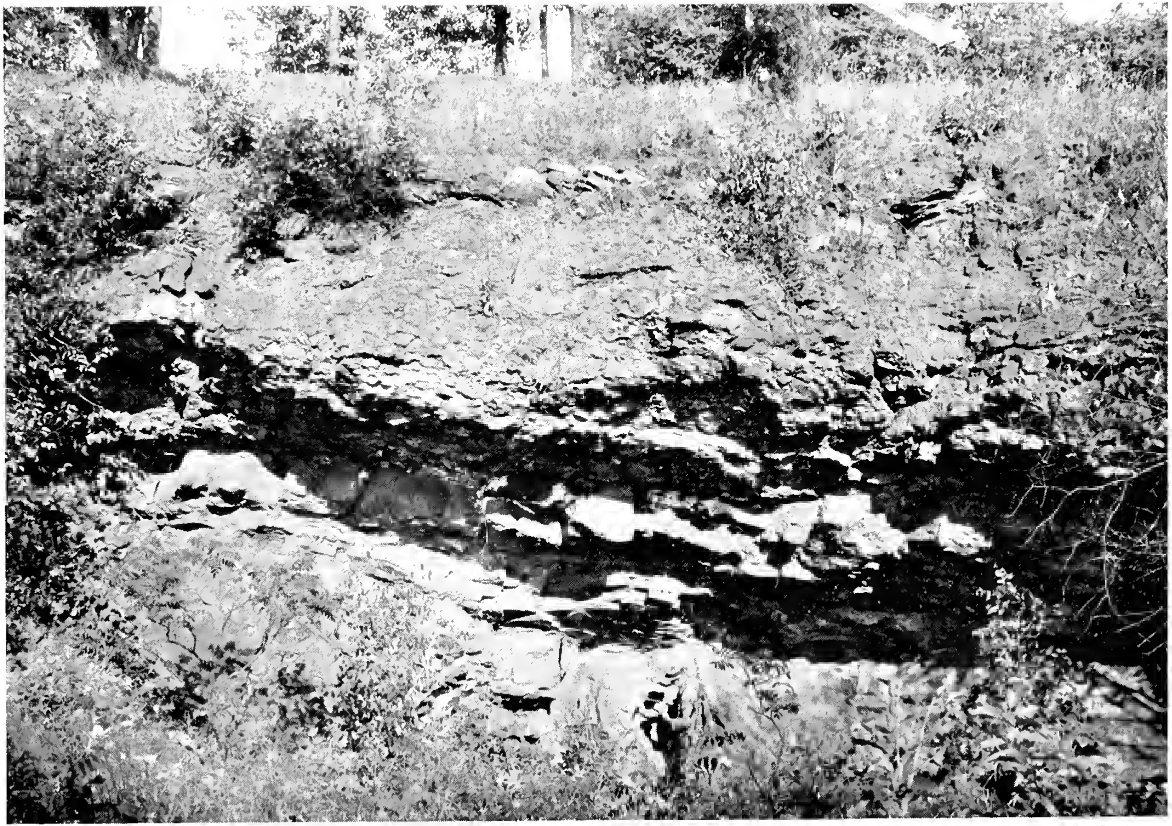
*Photograph by E. J. Stein*

Figure 27. Adits of the old Mount Tom mine. The ore-bed reaches to the roof of the adit on the left and to the projecting point in the side wall of the other. The overlying beds are calcareous grit.



*Photograph by E. J. Stein*

Figure 28 Abandoned workings in the ore-bed on Plass hill. The ore-bed extends from the bottom to the projecting bed of calcareous grit. A stratum of shale in the ore-bed is seen above the figure at base of outcrop.

# SUPPLEMENTARY NOTE ON COCCOSTEUS ANGUSTUS

BY

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Under this above name I recently (New York State Museum Bulletin 281, published 1929) described a new species of *Coccosteus* from the Portage Shales of western New York. Doctor White of the Department of Geology, British Museum (Natural History), has called my attention to the fact that the specific name is preoccupied, having been used by Traquair (1903, Trans. Royal Soc. Edinburg, XL:732).

Therefore I propose to rename the new Portage species *Coccosteus involutus* in reference to the unusual development of the lateral plates which quite inclose the fore part of the trunk of this fish.

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