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# ORDOVICIAN HIGHGATE SPRINGS SEQUENCE OF VERMONT AND QUEBEC AND ORDOVICIAN CLASSIFICATION

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ABSTRACT. The Highgate Springs slice, eighty miles long and a mile or so wide, extends from north of St. Dominique, Bagot County, Quebec, to northwestern Chittenden County, Vermont. The Canadian Beldens limestone persistently forms the base of the stratigraphic sequence. In the Chazyan, argillaceous quartz sandstone is succeeded by varying proportions of limestone, argillaceous limestone and calcareous argillite—the Carman quartzite and Youngman formation in Vermont and extreme southern Quebec, and the St. Dominique formation in Bagot County, Quebec. The Blackriveran Isle la Motte limestone, a constant unit of a few tens of feet, is succeeded by the Trentonian Glens Falls limestone and Hortonville shale. The slice lies on the Highgate Springs thrust fault, which crosses the structures in the Ordovician shales beneath and to the west; the slice is cut off on the east by the Granby thrust, Philipsburg thrust and Rosenberg thrust beneath slices of dissimilar rocks.

Of greatest interest stratigraphically is the Chazyan Series, which contains a sparse fauna that in the argillaceous facies contains fossils not known from the type Chazyan and supposed to be distinctive of post-Chazyan rocks; thus the Highgate Springs sequence bears on the classification of the stages in the Ordovician System. Structurally, the slice seems to be the attenuated east limb of the essentially synclinorial structure of the northern Champlain Lowland.

## INTRODUCTION

The Ordovician rocks at Highgate Springs, Franklin County, northern Vermont, are of a distinctive sequence that outcrops in scattered areas from east of St. Hyacinthe, Quebec, to southwest of St. Albans, Vermont, for about 80 miles (fig. 1). The succession has been called the Highgate Springs Series (McGerrigle, 1930, p. 131), the lower part being Division E of the Quebec Group of Sir William Logan (1863, p. 854); the term Highgate Springs sequence is here used to avoid the connotation that it is a formal stratigraphic series. The sequence is discussed as forming a single slice, though there are faults and folds within it.

The sequence lies on a thrust fault, the Highgate Springs thrust, separating it from the relatively gently deformed rocks of the structural foreland (Hawley, 1957) along Lake Champlain and the upper Richelieu River. The principal structure (Clark, 1934; 1955) is a northeast-pitching synclinorium having an axial trend somewhat more northeasterly than the fault trace (Hawley, 1957). On the east, from Swanton northward into Quebec, the Philipsburg thrust separates the Philipsburg sequence, a northeast-pitching syncline of Ordovician (Clark, 1941) from the underlying Highgate Springs slice, or the foreland rocks where that is cut out along the fault trace. The Rosenberg thrust lies east of the Philipsburg sequence and, as the Champlain thrust, adjoins the Highgate Springs slice from Swanton southward, coming to adjoin the foreland from Malletts Bay southward. The sole of the Rosenberg slice is Lower Cambrian dolomite. In west-central Vermont, the Middlebury Synclinorium, plunging south and lying east of the Champlain thrust, has a core of Ordovician sediments most like those in the Highgate Springs slice (Cady, 1945).

This very narrow belt of rocks of such great linear extent, the westermost belt of strong deformation, provides fuller understanding of the structure and structural history of western New England.

The Highgate Springs sequence consists of diverse sediments ranging from uppermost Canadian to upper Trentonian. Equivalent rocks are well

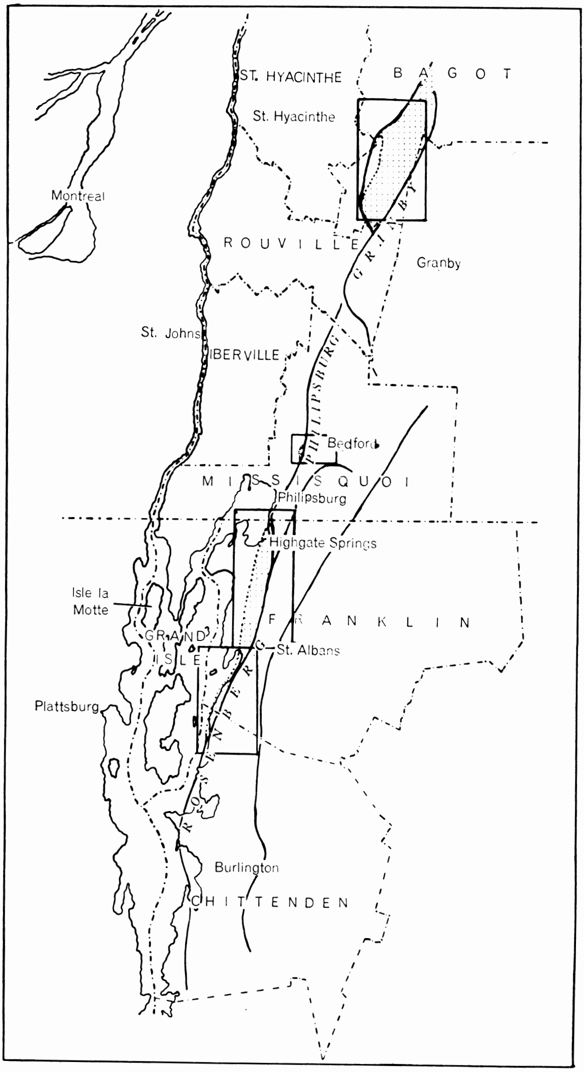


Fig. 1. Map of the outcrop belt of the Highgate Springs sequence in Quebec and Vermont. Rectangles indicate areas of figures 6, 5 and 7 (north to south).

shown in the foreland sequence, and some of them are quite alike. The Philipsburg sequence, which lies to the east, encompasses this time span, but there is little obvious similarity. The Rosenberg slice farther east is of older rocks, but its structural continuation to the south, the Middlebury Synclinorium, has formations resembling those in the Highgate Springs sequence.

The Highgate Springs sequence has received only brief and cursory attention since the study by Sir William Logan a century ago. There is more than local interest in the structure and stratigraphy. The rocks of the sequence are exposed interruptedly for about 80 miles along a belt that is generally only a few hundred yards broad, rarely a mile. The intricate local structure of this peculiarly narrow slice is challenging to resolve. But the structural setting is more difficult to understand—that a few hundred feet of section of constant stratigraphic span should persist in between older rocks of several thrust slices on the east, and younger argillites on the west. Some of the rock types in the sequence change significantly along the trend, and contrast with rocks of the same age on the west. Knowledge of the sequence adds measurably to understanding the paleogeography as well as the structural history of medial Ordovician time.

The field studies were carried forward interruptedly during the past twenty years, partly supported by Graduate Funds of Columbia University. Graduate students made large-scale plane table maps of the areas of largest exposure at Highgate Springs and Fonda Junction. Studies of the Ordovician rocks in surrounding regions by T. H. Clark, W. M. Cady, Philip Oxley and L. D. Hawley have increased our understanding of the significance of local observations. John Chatfield prepared most of the illustrations. G. A. Cooper kindly aided in the identification of brachiopods.

This text presents first a summary of the geology of the Highgate Springs area, and then of the local outcrop areas to the north in Quebec and south in Vermont. There follows a discussion of the stratigraphic units and their regional stratigraphy, then of the structural significance of the slice.

## LOCAL GEOLOGY

*The Highgate Springs area.*—The geology around Highgate Springs was crudely sketched by Hitchcock (1861, p. 283), and the principal lithic units and structures were outlined by Logan (1863, p. 273-275, 855-856), Brainerd (1891, p. 298) Gordon (1923) and the writer (Kay, 1937, p. 254) for the upper part of the section. The stratigraphy and structure have not been adequately described and mapped.

The rocks are exposed in a number of linear ridges separated by meadows. They are the limbs of asymetrical folds with east-dipping axial planes, broken by low-angle faults that produce interruptions and repetitions, and by a few offsetting high-angle faults that cross the dominant trends. The geologic map (fig. 2) shows the principal outcrop area, though similar structure continues half mile to the south to Youngman Creek, and there are good exposures on Limekiln Point, across Phelps Bay on the north. The most obvious rock is a massive limestone; it forms the long U-shaped band of ledges that opens northward from the roadside west of the center of the village and

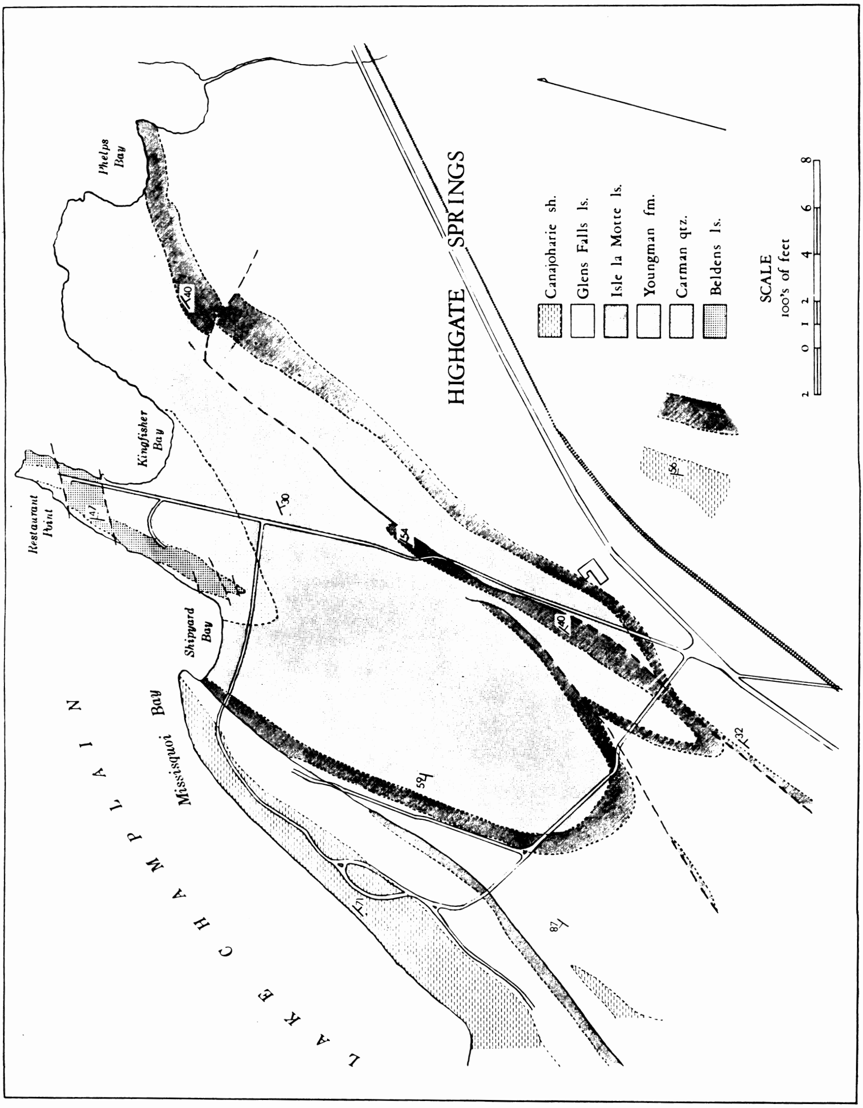


Fig. 2. Geologic map, Highgate Springs, Vermont.

delineates a south-pitching anticline. Progressively older beds within the core of the anticline are argillaceous limestones, quartz sandstones, and interbedded white-weathering calcite limestones and buff-weathering dolomites that extend on to Restaurant Point and the island to the north. The units succeeding the massive, ledge-forming limestone are dark, thin-bedded fossiliferous argillaceous limestones and dark shaly argillites. The six divisions recognized by Logan as described by him (1863, p. 273-274) but with present names and recently determined thicknesses, are from youngest to oldest:

| | |
|---|---|
| "Black, brittle shales" "of the Utica Formation"—the Hortonville shale exposed for about | 20 feet |
| "Black thin bedded shaly nodular limestones" that "belong to the Trenton" Glen Falls limestone, about | 100 feet |
| "Massive black limestone" the Isle la Motte limestone, about | 70 feet |
| "Blackish thin bedded shaly nodular limestones", the Youngman formation, only partly exposed, some | 300 feet |
| "Greenish-grey calcareous fine grained sandstones" . . . the Carman sandstone, some | 120 feet |
| "Dove-grey limestone . . . associated with bands of brownish-grey, buff-weathering dolomite", the Beldens formation, exposed for about | 150 feet |

Logan did not recognize the complexity of the structure, and hence misjudged thicknesses, giving 50 to 100 feet, more than 60 feet, about 30 feet and between 300 and 400 feet for the Carman, Youngman, Isle la Motte, and Glens Falls respectively.

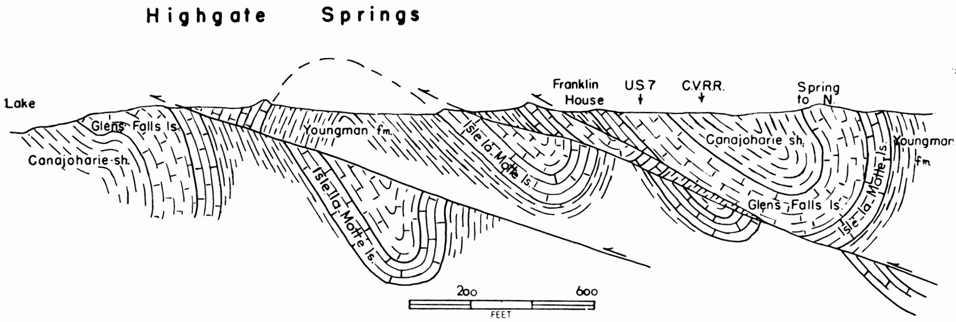


Fig. 3. Structure section, Highgate Springs, Vermont.

The Highgate Springs Sequence thus consists of a few hundred feet of Ordovician limestones, sandstones and shales, with Beldens at the base and the black "Utica" shale at the top (fig. 4). It is unlike the nearest rocks either to the east or to the west, which are classified in other sequences. The nearest exposures to the east, at an abandoned limekiln a quarter mile from the village, consist of a belt of white calcitite having patches of dolomitization, a "curdled" structure, and a few beds with rounded quartz sand grains. This rock has been thought to be in the Upper Cambrian Rock River formation in the Philipsburg Sequence (McGerrigle, 1930), a formation that the Philipsburg thrust throws against the Ordovician black shale at the shore of Missisquoi Bay from Philipsburg to the International Boundary.

About a mile east of Highgate Springs is the continuous escarpment of Lower Cambrian dolomite of the Rosenberg sequence, overlying the Rosenberg or Champlain thrust; and Cambrian rocks continue eastward into the Green Mountains. West of Highgate Springs is the delta of the Missisquoi River: there are scattered exposures of black shale on Hog Island, a peninsula beyond. Rocks like those in the Highgate Springs Sequence next appear in the foreland on Isle la Motte in Lake Champlain ten miles farther westward.

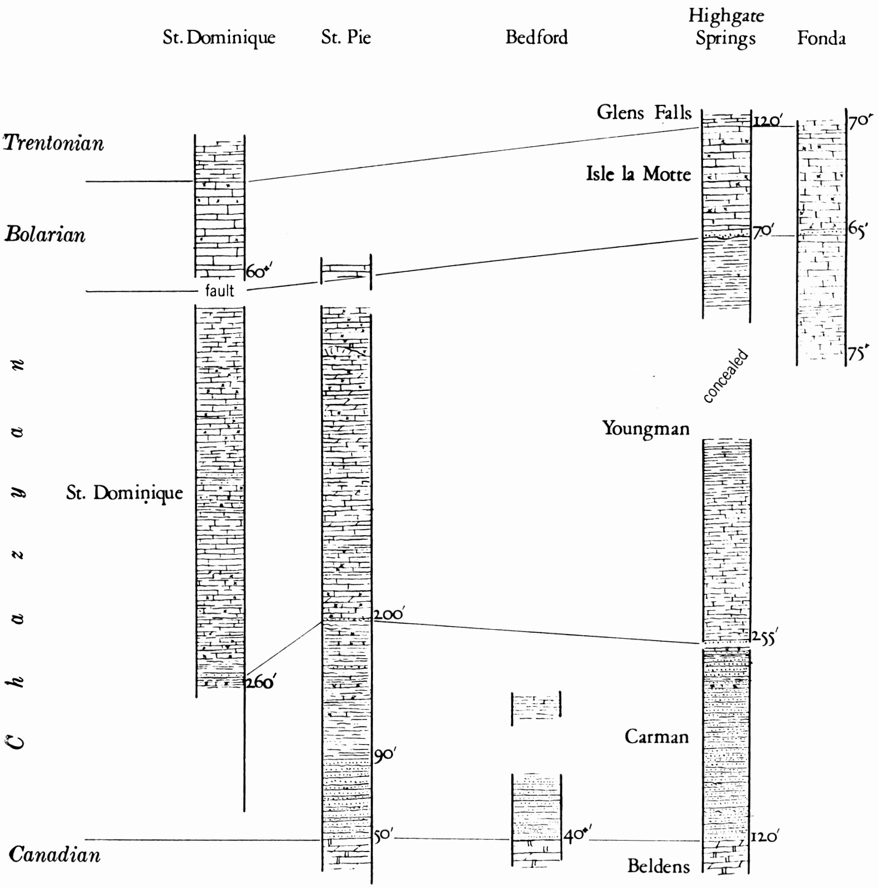


Fig. 4. Stratigraphic sections in the Highgate Springs Sequence.

There, Isle la Motte limestone underlies Glens Falls limestone, much as at Highgate Springs, but lies on Chazy limestone unlike rocks in the typical Highgate Springs sequence (Oxley, 1952); a basal quartzite resembling the Carman quartzite lies on Beekmantown Bridport dolomite like the dolomite interbeds in the Beldens, but lacking the dominant laminated limestone.

On the other hand, rocks like those at Highgate Springs are found interruptedly to the north in a continuing trend as far as St. Dominique, Bagot County, Quebec, some fifty miles away, and southward along the Lake Champlain shore to Camp Rich, twenty miles away in northernmost Chittenden County, Vermont, see figures 6 and 7.

## AREAS OF HIGHGATE SPRINGS SEQUENCE IN QUEBEC

Rocks similar to those at Highgate Springs are exposed in but two areas northward in Quebec, a very small one in Stanbridge Township near Bedford, Missisquoi County and a much larger one extending from north of St. Pie to northwest of St. Dominique de Bagot in Bagot County.

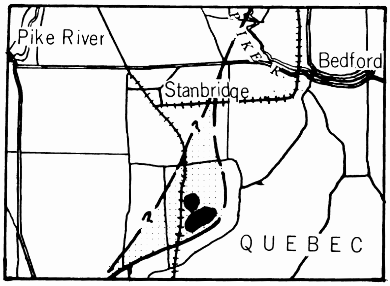


Fig. 5. Map of exposures of Highgate Springs Sequence in Stanbridge Township, near Bedford, Quebec.

*Stanbridge area.*—Two isolated exposures lie in lot 5, Conc. 8, Stanbridge Township, east of the Central Vermont Railroad south of the road crossing about a mile southeast of Stanbridge Station (fig. 5). The rocks, referred to "division E" by Logan (1863, p. 854), are "seventy feet of dove-grey limestone, fifty feet of white-weathering sandstone, and twenty feet of thin-bedded slaty black limestone", the Beldens, Carman and basal Youngman formations. The western exposure, 100 feet from the track, has a core of marble enclosed in a west-pitching anticline of quartzite. An eighth of a mile southeast is a ridge of quartzite forming the northeast limb of an east-pitching anticline with dips of 30 degrees or so on the north. Exposures are too few to permit reconstruction of the intervening structure. Half a mile northeast toward Bedford is a large quarry in Corey limestone of the Philipsburg Sequence. Beyond the road to the north is an exposure of the Mystic conglomerate of the same sequence, so the trace of the Philipsburg thrust lies in intervening meadows. Exposures to the west are entirely of dark slate.

*St. Pie Hill.*—St. Pie Hill rises from the lowland 1.5 miles east-northeast of St. Pie, Bagot County. It forms the southern end of an escarpment of discontinuous exposures extending for eight miles northward to beyond St. Dominique. The best exposures are at St. Pie Hill and four miles northward along Highway 12 west of St. Dominique; the areas are discussed separately. The section has been noted by Clark (1955, p. 11).

The principal exposures on St. Pie Hill are in a homocline dipping 35 to 45 degrees east (fig. 6). On the west is a cliffed escarpment of quartzite and argillaceous shale, beds that partially surround a south-pitching anticline with a core of white calcitite and buff-weathering dolomite, the Beldens limestone. On the west, these rocks are separated by a thrust fault from exposures of vertical to steeply west-dipping fossiliferous Glens Falls limestone; the fault trends more northerly than the beds to east, so that the Beldens lies against Glens Falls near the road north of the hill, but the limestones in the stratigraphic position of the Youngman adjoin it at the south. At the farm buildings northeast of the hill, east of the farmhouse, dark, aphanitic "Isle la Motte" limestone is poorly exposed and fossiliferous Glens Falls limestone dips steeply to the east.

*St. Dominique.*—A number of quarries have been opened in the limestones on both sides of the St. Dominique—St. Hyacinthe highway, in the

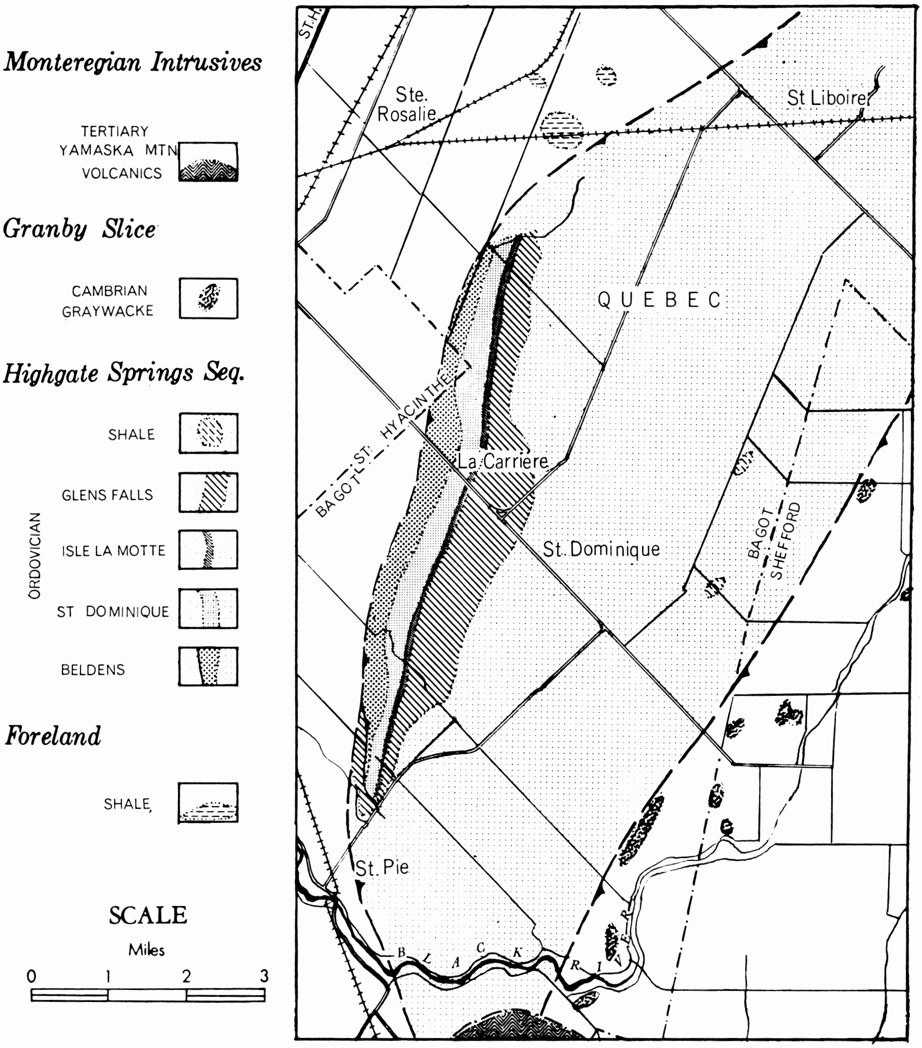


Fig. 6. Geologic map, St. Dominique to St. Pie, Quebec.

escarpment about a mile west of St. Dominique. The rocks in the quarries have been analyzed by Goudge (1935). On the west, Carman quartzite crops out in the lowest continuous exposures, but white-weathering calcitite and buff-weathering dolomite of the Beldens crop out in a quarry and adjoining low hills half a mile north of the highway west of the escarpment. The principal exposures are in large quarries in the siliceous limestone overlying the Carman and having the stratigraphic position of the Youngman; the dips are generally about 15 to 20 degrees southeast to south-southeast.

Beyond the crest of the hill and east of the siliceous limestones is a belt of high-calcium limestone, the "Isle la Motte." The contact of the two formations is a fault dipping 75 degrees or so southeast. The heavy ledges of relatively pure Isle la Motte, dipping about 20 degrees southeastward, attain an exposed thickness of 40 feet in the La Pointe quarry south of the road, and the belt has been excavated for a mile southward. To the east is fossiliferous thin-bedded Glens Falls limestone and, beyond St. Dominique, the succeeding dark shaly argillite.

St. Hyacinthe is about 4 miles northwest of the Beldens exposures in front of the escarpment of siliceous limestone. Lorraine quartz sandy shales crop out in the Yamaska River at St. Hyacinthe with dips of about 65 degrees southeastward (Foerste, 1916, p. 53-56): marine sand and clay conceals the bedrock under the intervening plain. At St. Pie, a thrust fault bounds the homoclinal sequence on the west, for the Beldens, Carman and Youngman progressively lie in contact with Glens Falls limestone. But there is no direct evidence of the magnitude of the fault—whether the succession below the Glens Falls on the west would be similar to that on the east of the thrust. The exposures of dark argillite in the river at St. Pie are somewhat west of the projection of this fault. Farther south, the dark quartz silty argillites show in several localities west of Yamaska Mountain. Probably the Highgate Springs sequence is cut out by faulting southward from St. Pie Hill and northward from outcrops about three miles north of St. Dominique, but exposure is not sufficient to permit direct observation of the relations.

## AREAS OF HIGHGATE SPRINGS SEQUENCE SOUTH OF HIGHGATE SPRINGS VERMONT

Rocks like those at Highgate Springs are recognized in scattered exposures southward through Swanton and St. Albans Bay to the vicinity of Beans Point and Camp Rich, some twenty miles from Highgate Springs in northern Chittenden County (fig. 7). Invariably, Cambrian sediments lie to the east beyond the Rosenberg or Champlain fault, and dark Ordovician argillaceous and quartz silty shales are to the west. The localities have been reviewed briefly by Logan (1863, p. 855-858) and by Gordon (1923, p. 191-196, 202-204, 207-209 and 214-215): the St. Albans Bay area was crudely discussed by Edson (1906, p. 139-143) and mapped by Pretzer (1945). Little can be added by repetitious descriptions of the successive outcrops; hence their distribution is briefly listed so that the significant aspects can be discussed in subsequent pages. Most are isolated small areas exposing one formation which would appear as spots with enigmatic structure on a small scale map. The best single area to show the nature of the structure is Fonda Quarry Hill (figs. 8 and 9).

*Swanton area.*—The rocks are exposed in four separate areas in the vicinity of Swanton; three show only the Beldens formation. In the southeastern part of the village, Beldens white-weathering calcitite with buff-weathering dolomite interbeds is widely exposed north of the Missisquoi River; it is quarried at the Swanton Lime Works. The structure within the formation is involved in recumbent folds that can be mapped only on a very large scale and are difficult to understand in the absence of distinctive marker beds. The floor of the western quarry now filled with water, showed a nearly

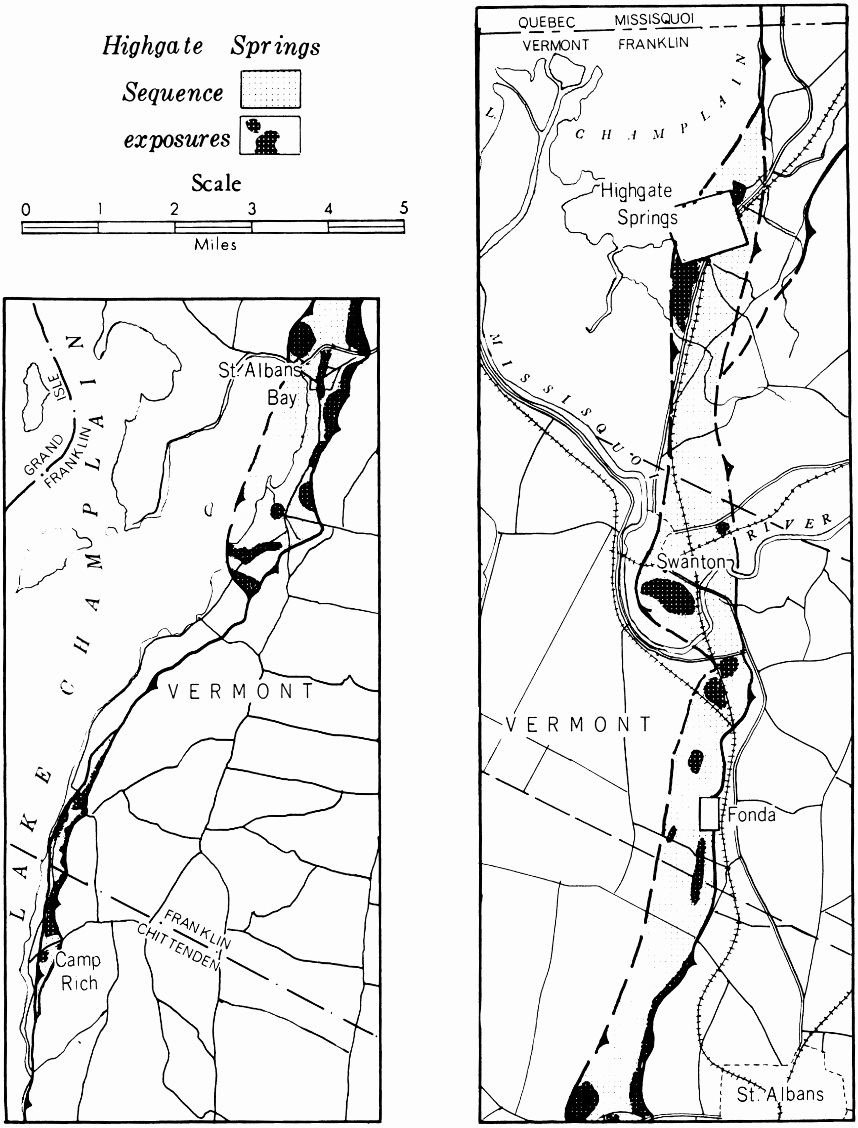


Fig. 7. Map of exposures of Highgate Springs sequence in Vermont; see figures 2 and 8 for details at Highgate Springs and Fonda.

horizontal thrust plane beneath Beldens and above black shales (Gordon, 1923, p. 192) like those extensively exposed in the river west of the village.

Half a mile east of Swanton Junction, similar Beldens carbonate rocks crop out in a small area between the St. Johnsbury and Lamoille County Railroad and Highway 104. Logan interpreted the structure as a south-pitching syncline (1863, p. 856) but this is too simple. The main exposures which form the eastern part of the hill are principally of overturned, apparently west-dipping Beldens beds that reveal their attitude by cross-lamination and channels in dolomitized arenitic beds. The section is one of the best continuous exposures of the Beldens, but shows neither overlying nor underlying stratigraphic units.

One and one-half miles south of Swanton the Central Vermont Railroad crosses Route 104A. Just southeast of this crossing is a hill of Beldens marble apparently dipping rather constantly to the southeast. At the northwest, near the crossing, are exposures of dark slate that presumably lie below a thrust passing under the Beldens. Half a mile south of the crossing on the west side of the railroad a second hill lies between the Central Vermont and the Alburg line of the Canadian National Railroad to the southwest. This hill is dominantly of Carman quartzite, but there are limited exposures of Beldens in the cores of anticlines in the southeastern part of the hill, and the Youngman is infolded and infaulted as northeast-trending strips of argillaceous thin bedded limestones within the hill. The quartzite has been folded and broken by northeast-trending faults that are downdropped on the northwest side. In detail, the hill has quite complex patterns of outcrop of the three formations, but it is essentially of northwest-dipping Carman quartzite, broken and folded.

*Fonda Junction.*—The geology of the principal area of exposure west of Fonda Junction is shown in figure 8. The Lower Cambrian Dunham dolomite of the Rosenberg sequence has been thrust over a recumbent fold of Beldens limestone that structurally overlies Carman quartzite on the west; the thrust is represented by a number of planes, some enclosing lenses of Beldens within the Dunham, and the Dunham dolomite is brecciated, though not obviously so. The Carman has been thrust over Youngman, Isle la Motte and Glens Falls limestones, and the whole is torn by several faults that break the continuity of the quartzite hogback (fig. 9). This is Smiths Lime Works of Logan, who recognized the principal relations (1863, fig. 445, p. 855). Similar relations continue southward through the abandoned Rich Quarry nearer the St. Albans town line, and Glens Falls and Isle la Motte limestones crop out north of the road to the west of the Rich Quarry. On a hill about half a mile northwest of Fonda Quarry Hill are excellent exposures of upper Youngman, Isle la Motte, Glens Falls and succeeding black shale in a nearly vertical homocline on the west limb of an anticline that seems, from cleavage-bedding relations, to plunge south.

*St. Albans Bay.*—The escarpment of Lower Cambrian Dunham dolomite overlying the Champlain thrust stands just east of the roads leading north of St. Albans Bay to Tuller School, and south of the village to and beyond Everett School on Mill River. The thrust places the Dunham on the Beldens white limestone north of St. Albans Bay, the contact being visible within half a mile of the village. Exposures to the west and below are principally of Beldens, but the stratigraphically succeeding Carman quartzite forms quite complicated patterns including some overturned synclines—structural anticlines—along the roadside, torn by high angle faults. The Burton hills, an isolated pair of hills north of the village and east of Stevens Brook, are also

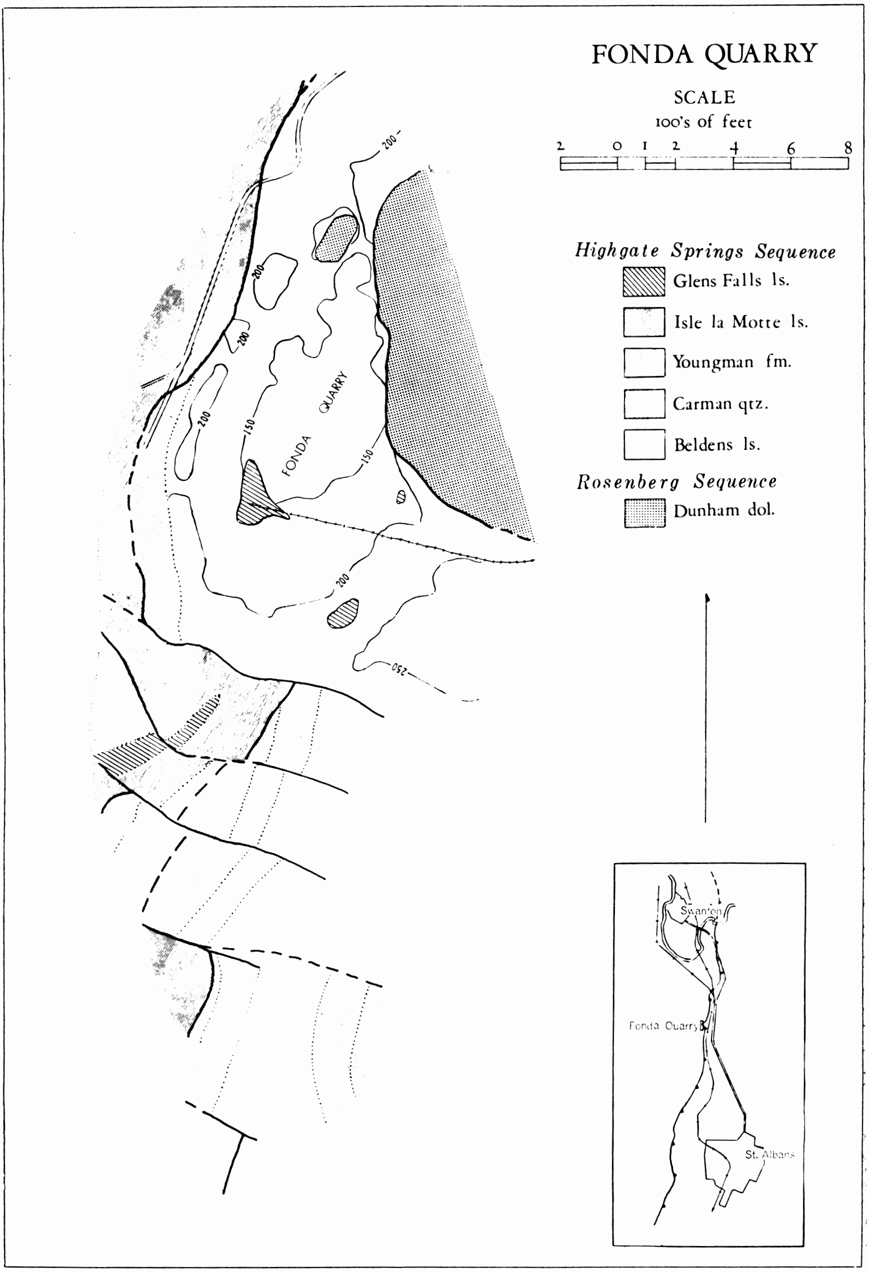


Fig. 8. Geologic map, Fonda quarry area, Vermont.

dominantly of Beldens, which has been thrust on dark slates exposed on the west slope of the western hill, the thrust plane dipping about 35 degrees to

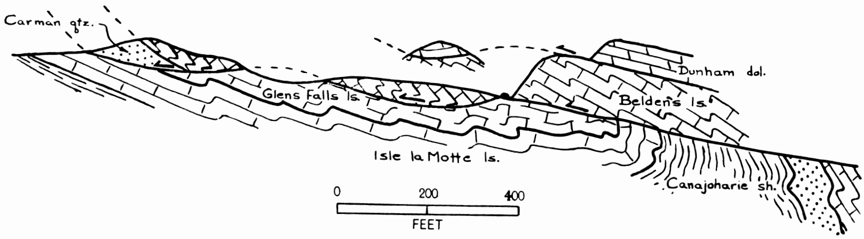


Fig. 9. Structure section through Fonda quarry.

the east; a wedge of Carman quartzite intervenes between the Beldens and the slate on the northwest slope of this hill.

The most conspicuous exposures within the village are in a north-south trending ledge of Glens Falls limestone that parallels and is just east of the shore road. Farther east near the stream are exposures of Youngman argillaceous limestone and small exposures of Carman quartzite. Still farther east is Beldens limestone, the western margin of which cuts across the trend of the younger rocks as though separated from them by a fault. The eastern exposures of the Beldens, particularly those just south of the south road, contain quartz sand and are lithically unlike other exposures seen in the slice. The Beldens continues southward along the base of the Champlain thrust escarpment through Everett School to a ridge trending southward from Lime Rock Point. Carman quartzite is exposed west of the shore road in and near Mill River, and on the shore just east of Lime Rock Point. On the point, the Beldens has been thrust over dark shales, the well-exposed surface dipping 15° N. 60° E. The thrust then trends southward toward School No. 2, for black shale is west of the Beldens ridge at the road and southward. The Dunham dolomite seems to lie directly on black shale southwestward for two miles from east of Melville Landing.

*Beans Point area.*—The Beldens limestone forms conspicuous exposures between the escarpment of Dunham dolomite and the black shale of the shore cliffs for two miles north and two miles south of the Franklin County—Chittenden county line, which is a mile north of Camp Rich and Beans Point. In the exposures in the slopes northeast of Camp Rich and along both sides of the road near the county line, relatively pure Beldens white-weathering gray calcilutite dips generally southeast from 15 to 60 degrees. South of the county line, the Beldens exposures form a hill above shore cliffs of slate, which lies below the gently east-dipping thrust fault. There are scattered exposures southward to Camp Watson. Throughout this narrow belt between the black shales and the Dunham, only Beldens limestone was observed.

The Champlain Fault cuts out the Highgate Springs sequence southward, so that the Dunham dolomite structurally overlies the Ordovician slates northwest of Burlington, as at Red Rock Point. The nearest exposures of similar rocks are in the northwest part of the Middlebury Synclinorium (Cady, 1945) near Weybridge, more than 30 miles to the south, and east of the Champlain thrust.

## STRATIGRAPHY OF THE HIGHGATE SPRINGS SEQUENCE

*Introduction.*—Six lithologic divisions have been recognized in discontinuous and isolated exposures from north of St. Dominique, Bagot County, Quebec, to near Camp Rich, northwestern Chittenden County, Vermont, a distance of about 80 miles. Dissimilar rocks are present on each side of this narrow belt. The rocks within the belt are structurally so disturbed and so imperfectly exposed that full sections of each of the formations are few. The following pages summarize the sections, their similarities and contrasts, the faunas and the correlations.

*Beldens limestone.*—The Beldens limestone (Cady, 1945) is named from a locality in the Middlebury synclinorium north of Middlebury. The typical Beldens is dominantly fine-textured, well-bedded calcitite interbedded with buff-weathering, dark, fine-textured, brittle dolomite. The oldest rocks at Highgate Springs are Beldens, in the core of the anticline extending through Restaurant Point and the nearby islands and in the old quarry on Limekiln Point to the north. On the west side of Restaurant Point, the laminated, fine-textured, white-weathering calcitite with beds of buff-weathering dark, fine-textured dolomite is exposed in contact with the sharply contrasting quartzite of the Carman formation. In a number of small folds in the Beldens, the factured dolomite beds have been bent into regular similar folds as the adjoining calcitite has retained its continuity by flowing. The quarry in Limekiln Point exposes 50 feet of laminated calcitite, interrupted exposures of shaly carbonate rock containing quartz silt and of calcitite and dolomite extend to the exposures of Carman quartzite along the bay to the south.

The best sections of the Beldens are 1) in the lowland northwest of the escarpment west of St. Dominique, half a mile north of the highway, 2) in the hill south of Highway 104 half a mile east of Swanton, 3) west of the road to Tuller School, half a mile northeast of St. Albans Bay village and 4) on Mill River south of St. Albans Bay. The two sections near St. Albans expose the contact with the younger Carman quartzite; others are at unascertained positions within the Beldens, but they exemplify the varied rocks in the formation, and their proportions.

The dominant rock in the formation is laminated, quite pure calcitite, such as was quarried in the Fonda Quarry, where it is separated from the Carman quartzite by about ten feet of buff impure calcitite. The section north of St. Albans Bay shows that magnesium beds are not limited to the upper few feet of the 160 feet exposed below the Carman quartzite. Along Mill River to the south, 200 feet of Beldens is exposed; dolomite is virtually lacking in the upper 150 feet. In the hill east of Swanton, the formation through about 200 feet is dominantly laminated calcilutite, but contains beds of dolomitized, cross-bedded calcarenite. The section north of St. Dominique shows 120 feet of orange-weathering dark impure somewhat laminated dolomite, which tends to develop axial plane cleavage, as well as quite pure calcilutite. Similar beds are known throughout the extent of the Beldens, as in the Sudbury Nappe just north of the Taconic Mountains. The dolomite beds in the formation show excellent boudinage.

The Beldens was classed as Chazyan by Cady (1945, p. 550-552), for it succeeded rocks long identified as "Crown Point", probably because they contained poorly preserved fossils resembling *Maclurites*, characteristic of the middle Chazyan Crown Point limestone of the section in New York. The "Crown Point", of the Middlebury synclinorium was renamed the Burchards limestone (Kay and Cady, 1947) because of its structural separation from the typical Crown Point, and the Burchards and Beldens were placed in the Chipman Group, thought Chazyan. Subsequently, the Beldens was interpreted as a calcitic facies of the Bridport dolomite, the upper part of the typical Beekmantown or Canadian farther west (Kay, 1950, p. 1476), on the basis of structural continuity with the Bridport and of the presence in the Weybridge member of the Beldens of brachiopods and trilobites of Canadian affinities.

On the geologic map of west-central Vermont (Cady, 1945, pl. 10) the sequence in eastern Shoreham, Addison County, is successively Bascom-Bridport-Crown Point-Beldens-Middlebury. Along the same belt of exposure in southern Cornwall, it is Bascom-Crown Point-Beldens (including Weybridge)-Middlebury; exposures are quite discontinuous along the outcrop belt. The Bridport in east Shoreham, though dominantly of brown weathering, laminated, medium-bedded dolomite, has several beds of white-weathering calcitite; and though the Beldens formation in Cornwall is largely of white-weathering laminated calcitite, it has many beds of buff-weathering dolomite like the dominant rock in Bridport, as well as the darker gray, fine-quartz-sandy laminated, cross-laminated and thinly-bedded Weybridge member. The Burchards ("Crown Point") in Cornwall has partially dolomitized sections of fossils of the general form and dimensions of gastropods of the genus *Maclurites*, but the poorly-preserved structures may be coiled cephalopods such as *Eutrephoceras*. *Maclurites* is a long-lived genus that is abundant not only in the Chazyan Crown Point limestone, but also in the Corey limestone near the top of the Canadian in the Philipsburg Sequence near Bedford, Quebec. Rarely, specimens of *Maclurites* are present in the Beldens too, as in exposures near Camp Rich, Vermont. And *Maclurites* sp. is common in the Youngman (St. Dominique) limestone three hundred feet above the Beldens on St. Pie Hill and northward in Bagot County, Quebec.

Not only does the Beldens seem to pass laterally into the Bridport from Cornwall to Shoreham, but the Weybridge member of the Beldens contains fossils that seem diagnostic of Canadian age. These fossils have been collected most successfully in the quartz-sandy laminated dark calcitites of the Weybridge east of the road east of "The Ledges" on the Cornwall-Weybridge town line two miles west of Middlebury. The fossils are generally poorly preserved, for the quartz grains have grown and penetrated the calcite. Species of the brachiopod genera *Diparelasma*, *Orthambonites* and *Syntrophopsis*, and of the trilobites *Goniurus* and *Isoteloides* have been identified, forms that are widely distributed in Upper Canadian sediments (Ulrich and Cooper, 1938).

In the Highgate Springs sequence, the Beldens is the oldest stratigraphic unit that has been identified confidently. In a few localities there are thin-bedded quartz silty limestones resembling the Weybridge facies—above the quarry on Limekiln Point near Highgate Springs, and in the northwestern exposures near Highway 104 east of Swanton. But recognizable fossils have not been seen. A small area of calcitite containing coarse quartz sand associated with the Beldens, either within or below the formation, lies south of the road just east of St. Albans Bay Village. The sandy beds have erosional disconformable contacts and contain orthoceracone cephalopods of undetermined identity.

The exposures of equivalent rocks that lie nearest to the Highgate Springs sequence are on "The Head" at the south end of Isle la Motte, ten miles directly west of St. Albans Bay. The Bridport, there underlying the basal Chazyan Day Point sandstone, consists of tan-weathering, very dark gray, laminated, medium-bedded somewhat siliceous dolomite, with very thin-bedded argillite layers. This sort of rock is again present on Providence Island off southern South Hero, Grand Isle County, Vermont, and in western belts in west-central Vermont (Cady, 1945). As stated above, the Bridport dolomites pass laterally eastward into the Beldens calcitites with interbedded dolomites. In the Highgate Springs sequence, the only section in which the Bridport facies dominates through a considerable thickness is that northwest of St. Dominique. The nearest exposures to the west are on Ile Jesus and near Chateauguay in the Montreal area (Clark, 1952), about 40 miles west of St. Pie. The Canadian Beauharnois formation is dominantly of bedded dolomite and argillite in the thickest sections, but the youngest fossil-dated beds are thought to be older than the Bridport. The Canadian beds are known also from several wells between the Montreal outcrop and the St. Dominique belt (Clark, 1955, p. 8).

The thickness of the Beldens is determined only as a minimum, the two hundred and fifty feet of so measured in continuous sections; the thickness may be considerably greater and is estimated as 600 to 700 feet on the east limb of the Middlebury Synclinorium to the southeast (Cady, 1945, p. 551); the Bridport dolomite has an estimated thickness of 470 feet in East Shoreham, west of the synclinorium (Brainerd and Seely, 1890, p. 3).

The most striking fact about the Beldens in the Highgate Springs slice is that it is persistent throughout the belt of exposure, yet in no place has the underlying Burchards formation been definitely recognized; even if the quartz-sandy calcitite near St. Albans Bay be older than Beldens, the area of exposure is very small. Yet the Beldens commonly lies directly beneath the Lower Cambrian rocks of the Rosenberg slice, as well displayed in Fonda Quarry, and as essentially true southward to Camp Rich. The Beldens has been severely folded and has flowed; not only are small folds frequently recognized by the course of dolomite beds, but the calcitite thins across the swells in dolomite boudinage structures. The formation was relatively incompetent and served as a glide-plane along which the thrust advanced.

Paleogeographically, the Beldens is a facies of the Bridport. On a paleolithologic map dolomites would dominate in a belt extending westward from west of the west limb of the Middlebury Synclinorium, cutting the outcrop about in eastern Shoreham.

*Carman Quartzite.*—The Carman quartzite has its type section at the head of Shipyard Bay in the Highgate Springs area (Kay, 1945); it contains about 120 feet of thin- to medium-bedded quartz sandstone having a few argillaceous partings, and includes some calcarenite beds in the upper part. The section exposes the contact with the underlying Beldens calcitite, but the top is cut off by a fault. The quartz sandstones are somewhat argillaceous; surfaces commonly show rod-like structures, "fucoids". In other sections, the upper part of the formation is varyingly argillaceous. The type section is the thickest that has been seen, even though incomplete. The formation is completely exposed in Stanbridge Township, where it is but 40 feet of quartzite passing up into argillites with nodular calcareous lenses. On western St. Pie Hill, it is about 120 feet thick; the lower half is quartzite, the upper half, quartz silty argillite with quartz sand and calcarenite beds. Only the uppermost beds are exposed west of St. Dominique, but calcarenites have yielded a small faunule. Southward from Highgate Springs, good exposures at Fonda Quarry show about 40 feet of quartzite, and many scattered bands are associated with the Beldens north of St. Albans Bay and southward to the cove east of Lime Rock Point.

The Carman quartzite is like the quartz sandstones and associated argillites in the base of the Day Point formation of Grand Isle County, Vermont, to the west (Oxley, 1952). Moreover, the faunules from the immediately succeeding limestone at St. Dominique have many specimens of *Raphistoma striata* (Emmons), abundant in lower Chazyan Day Point calcarenites in New York and the islands of Lake Champlain (Oxley, 1952; Raymond, 1906).

In the northern Middlebury Synclinorium, quartzite is not constantly present in the basal part of the Middlebury formation, but quartz-sandy beds are common, as in exposures north of Center Weybridge, three miles northwest of Middlebury. In the Sudbury Nappe at the northern end of the Taconic Range, either the Middlebury argillicalciutite lies directly on Beldens calcitite, or else they are separated by as much as 50 feet of partly dolomitized, thin-bedded to medium-bedded, somewhat argillaceous calcisiltite, which forms conspicuous hills around Sudbury and in which axial-plane cleavage is well developed as magnificently shown on "Recumbent Hill", west of the Lemon Fair River a mile west of Sudbury church.

*Youngman formation.*—In the type section at Highgate Springs, Vermont, the Youngman formation (Kay, 1945) has exposure of a lower 180 feet of argillaceous calcitite and argillite lying on Carman quartzite, and beyond interuption an upper 30 feet of argillite with calcareous beds below Isle la Motte limestone (fig. 4). The full thickness in this locality is probably more than 300 feet, and there are several quite fossiliferous horizons.

In some respects, the type section is unique. Other sequences in the same apparent stratigraphic position along the thrust slice are not lithically identical, though varyingly similar, and in Vermont they are virtually nonfossiliferous. East of St. Hyacinthe, Quebec, the St. Dominique limestone (Clark, 1955) in the same stratigraphic relations is more calcareous and quartz-silty and has common fossils. The type Youngman contains some fossils known in the Chazy limestones to the west along Lake Champlain, but others that are unknown there and have been thought diagnostic of later age; hence the classification of the Youngman as Chazyan has more than local interest.

In the type section of the Youngman along the lake shore north of the village, the lowest 150 feet is dominantly argillaceous calcisiltite and calcilutite with partings and thin beds of argillite. The succeeding exposures are dominantly argillite, but with thin beds of calcitite. The rocks have been deformed so that argillaceous matter has penetrated calcareous beds along cleavage, making them cobbly, or producing slaty cleavage that is more evident than the bedding; thus the field geologist tends to call the formation a slate.

The only other continuous exposure of considerable thickness is in a hill .7 mile north and a little west of Fonda Quarry, south of Swanton, where 80 feet of section extends to the top of the formation. These beds bear little resemblance to the upper Youngman at Highgate Springs, for the section is dominantly of well-bedded calcisiltite, though with argillaceous partings and several feet of argillite with calcareous cobbles in the lower 20 feet. There are many scattered exposures of smaller parts of the formation, most of them of cleaved calcareous argillite as in the two good sections. To the north in Quebec, the basal few feet, argillite with calcareous interbeds, crop out in Stanbridge. The sections in the same stratigraphic position at St. Pie Hill and St. Dominique are discussed below as the St. Dominique limestone.

The thickness at Highgate Springs can be computed as 285 feet, but is greater, for a fault crossing the section cuts out beds along the strike; the true thickness is probably greater than 300 feet.

The Youngman formation is ordinarily non-fossiliferous, but fossils have been found in thin lenses and beds at several horizons at Highgate Springs. *Lonchodomas halli* (Billings) is abundant in faunules from both the basal 20 feet and the upper 50 feet. *Christiania* sp. cf. C. *subquadrata* (Hall) is abundant in the lowest beds. The associated forms are listed in a table; G. A. Cooper has been helpful in the identification of the brachiopods.

*St. Dominique limestone.*—The St. Dominique formation was described (Clark, 1955, p. 9) as consisting of the St. Dominique sandstone member, about 110 feet thick at St. Pie Hill, and the St. Dominique limestone member, 225 feet in the same section. The writer has earlier (1945) considered these to be the Carman and Youngman formations, but the differences are sufficient to make separate designation preferable. The Beldens is succeeded by 120 feet of argillite with quartz arenite dominant in the lower part and calcarenite beds frequent in the upper; These are overlain by about 200 feet of carbonate rocks, principally calcarenite and calcisiltite, partially dolomitized, to a concealed interval. The writer computed a thickness of 340 feet from the Beldens to the "Black River," almost identical to the 330 feet given by Clark.

The other section of the St. Dominique is along the highway northwest of St. Dominique. The basal sandstone is incompletely exposed but the succeeding limestones are extensively quarried through a thickness of nearly 300 feet, principally of somewhat siliceous calcisiltite, but with calcarenite prevalent particularly in the upper part.

TABLE 1

Faunules from Youngman Formation, Highgate Springs, Vermont

| Localities: | a | b | c | d |
|---|---|---|---|---|
| *Christiania subquadrata* (Hall) | a* | . | . | . |
| *Hesperorthis* ? sp. | f | . | u | . |
| *Leptellina* sp. | c | . | . | . |
| *Lingulella* ? sp. | u | . | . | . |
| *Platymena* sp. | f | u | . | . |
| *Protozyga* sp. | . | r | . | . |
| *Rostricellula* sp. | . | . | u | f |
| *Skenidioides* ? sp. | . | . | r | . |
| *Sowerbyella* sp. | . | . | c | . |
| *Valcourea* sp. cf. *V. strophomenoides* (Raymond) | . | . | c | . |
| *Maclurites* sp. | . | r | . | . |
| Orthoceracone | x | . | . | . |
| *Bathyurus* sp. | . | . | f | . |
| *Ceraurus* ? sp. | r | . | r | . |
| *Calliops* sp. | . | . | u | . |
| *Illaenus* sp. | u | . | . | . |
| *Isotelus* sp. | . | . | c | . |
| *Lonchodomas halli* (Billings) | c | . | a | . |
| *Onchometopus* sp. | . | . | c | . |
| *Remopleurides* sp. cf. *R. americanus* Raymond | r | . | . | . |
| *Lepidocoleus* sp. | r | . | . | . |
| *Aparchites* sp. | c | . | c | . |
| *Eridoconcha* sp. | . | . | r | . |
| *Euprimitia* sp. | f | . | . | . |
| *Eurychilina* sp. | . | . | r | . |
| *Schmidtella* sp. | c | . | . | . |
| *Thomasatia* sp. | . | . | r | . |
| *Winchellatia* sp. | . | . | r | . |

Localities:—along shore of Missisquoi Park from Kingfisher Bay to Phelps Bay; a- basal 20 feet; b- succeeding 150 feet, from several beds; c- single 1-inch lens, 27 feet from top of section; d- bed 15 feet from top of formation.

* Frequencies: a- abundant, c- common, f- frequent, u- uncommon, r- rare, x- present.

Fossils are frequent in the lowest calcarenites exposed above the quartzite south of the highway, and in calcarenites near the top of the formation north of the large quarry north of the road (table 2). At St. Pie Hill, the upper St. Dominique limestone has reefy beds in which *Eospongia* and *Maclurites* are frequent, much as in the upper beds of the middle Chazyan Crown Point formation in New York. The lowest beds at St. Dominique have abundant *Raphistoma stamineum* Hall; though this form is rather distinctive of the lowest Chazyan Day point formation in New York, virtually identical forms have long range.

*Classification of the St. Dominique and Youngman formations.*—The exposures at St. Dominique have invariably been classified as Chazyan by those who have studied them since the time of Logan (1863, p. 206), and have been correlated with the exposures at Highgate Springs (p. 820; also Raymond, 1906, p. 555). Though *Lonchodomas halli* was originally described from Highgate Springs and has been reported from St. Dominique and the typical Chazy of New York (Raymond, 1905, p. 334) through considerable range, *Christiania subquadrata*, common in the lower Youngman at Highgate

TABLE 2

Faunules from St. Dominique limestone, Bagot County, Quebec

| Localities: | 1a | 1b | 2a | 2b |
|---|---|---|---|---|
| Bryozoans | x* | x | . | x |
| *Eospongia* sp. cf. *E. roemeri* (Billings) | . | . | . | f |
| *Camerella* sp. | . | r | . | . |
| *Hesperorthis* ? sp. | u | . | . | . |
| *Platymena* sp. | c | . | . | . |
| *Sphenotreta* sp. | . | c | . | . |
| *Valcourea* sp. | c | a | c | . |
| *Bucania sulcatina* (Emmons) | . | . | r | . |
| *Raphistoma stamineum* Hall | c | r | c | . |
| *Maclurites magnus* Leseuer | . | . | . | x |
| *Bronteopsis* ? sp. | . | r | . | . |
| *Bumastus* sp. | . | . | x | . |
| *Calliops* sp. | . | f | . | . |
| *Ceraurinella* sp. cf. *C. pompilius* (Billings) | . | . | r | . |
| *Illaenus* sp. | . | r | . | . |
| *Isotelus* sp. | c | . | c | . |
| *Platymetopus* sp. cf. *P. minganensis* (Billings) | . | u | . | . |
| *Pseudosphaerexochus* sp. | r | . | . | . |
| *Remopleurides* sp. | r | . | . | . |
| *Aparchites* sp. | c | c | . | . |
| *Bythocypris* sp. | . | r | . | . |
| *Dilobella* ? sp. | r | . | . | . |
| *Eridoconcha* sp. | . | r | . | . |
| *Euprimitia* sp. | f | . | . | . |
| *Eurychilina* sp. | f | f | . | . |
| *Schmidtella* sp. | . | f | . | . |
| Cystid fragments | a | a | . | c |

Localities: St. Dominique: la-calcarenite immediately above quartzite south of highway at west face of quarry hill; 1b- calcarenite ledges about 50 feet from top of formation northeast of quarry north of highway. St. Pie Hill: 2a- ledges in upper part of formation near north end of hill; 2b- bioherms on northeast slope of hill.

* Frequencies: a- abundant, c- common, f- frequent, r- rare, x- present.

Springs, seems to have been discovered first by the writer. Experience with this genus and its associates had led to the judgement that in the Appalachian region *Christiania* is post-Chazyan, and it is so indicated on the Ordovician Correlation Table (Twenhofel and others, 1954) though Rodgers (*ibid.*, p. 267) suggests that—"*Christiania* ranges even lower than shown on the chart into equivalents of the Chazy". Those who have studied brachiopods most diligently have been reluctant to accept the Chazyan age of the Youngman formation (p. 287). This becomes further involved in the relative age of the "upper Lenoir" *Christiania* zone to the Lincolnshire limestone, which Rodgers places above the zone and Cooper below it. B. N. Cooper (*ibid.*, p. 274) tentatively correlates the Lincolnshire with the upper Chazyan, noting that "*Sowerbyella, Sowerbyites,* and *Dinorthis* are unknown in the type Chazyan of the Champlain Valley": the writer has classified the Lincolnshire as upper Chazyan (1956, p. 98), because of the similarity of the *Billingsaria* reefs in the Lincolnshire and Valcour, as well as approximate stratigraphic position.

The stratigraphic relations of the Carman and Youngman seem to preclude their being other than Chazyan. If they were two similar lithic sequences, each a sandstone-limestone couple, they would have to persist in contiguous areas, yet each be absent where the other is present. This contrast would have to take place not only from the Highgate Springs sequence to the foreland, but also between the St. Dominique and the Carman-Youngman along the same trend; the Middlebury would continue this enigma.

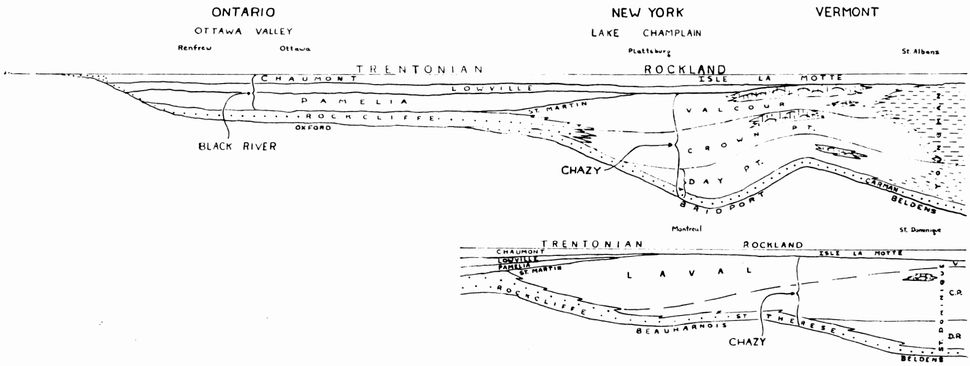


Fig. 10. Restored sections of the Chazyan rocks from the Ottawa Valley to Quebec and Vermont.

The conclusion reached by the writer is that the Carman-Youngman is Chazyan of a facies different from the typical Chazy group (fig. 10) and from the St. Dominique, and that the presence of *Christiania*, *Sowerbyella*, *Platymena* and other forms in the formation must be accepted as showing that the ranges of these genera are somewhat greater than had been recognized, and that their sensitivity in correlation is somewhat reduced. It is unfortunate that the fossils are so rarely present, and not preserved so that they might be etched and better examined. The writer has tried material by several methods of preparation, and found none that is better than tooling them from the calcite matrix.

*Isle la Motte limestone.*—The Isle la Motte limestone was named by Emmons (1842) from the island town of Grand Isle County, Vermont, in northwestern Lake Champlain; he correlated it with the "Seven-foot Tier", the upper part of the Chaumont limestone of the Black River group of northwestern New York. Though the writer considered it lower Trentonian (1937, p. 260), he is inclined to consider this in error, though the evidence is somewhat contradictory; the question is discussed below. In the Highgate Springs sequence, a similar limestone persists between the Youngman formation and the Glens Falls limestone; the "Lowville" calcilutite that separates the typical Isle la Motte from the Chazyan is not present.

The formation is everywhere thick-ledged, though medium-bedded, resistant calcitite and tends to form ridges, particularly where the Youngman is argillitic as at Highgate Springs; black chert is locally present. The full thickness of the formation is shown on the south side of Phelps Bay, Highgate Springs, where about 70 feet is exposed; the lowest beds contain quartz sand and lie with nearly a foot of erosional relief on argillaceous Youngman containing nodular calcilutite beds. The base is similar where exposed on the southwest side of the U-shaped loop of its outcrop west of the village. The contact with the succeeding Glens Falls is excellently exposed on the west side of the hill directly south of the village crossroad, the lithology changes abruptly into the more argillaceous, thin-bedded fossiliferous Glens Falls. The Isle la Motte is generally calcisiltite, with some well-indurated calcarenite interbeds and lenses; rarely, chert is present. Fossils are uncommon and not readily extracted; colonies of the coral *Foerstephyllum* are occasionally seen.

At St. Dominique, the Isle la Motte is well exposed in a lime quarry south of the highway. The beds are thick-ledged, generally medium- to thin-bedded rather pure calcitite with abundant pelecypods in some beds. In the quarry, 48 feet can be measured; the base seems to be faulted against a surface of Youngmans, and the top is sod covered, though farther south the contact with the Glens Falls is exposed. A third excellent section of the Isle la Motte is in the hill northwest of Fonda Quarry where 70 feet of dark, thick-bedded, fractured and calcite-veined calcitite lies on similarly thick-bedded Youngman calcisiltite that has more common argillaceous seams. The basal part of the Isle la Motte contains quartz sand, but the contact with the Youngman is not striking. Moreover, the upper contact with the medium- to thin-bedded Glens Falls is not conspicuous, though the latter is distinctly more argillaceous and is fossiliferous rather than essentially barren.

With regard to correlation and classification, this unit is lithically like the Isle la Motte limestone exposed in belts to the west. The typical Isle la Motte overlies light-weathering calcilutite that is presumably "Lowville", which in turn lies disconformably on the Upper Chazyan Valcour limestone. The Isle la Motte is succeeded by thin-bedded argillaceous Glens Falls limestone, commonly fossiliferous, and the fossils seem Kirkfieldian in the type area. Thus the typical Isle la Motte could be Blackriveran Chaumontian or lowest Trentonian Rocklandian on the basis of stratigraphic position, if the correlations of the Lowville and Glens Falls are correct. The fossil considered most diagnostic of upper Rocklandian is *Triplesia cuspidata* (Hall), found below the Glens Falls at Crown Point (Raymond, 1903, p. 23; Kay, 1937, p. 261); the writer considered these beds to be in the Isle la Motte. However the sixteen feet of limestone below the Glens Falls at Crown Point is calcarenite and calcisiltite that is softer, less brittle and coarser textured than the underlying beds; as the latter are like typical Isle la Motte, this opposes classification of the Isle la Motte as Rocklandian. The Isle la Motte contains species of *Receptaculites*, *Maclurites* and *Foerstephyllum* like those particularly common in the Rockland in Ontario; but similar or indistinguishable forms may well be present in the Black River equivalents, particularly as the lithologies, and presumably the ecologies represented, are so similar that rocks of these ages are frequently confused. The writer was further influenced by finding "*Rafinesquina*" sp. and "*Calymene*" sp. in the "Isle la Motte" of Highgate Springs, which lies directly on Chazyan-classified Youngman rather than on "Lowville"; these genera are not known below Trentonian in western New

York; perhaps they ranged lower than has been supposed, and moreover I suspect misidentification.

In summary, the Isle la Motte formation is now classified as Blackriveran, and correlated with the Chaumont limestone of the Black River group of northwestern New York.

*Glens Falls limestone.*—The Glens Falls limestone was named by Ruedemann (1925, p. 22) for the "basal Trenton limestone" . . . "lower than any exposed at Trenton Falls", between the Amsterdam limestone and the Canajoharie shale. The formation has two members, the Larrabee and Shoreham, correlated with the Kirkfield and Shoreham limestones of the Trentonian of western New York (Kay, 1937, p. 262-267; Chenoweth, 1952). The Highgate Springs sequence has many exposures of beds faunally and lithically like those south and southwest of Highgate Springs crossroads, where they succeed the Isle la Motte; fossils are abundant in several horizons, and show that the lower 35 feet is equivalent to the Larrabee, and the higher *Cryptolithus-Reuschella*-bearing beds, to the Shoreham. The beds are rather uniformly thin-bedded, black, dark gray-weathering, quite argillaceous calcilutite and calcisiltite, with occasional beds of coquinal calcarenite. The thickness can be measured in the hill directly south of the spring east of the railroad, for the discontinuous vertical-dipping exposures are flanked by Isle la Motte and Hortonville; it is almost 100 feet. The higher part of the Glens Falls and the succeeding black shale are exposed along the southwest shore of Shipyard Bay. There are east-dipping exposures of the Glens Falls in the fields east of the Isle la Motte limestone quarries at St. Dominique. The formation is quite fully exposed with nearly vertical dip on the west slope of the hill northwest of Fonda Quarry, and there are scattered exposures along the road west of Rich quarry, as well as in St. Albans Bay village.

The abundant fauna of the Glens Falls permits it to be correlated readily with the formations of western New York. *Reuschella edsoni* (Bassler) was first described from the Shoreham beds at Highgate Springs; it has been seen elsewhere only in the section at Larrabee Point in Addison County, and in exposures in hills one mile west of Hyde Manor, in calcarenites directly beneath the typical Hortonville. The genus was described originally from the Caradocian on the Onny River, Shropshire, England, and has been found to be common in the Oranda formation in the Appalachians of Pennsylvania (Craig, 1949) and the Virginias (Cooper and Cooper, 1946). *Cryptolithus tesselatus* Green, on the other hand, characterizes a single limestone unit called the Shoreham as far westward as southeastern Ontario (Chenoweth, 1952, p. 526.)

The Glens Falls limestone seems rather constant throughout the area east of Lake Champlain, whether in the Highgate Springs slice and the Middlebury Synclinorium, or in the unthrust terrane to the west. The formation is directly succeeded, however, by black shaly argillutite in the overthrust sequences, but by the interbedded argillaceous calcisiltites and argillutites of the Cumberland Head formation along Lake Champlain (Hawley, 1957). Inasmuch as the name Hortonville was applied to shales directly succeeding Glens Falls, the term is applied in the Highgate Springs sequence. The Stony

Point black shales that overlie the Cumberland Head formation along Lake Champlain to the west are presumably somewhat younger at their base.

*Hortonville Shale.*—The Hortonville shale (Keith, 1932, p. 360; Cady, 1945, p. 558) overlies the Glens Falls limestone. The laminated black argillaceous shale is exposed only in limited areas within the slice, and no section is continuous for more than a few feet. The basal few feet tend to contain thin calcilutite beds, but they disappear upward into dark shale. Only rock that is in rather continuous exposure and structure with older formations in the sequence can be confidently attributed to the Hortonville in the slice. For example, at Lime Rock Point and southward, to the southwest of St. Albans Bay, the Beldens white-weathering calcitite is thrust on dark shales, but the latter are in the Iberville formation, and may be as much as half a mile stratigraphically above the base of the Hortonville shale (Hawley, 1957). The recognition of the great stratigraphic difference between the shales in the Highgate Springs sequence and those that lie across the Highgate Springs fault on the west emphasizes the significance of the fault. The youngest preserved shale formation to the west, the Hathaway, contains radiolarian cherts on Hathaway Point in St. Albans Bay, but also blocks of Glens Falls limestone which lies half a mile below and must have been elevated in a structure to the east in Hathaway time.

On the east, there are no problems where rocks bound the Highgate Springs sequence from its southernmost exposures in Chittenden County to the southern and undetermined limit of the Philipsburg sequence in the vicinity of Swanton. From here to the latitude of Bedford, the Philipsburg sequence contains formations that can be confused only with the Beldens formation in the Highgate Springs sequence, if with that. Northward, the carbonates of the Philipsburg sequence are succeeded in the axis of a northward pitching synclinorium by the Mystic limestone boulder conglomerate and the dark, laminated argillites of the Stanbridge shale, which are middle Ordovician and much resemble the shales of the Highgate Springs sequence. The Philipsburg thrust can be traced readily northward to the latitude of Bedford, where the fault, trending more northeasterly than the axis of the synclinorium, brings Stanbridge slate over Iberville and Stony Point shale of the more westerly sequence, the Highgate Springs Sequence being cut out. The structural position of the slates exposed at Farnham and St. Pie has not been determined. Just to the north, on St. Pie Hill, the Beldens has been thrust over the Glens Falls limestone, but this may be a fault within the Highgate Springs sequence. Cincinnatian Lorraine sandstone and shale is well exposed in the river at St. Hyacinthe, but there is no exposure in the several miles southeastward to the Beldens northwest of St. Dominique. Thus, shales known to be Hortonville because of structural continuity with Glens Falls in the Highgate Springs sequence can adjoin similar Stony Point, Iberville or Hathaway shales west of the Highgate Springs fault, and similar Stanbridge shales east of the Philipsburg fault.

## STRUCTURAL GEOLOGY

The structural relations of the sequence have been briefly discussed. The Rosenberg sequence lies next east in the hanging wall of the Champlain or Rosenberg thrust, from Beans Point, Chittenden County, Vermont to the vicinity of Swanton. The fault contact is beautifully displayed in Fonda Quarry and can be seen or closely approached for miles to the southward. The strata that adjoin the Highgate Springs sequence are invariably Lower Cambrian, and generally within the Dunham dolomite, a relatively competent, gently east-dipping thick-bedded reddish dolomite that succeeds Cheshire quartzite in normal sequence on the east limb of the Middlebury Synclinorium. Thus the Rosenberg thrust has clearly moved at or above the contact between the Cheshire and the Dunham.

The Rock River dolomite of the Philipsburg sequence overlies the Philipsburg thrust where it bounds the Highgate Springs sequence north and south of the Vermont-Quebec boundary, or, as at Philipsburg, cuts over onto the sequence normally west of the Highgate Springs (McGerrigle, 1930). Northward in Quebec, the trace of the Philipsburg Thrust cuts upward in the stratigraphic section: the Corey limestone, which lies a quarter mile east of the Highgate Springs sequence exposures in Stanbridge Township, is nearly 2000 feet higher in section than the Rock River. The formation on which the Rock River lies is not exposed, but by analogy to similar sequences in Vermont, it should be heavy-ledged carbonate rock. Northward, it is presumed that the Philipsburg thrust continues unrecognized between Stanbridge shale on the east and Hortonville shale on the east flank of the St. Pie-St. Dominique homocline.

The most striking features of the Highgate Springs sequence are the persistence of a group of formations of mixed types and only a few hundred or a thousand feet thickness for such a long distance in such a narrow strip, and the constant presence of the Beldens high-calcium limestone interbedded with dolomite as the oldest rocks in the thrust slice. The underlying formation must originally have been the Burchards, somewhat dolomitized calcitite, or the Bascom, argillaceous limestone, partly rather shaly, but commonly medium-bedded. Whatever the cause, the Highgate Springs slice seems to have moved on a thrust surface within or about the base of the Beldens formation. The effect of the proximity of the thrusts above and below is evident in the severely folded and fractured sediments, as at Highgate Springs and Fonda Quarry.

The several formations have reacted differently. The Beldens calcitite flowed readily, the interbedded dolomite being drawn out into lens-sectioned slivers or boudins. The Carman has been rather severely folded in spite of being quartzite but it commonly also has gash or tension fractures normal to the surfaces of the beds. The Youngman, where shaly and argillaceous, has developed axial-plane cleavage to such a degree that the cleavage surfaces, along which the argillite has flowed, come to be quite as obvious a series of parallel bands as the bedding; the two can easily be confused. The Isle la Motte is more resistant and tends to be crushed and to develop calcite-filled veins. The Glens Falls develops excellent axial-plane cleavage, which causes the rock to break into rhomb-shaped cleavage fragments. The Hortonville, when well cleaved, is a slate.

The Highgate Springs slice is essentially a torn and deformed segment from the overturned east limb of a northeast-plunging recumbent synclinorium cored by Ordovician chert and shale in Vermont (Hawley, 1957). The sole of the Highgate Springs slice, the Highgate Springs thrust, has a more northerly trend than the northeast-trending axis of the synclinorium. In Quebec, the trace of the Highgate Springs Thrust cuts the east limb of the southern end of the Chambly-Fortierville synclinal basin (Clark, 1947).

The principal structure to the east in Vermont is the northward-plunging synclinorium of Cambrian sediments having its west limb in the Rosenberg slice and its east limb in the Oak Hill sequence (Booth, 1949). At the international boundary and northward, the Rosenberg slice is separated from the Highgate Springs slice by another north-plunging syncline, the Philipsburg slice. The Rosenberg thrust is a bedding plane slip on the lower Cambrian, presumably on some relatively incompetent horizon beneath the Dunham dolomite, which crops out constantly at the base for scores of miles in Vermont and Quebec. The displacement of the Rosenberg slice over the Philipsburg was sufficient for the Rosenberg slice to cut over progressively younger beds northward, but the Philipsburg sequence being almost wholly Ordovician, and the Rosenberg Cambrian, there is little to compare stratigraphically between them. On the other hand, the Philipsburg sequence has strata of the same stratigraphic level as but lithologically distinct from, the Highgate Springs sequence and must be rather far travelled, as the Highgate Springs sequence is comparatively constant for several scores of miles. The strongest stratigraphic similarities of the latter are with sediments in the northern Middlebury synclinorium, a south-plunging structure in the southern continuation of the Rosenberg slice block, above the Champlain-Rosenberg thrust.

Recent studies in the synclinorium west of the Highgate Springs slice suggest that folding began in Trentonian time. Submarine breccias in the Hathaway formation in the core of the synclinorium (Hawley, 1957) contain fragments of Glens Falls limestone, which lies far below the Hathaway in normal sequence. Hence, a welt of Ordovician must have risen to the east of the synclinorium and yielded the Glens Falls boulders. As the Glens Falls is present in the Highgate Springs slice and in the Middlebury synclinorium, but absent in the Philipsburg Sequence, the source may have been in an arch rising on the east flank of the Highgate Springs belt.

## CLASSIFICATION OF THE ORDOVICIAN SYSTEM

*Introduction.*—The stratigraphy and fauna of the Highgate Springs sequence bears on current classifications of the post-Canadian—pre-Trentonian Ordovician. To avoid ambiguity in nomenclature, it is considered that the Canadian Series extends to the top of the Bridport and Beldens formations in the Champlain Valley, and that the Trentonian Series has its base at the contact of the Selby member of the Rockland formation on the Chaumont limestone of the Black River Group in northwestern New York and eastern Ontario.

*Principles in terminology.*—Stages are time-stratigraphic units defined by rocks in a place. Lithically distinct units are formations or members. Some units called formations were defined as stages. Thus Raymond's (1914, p. 348) "formations" in the Trenton were zones he thought time-defined by fossils; subsequently the lithologies were distinguished, but Rockland limestone and Rocklandian stage are identical at Rockland, Ontario. Other formations in the stage have lithic differences or were named as an incident to their isolation. Cushing's divisions of the type Chazy were described as substages (1905, p. 368).

It is better to give a new name than to redefine an old one that has clearly stated and established content, unless the proposed changes are minor or a reflection of ambiguity. The Chazyan Series corresponds to the Chazy limestone as originally used for rocks above the Calciferous and below the Black River near Lake Champlain. The Trentonian extends from the top of the Black River in northwestern New York to the top of the Utica. The Bolarian Series includes only rocks younger than the Lincolnshire and older than the Nealmont in Virginia (Kay, 1947). If such terms are inapplicable to spans that should have names, they should not be redefined. There may be a little inconvenience in the introduction of new terms, but that is better than confusion.

*Ordovician Classification.*—Classification becomes involved in judgements of correlations unless the full sequence is in one locality. The classification of rocks younger than Canadian and older than Trentonian concerns sequences a) along Lake Champlain, containing the type Chazy, b) in northwestern New York, containing the typical Black River and Trenton, and c) in the Appalachians, particularly the Virginias, where there are type sections of the Bolarian Series and of a number of recently named stages (Cooper, 1956, p. 8). Classification and correlation discussed within the past two years (Cooper, 1956; Kay, 1956; Twenhofel and others, 1954) must be reconsidered.

*Champlain Valley and northwestern New York.*—The Chazy limestones lie on the Canadian along Lake Champlain; now that the Canadian age of the Beldens limestone has been recognized, there is no problem in the placement of the boundaries. The Chazy lies on a regional unconformity with an overlapping basal quartz sandstone. The Chazy has long been divided into three lithologic and faunal zones (Brainerd and Seely, 1888) which were given the "substage" names Day Point, Crown Point and Valcour (Cushing, 1905; as stages these have been called Dayan, Crownian and Valcourian (Oxley, 1952).

The Black River group of northwestern New York lies on Precambrian crystalline rocks or Cambrian (Young, 1943). The original Black River has come to be divided into the Pamelia, Lowville and Chaumont formations in northwestern New York, but younger beds have been called "Black River" in Ontario (Kay, 1942, p. 596; 1956, footnote, p. 96). The limestones that succeed the Chazyan along Lake Champlain are assumed to be correctly cor-

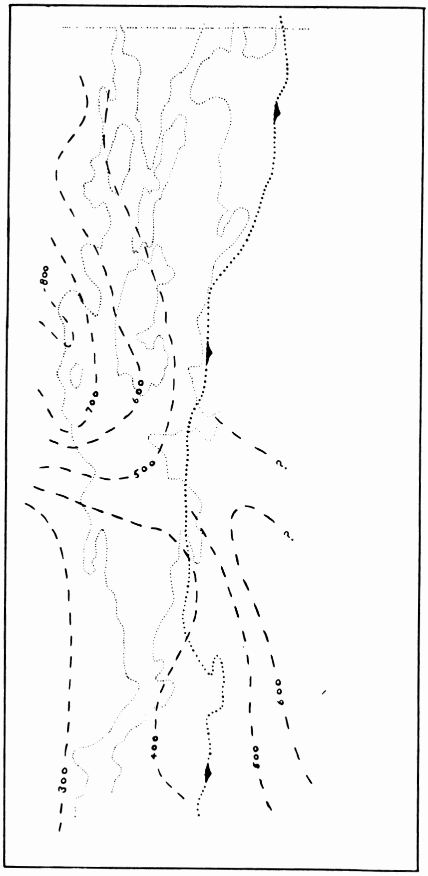

Fig. 11. Thickness of Chazyan rocks along Lake Champlain in New York and Vermont, based largely on data from Oxley, 1952.

related with the Lowville and the Chaumont (Isle la Motte); the Lowville is interruptedly present. Thus the upper Black River is younger than the type Chazyan. In the Ottawa-St. Lawrence Lowland (Wilson, 1946), the St. Martin limestone has been classified repeatedly as Chazyan Valcourian: it underlies Pamelia beds. Thus if the generally accepted correlations are correct, the Chazyan Series is older than some or all of the Pamelia formation of the Black River group of northwestern New York.

*The Appalachian Region.*—The Appalachian region has been thought to have fuller sequences of post-Canadian rocks than New York, but the recent studies cast some doubt on this assumption. If one established an Appalachian standard, one could correlate to New York sequences: there are problems of correlation within the Appalachian sections, so a single one must be used. The top of the Canadian seems marked by a readily recognized disconformity in most places. The writer considers the top of the Black River equivalents to be the Stover limestone in Pennsylvania and the McGraw limestone in the

Virginias (Kay, 1956, p. 97). To the southwest, there is disagreement whether the base of the Trentonian is within the upper Witten formation or at the top. Cooper (1956) placed the lowest Trentonian as well as Black River equivalents in his Wilderness stage.

The Bolarian Series was defined (Kay, 1947) as extending from the top of the Lincolnshire limestone to the base of the Nealmont limestone, which seems lowest Trentonian. The Lincolnshire was classified as Chazyan.

Rocks younger than Canadian in the Appalachian region have been assigned by Cooper to the Marmor, Ashby, Porterfield and Wilderness stages (1956, p. 8). The Marmor, based on formations in Tennessee "includes the Chazy group of rocks and its correlatives." As the type section of the Marmor is isolated from that of the others, I will refer to the rocks between the Canadian and the Elway and Lincolnshire formations of the type Ashby in Virginia as the Blackford "stage." Thus the Virginia sequence consists of the Blackford, Ashby, Porterfield, (containing Ward Cove, Peery and Benbolt formations) and Wilderness "stages"; the writer prefers that stage names have "an" or "ian" endings, but will apply quotation marks to distinguish "stages" from formations. There is question of their correlation with the "Marmor." The essential problem is that of the time correlation of these with the Chazy and Black River in New York.

*Bearing of the Highgate Springs Sequence.*—The stratigraphy and faunas of the Youngman formation and St. Dominique limestone bear directly on the classification. If they are Chazyan as they seem, they contain fossils that have been considered distinctive of the "Marmor", "Ashby" and "Porterfield" stages in the Appalachians, rather than of the first alone.

The faunas from the Youngman and the St. Dominique formations have strong similarities to those of the "Ashby" and "Porterfield" units in Virginia. Among the brachiopods, *Christiania*, *Playtmena* and *Leptellina* are particularly suggestive of "Porterfield", *Valcourea* of "Ashby". Trilobites such as *Lonchodomas* are frequent in argillaceous "Porterfield" rocks. The coral *Billingsaria* is present in small reefs in the St. Dominique, as it is in the Crown Point and Valcour limestones of the type Chazyan, the Lincolnshire of the type "Ashby", and the Lenoir limestone of Tennessee (Twenhofel et al., 1954, p. 274). Ostracodes in the Crown Point are said to be like those in upper "Ashby" (Lincolnshire) and "Porterfield" (Edinburg) (Swain and Kraft, 1956; Swain, 1957). The fossils in the more argillaceous Youngman generally resemble those in the "Porterfield"; those in the St. Dominique, resemble those in the type Chazy and the "Ashby.",

The writer has thought that the Bolarian Series (that is, the "Porterfield" and younger pre-Trentonian) in the Appalachians is younger than the Chazyan, and that its lower part is older than the type Black River (Kay, 1948; 1956). Cooper (1956) thought the Chazy considerably older, in a stage ("Marmor") separated by the "Ashby" from the "Porterfield" (Arline); but with the "Ashby" missing in the section above the type "Marmor" (Lenoir). Rodgers (1953; 1954) thought the Christiania-bearing "Porterfield" (Arline of Copper) a facies of the "Marmor" (Lenoir) rather than younger and separated by a disconformity. The Highgate Springs sequence strongly suggests that *Christiania*-bearing beds are in a facies of Chazyan and are correlative of "Ashby" and of "Porterfield". Thus the base of the Bolarian Series may lie within the upper Chazyan Series rather than above it.

*Classification.*—Correlations within the post-Canadian pre-Trentonian rocks cannot be made with assurance between distant sequences. In the north, it is possible by faunal and lithic means to subdivide the Chazyan and Black-riveran series each into three stages. In the Appalachians, it seems best to establish provincial stages from a single sequence such as that in the Virginias; "Blackford", "Ashby" and "Porterfield" are in such a sequence. The place of the "Marmor" stage is in dispute; it is not in the same sequence. The "Porterfield" and the pre-Trentonian part of the "Wilderness" stage constitute the type Bolarian Series. The "Blackford" and "Ashby" stages are believed by the writer to be Chazyan, but not to constitute the whole of that series; they are in a provincial series that is approximately the St. Paul Group (Neuman, 1951). The classifications are summarized in table 3.

TABLE 3
Classification of part of the Ordovician System

| NEW YORK | | VIRGINIA | |
|---|---|---|---|
| TRENTONIAN SERIES – Rocklandian stage | | | |
| BLACKRIVERAN | Chaumontian | L. "Wilderness" | BOLARIAN |
| | Lowvillian | | |
| | Pamelian | "Porterfield" | |
| CHAZYAN | Valcourian | | |
| | Crownian | "Ashby" | SAINT PAUL |
| | Dayan | "Blackford" | |
| CANADIAN | | | |

## CONCLUSIONS

The Highgate Springs sequence forms a very narrow but persistent thrust slice extending for eighty miles across the international boundary from Quebec to Vermont. The sediments range from upper Canadian Beldens limestone to middle Trentonian Hortonville shale. The Chazyan rocks are of particular interest because they change facies from St. Dominique limestone resembling typical Chazyan into Youngman calcareous shales having a sparse but distinctive fauna somewhat unlike that in typical Chazyan, and resembling lower Bolarian and older faunas in the Appalachians. The slice is the attenuated east limb of a synclinorium that seems to have slipped on an horizon in the upper Canadian Series. Submarine breccias in the medial Trentonian in the synclinorium are of rocks like those in the Highgate Springs slice, suggesting that the deformation was initiated in the Trentonian epoch.

The Chazyan Series seems equivalent to the strata in the Appalachians contained in the Blackford, Ashby and lower Porterfield "stages". The succeeding Black Riveran Series seems to be contained in the Bolarian Series of the Appalachians, but the lowest Bolarian seems older and equivalent to upper Chazyan.

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