BEDROCK GEOLOGY OF THE CENTRAL CHAMPLAIN VALLEY OF VERMONT

By

CHARLES W. WELBY

VERMONT GEOLOGICAL SURVEY
CHARLES G. DOLL, *State Geologist*

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ABSTRACT

The autochthonous rocks exposed within the Central Champlain Valley range from the Trempealeauian Ticonderoga dolostone through the Middle Ordovician Iberville shale. The sequence is continuous with no apparent interruptions in deposition; possibly a paraconformity exists between the Bridport dolostone and the Chazyan Day Point formation.

The Day Point formation previously thought to be restricted to the northern part of the Lake Champlain area is shown to extend southward at least to Crown Point, New York; the formation is inferred to be present east of the Champlain Thrust, which bounds the map area on the east. The Upper Chazyan Valcour formation pinches out to the east and northeast and is replaced by limestones of the Crown Point-Middlebury type. Evidence shows that deposition was continuous from the Valcour into the Lower Mohawkian Orwell limestone. The Glens Falls attains a thickness of approximately 450 feet throughout most of the area, and in Addison it likely is between two and three times this thick. The Stony Point and Iberville shales record the gradual rise of a landmass to the east or southeast with a concomitant influx of first argillaceous material and then quartz-rich detritus.

The lower formations of Canadian time indicate the presence of a shallow sea in the area; many local breaks in deposition are recorded by the intraformational breccias and conglomerates. The dolostones of these formations were formed as primary dolostones as is attested to by the abundant sedimentary phenomena found within them. The Canadian sequence is chiefly dolostone with limestone becoming important only in the Middle Canadian Cassin formation and the overlying Bridport dolostone. Of the several Canadian formations, only the Cassin is fossiliferous, and its type section is described in some detail. Rocks of Chazyan age record shallow seas teeming with life; no important organic

structures have been found. During the Canadian and the Lower Champlainian the detrital materials came from the west.

The dominant structural elements of the area are the faults. Thrust faults and high-angle faults attendant upon the Champlain Thrust, which apparently emplaced the overthrust mass during the Taconic Disturbance, lie along the eastern margin of the area; high-angle cross-faults and longitudinal faults formed subsequent to the Taconic Disturbance. The Champlain Thrust is offset throughout its length by a number of cross-faults which show throws up to 1500–2000 feet. Re-entrants of the Champlain Thrust are explained by the cross-faults. Stratigraphic relations suggest the presence of a "barrier" or less negative area near the eastern margin of the Central Champlain Valley during Chazyan and Mohawkian times; moreover, a less negative area may have existed also in the latitude of Burlington during the Chazyan.

Check-lists are provided for faunas of the various formations. The presence of a cerioid coral, *Nyctopora*, in the Crown Point is noted; its possible confusion with *Foerstephyllum* commonly found in the Orwell and correlative beds is pointed out.

Numerous lamprophyre and bostonite dikes and sills intrude the rocks of the area, seemingly having been emplaced during the same period of igneous activity; their relation to the cross-faults is unclear, although it is implied that the dikes came subsequent to the period of faulting. The time of the intrusions can be dated only as post-Champlainian.

INTRODUCTION

Location[1]

As a part of the central lowland of the Champlain Valley, the area is bounded on the west by Lake Champlain and farther west by the Adirondack Mountains. To the east lies the intensely folded and thrust-faulted Cambrian-Ordovician sequence bordering the Green Mountain

[1] In the summer of 1960, after submission of the manuscript for publication, the author mapped the rest of the Ticonderoga quadrangle between the Orwell thrust and Lake Champlain and south of a line from Bridport to West Bridport. The results of this work are shown on the Geologic Map (Plate 1). The mapping showed that the Iberville formation extends nearly to the southern border of the Ticonderoga quadrangle, and reconnaissance work in the Whitehall quadrangle to the south suggests strongly that this formation and the Stony Point shales are both present east of the thrust belt. The mapping also showed that the pattern of cross-faulting continues as far south as the southern margin of the Ticonderoga quadrangle. Footnotes have been utilized for specific comments on the results of the mapping.

Anticlinorium. Historically, the area has been of importance in the interpretation of the North American Ordovician System.

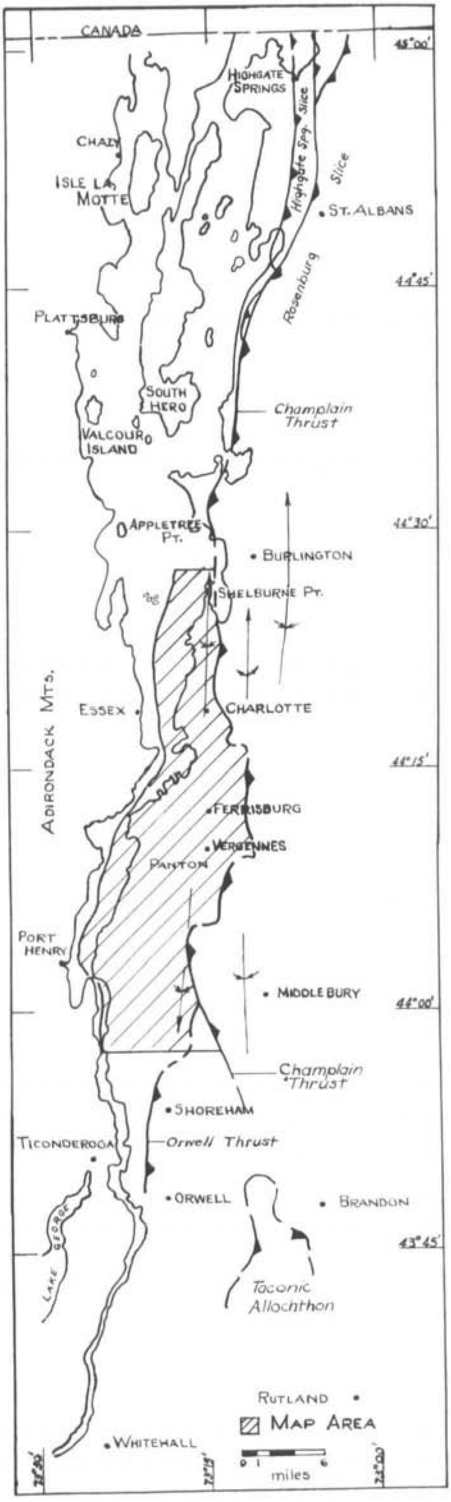
As one of the links in the chain of Ordovician deposits extending from the southern margin of the Adirondacks through the Champlain Valley to the valley of the St. Lawrence River, the sequence encompassed within the boundaries of the area informs of events that transpired in adjacent areas. Within the confines of the Central Champlain Valley is evidence for post-Taconic faulting and for facies changes. The lateral changes must be defined and properly evaluated before the regional history of the lowlands area from the Mohawk Valley to the Gulf of St. Lawrence can be correctly interpreted. A complete sequence of Lower and Middle Ordovician rocks outcrop within the area, perhaps one of the most complete sequences of this interval.

Beginning at the latitude of Burlington, Vermont, the area extends southward a distance of 34 miles to the general latitude of Bridport village. It expands in width from about a mile at the northern end to approximately 7 miles at the southern boundary, encompassing an area of approximately 150 square miles. The area lies within parts of the Burlington, Vermont, Middlebury, Vermont, Willsboro, New York-Vermont, Port Henry, New York-Vermont and Ticonderoga, New York-Vermont 15 minute quadrangles (Text-figure 1).

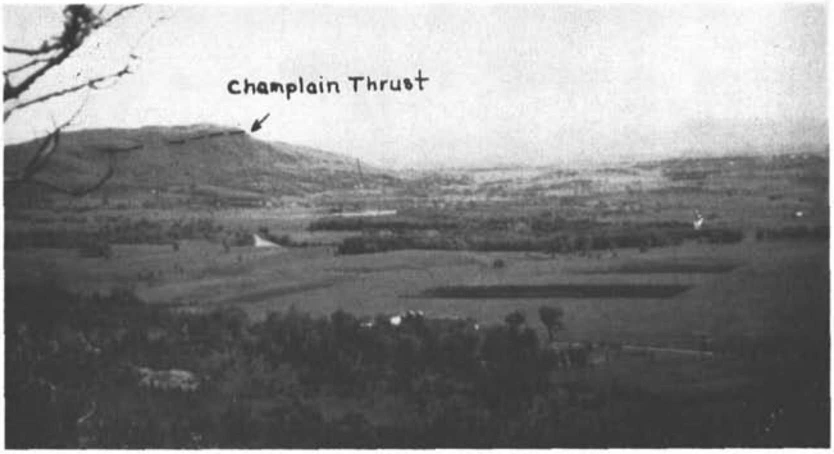
Topographically the area is flat except near its eastern margin where the ground surface rises sharply along the western face of the Red Sandrock Range, which is dominated by several peaks: Snake Mountain, Buck Mountain, Shellhouse Mountain, and Mt. Philo. Low, rounded hills and narrow, linear ridges mark many of the outcrops in the flat portion of the lowland. The flatness of the lower elevations may be ascribed to the lakebed and marine deposits of the Pleistocene which lie on the eroded and irregular surface of the Ordovician rocks. The Pleistocene material has covered all but the highest of the bedrock ridges and hills. The subsurface bedrock topography of a portion of the area is shown on Plate 3.

Except for the control exerted by the Champlain Thrust along its course, there is no readily apparent relationship between the topography and the underlying bedrock structure. However, mapping and study of the area has shown that some of the large topographic features, as well as many of the smaller ones, reflect the underlying structure. Pleistocene and Recent cover obscure details of the relationships.

The block diagram of Plate 13 illustrates the topography of the area and brings out some of the geologic relations also. Figure 1, Plate 4, a



Text-fig. 1. Outline map showing location of Central Champlain Valley area and major structural features of the region.



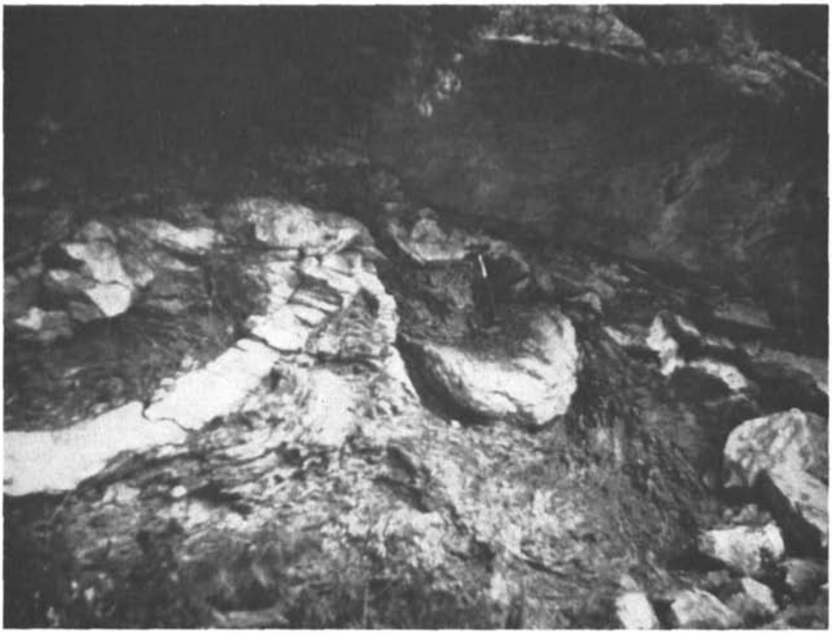


PLATE 4

Figure 1. View of north end of Snake Mt. looking south from near the top of Buck Mt.; note position of Champlain Thrust.

Figure 2. Champlain Thrust with massive Monkton dolostone over limestones and shales of Stony Point. Northeast corner of hill at southwest corner of Shelburne Bay. Hammer head approximately 6 inches below fault surface; Monkton dolostone in upper righthand corner.

view looking south from Buck Mountain toward Snake Mountain, emphasizes the sharp topographic rise from the valley up the west face of the Red Sandrock Range.

Procedures

The field work was initiated in mid-summer 1956 and continued in the summers of 1957, 1958, and several weeks in the summer of 1959. A number of weekends were devoted to field work during the fall and spring of each year; in all a total of about 9 to 10 months was devoted to the field work. Photographic enlargements of standard 15 minute quadrangles were used as base maps. The scale of these enlargements is 1 in. = 1760 ft.

A number of sections were measured in conjunction with study of the several formations; descriptions of these are given in Appendix I. Most were measured with a tape, but where the sections lie exposed in fields, pace and compass methods were used in determining the thicknesses. Rock colors were determined using the National Research Council Rock-color Chart (1948).

Initially conceived as a stratigraphic study, it soon became apparent that the investigation should concern itself with not only the stratigraphy of the area, which basically was known, but also with the detailed structure. In a short time experience demonstrated that the area is cut by a large number of faults and that projection of any contact farther than one can see it extend is a hazardous undertaking.

Projection of contacts beneath the Pleistocene cover represents interpretations based on the exposed rocks and must be understood as indicating the most probable relationship rather than the absolute answer. On the map (Plate 1) the contacts are projected to a position on the present surface, as if all the area were bedrock but with the present topography. Thus, if the cover were removed, the contacts would be found in entirely different positions than indicated, positions obtainable by downward projection along the dipping contact plane to the actual bedrock surface.

Outcrops vary widely in abundance. Along the lake shore outcrops are generally good, but locally they are accessible by boat only. Within the flat area of the lowland outcrops are low and sparse. Because of the uneven nature of the bedrock surface, every creek, stream, and gully can provide outcrops and thus must be investigated. On the slopes leading to the Champlain Thrust, the formations composed of massive, thick-bedded rocks outcrop well; the shaly and thin-bedded formations rarely form good outcrops but are represented by abundant fragments.

Acknowledgements

Dr. Charles G. Doll, State Geologist, gave to the author the opportunity of undertaking this study. To him appreciation and thanks are due not only for this, but for the several long discussions concerning the problems at hand, discussions which resulted in a better grasp of some of the problems.

Dr. John Rodgers of Yale University most generously loaned the author a copy of his manuscript on the Ticonderoga quadrangle and discussed at some length his maps of the area. In addition he pointed out important features in the New York portion of the Port Henry quadrangle. Dr. Wallace M. Cady of the United States Geological Survey and Professor David Hawley of Hamilton College each spent a day in the field with the author visiting outcrops within the area that were familiar to each. Professor Hawley, in addition, showed the author key outcrops of the shales in the northern Lake Champlain region. The author has had the benefit of the ideas of these people on several other occasions and gratefully acknowledges these opportunities; he alone, however, is responsible for the ideas set forth in the following pages.

Middlebury College and Trinity College, provided facilities and equipment for the laboratory studies made during the course of this investigation.

Dr. and Mrs. E. Kirk Roberts of Middlebury, Vermont, most kindly extended the hospitality of their home during weekends in the Spring of 1959 as the field work was being drawn to a close. Professor B. F. Wissler of Middlebury College and Professor Sterling B. Smith of Trinity College extended aid on several occasions. Dr. J. M. Van Stone kindly helped with preparation of the microphotographs. Professor Randolph C. Chapman discussed aspects of the igneous rocks with the author and clarified several points. Mr. James C. Carver, a student at Middlebury College, served capably as the author's field assistant during part of the summer of 1958.

To Eleanor Morse Welby is owed an indebtedness for help in the technical aspects of preparation of the manuscript, including editing and preparation of most of the typescript.

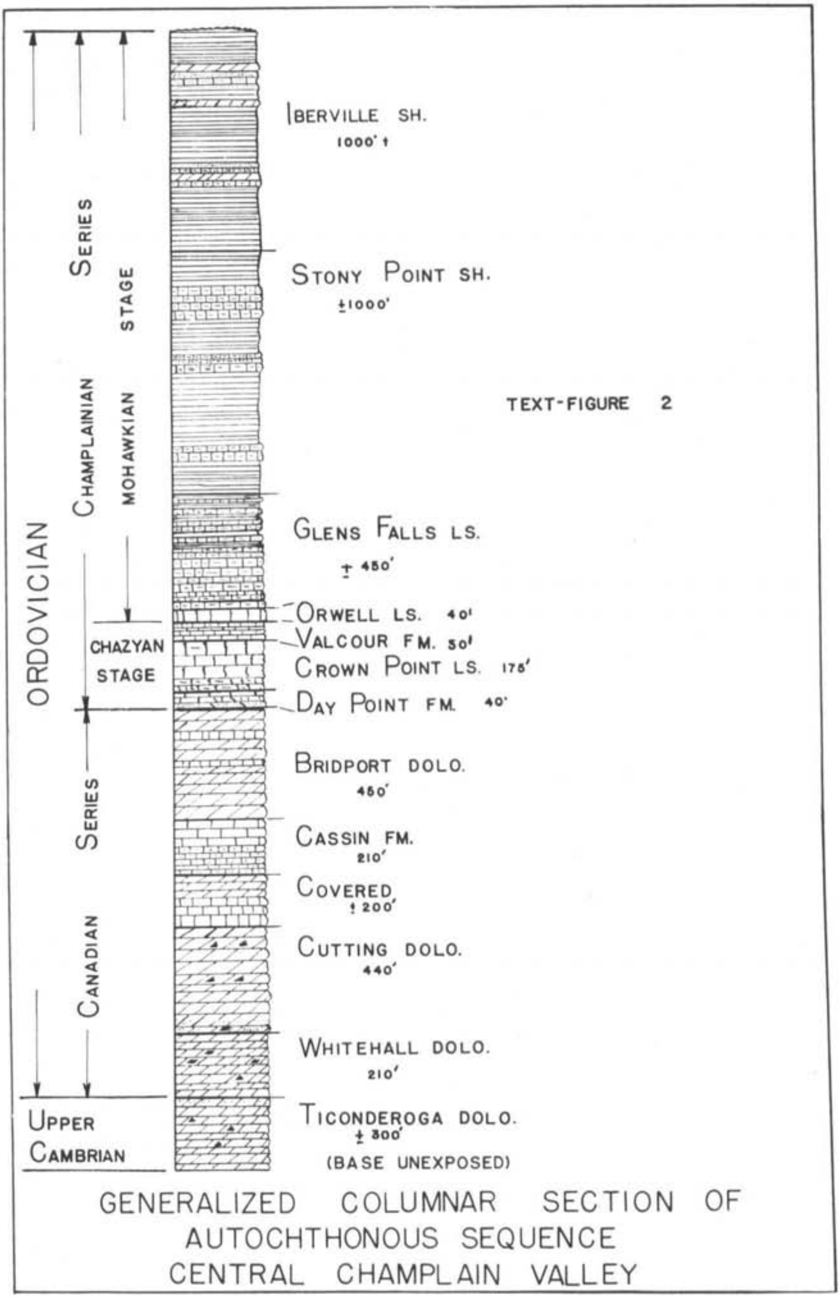
Previous Work

The first recorded geologic observations on the Central Champlain Valley seem to be those made by Peter Kalm in 1770 (cited in Raymond, 1902), who noted fossils at Crown Point on the New York side of Lake Champlain. Emmons in 1842, incidental to his studies of the Second Geologic District of New York, described rocks from Addison and Charlotte and explained the relations at Snake Mountain as caused by a vertical fault. Adams (1846, p. 162–164) discusses very briefly the distribution of the limestones and shales lying west of the Champlain Thrust, which was unrecognized by him. However, he did note (figure 96, p. 163) a high-angle fault west of Snake Mountain, approximately in the longitude of the road running at the foot of the mountain.

In the 1861 report (Hitchcock and others) outcrops of the various formations within the area were discussed, and the stratigraphy as it is now understood was essentially outlined. The outcrops from Crown Point, New York, northward to Charlotte were viewed as being part of an anticline with Chazy rocks in the middle and the younger Trenton rocks on the outside. It was recognized that the "Utica Slates" of the "Hudson River Group" are of two types; black, calcareous slate and "glazed shales, having an anthracitous luster" (Vol. 1, p. 301). The two varieties of shales were not distinguished in the mapping. The Beekmantown rocks at Vergennes were considered to be Chazy. In 1863 Logan (p. 283–285) recognized the extension of the Champlain Thrust from the Canadian border southward to Burlington and suggested that it continued southward.

Brainerd and Seely (1888, 1890a, 1890b, 1896) and Brainerd (1891) outlined the stratigraphy of the Beekmantown and Chazy rocks in the Champlain basin and adjacent areas by study of important outcrops in widely separated areas. In conjunction with this work they collected extensively from the Fort Cassin locality, and Whitfield (1886, 1889, 1890) described the fauna. Aside from maps of local areas discussed in these papers, no systematic areal map was prepared.

The map of the State accompanying the 1861 report seems to have been the only consistent attempt at mapping the area prior to Perkins' (1908) description of the geology of Chittenden County and the Burlington quadrangle (1910); Seely (1910) described the geology of the area in his discussion of Addison County, including a generalized map of the county. He interpreted the fault west of Snake Mountain as a high-angle fault. In the paper he listed some of the fossils found at Fort Cassin and provided plates figuring some of the more prominent ones. Earlier, Ruedemann (1906) had reclassified some of the forms. At about the same time Raymond (1902, 1906) studied the fauna of the Chazy and while not concerning himself directly with the rocks of Vermont's Central



Text-fig. 2. Generalized columnar section of autochthonous sequence.

TABLE 1

BEDROCK FORMATIONS OF THE CENTRAL CHAMPLAIN VALLEY

	General Lithology	Avg. Thick. Feet
ORDOVICIAN—Champlainian Series		
Mohawkian Stage (Trentonian Stage)		
Iberville shale	noncalcareous, black and dark-gray shale with yellowish-orange-weathering dolomitic silt-stone	1000+
Stony Point shale	black, calcareous shale and thin-bedded argillaceous limestone	1000 ±
Glens Falls limestone	black, thin- to medium-bedded, silty and argillaceous limestones with shale in upper part	450
Mohawkian Stage (Black River Stage)		
Orwell limestone	black, very light-gray-weathering, sublithographic and lithographic limestone; characterized by layers of fossil fragments	40
Chazyan Stage		
Valcour formation	dolomitic limestone, local sandy horizons; generally moderately thick beds	50
Crown Point limestone	thin- and moderate-bedded, sublithographic to coarse-grained, fossil-fragmental limestones characterized by black, silty partings and laminae	175
Day Point formation	quartz sandstone, noncalcareous shale, silty dolostone, dolomitic sandstone, and thin-bedded, fossil-fragmental limestone	40
ORDOVICIAN—Canadian Series		
Bridport dolostone	sublithographic-textured dolostone, buff- and light-gray-weathering; occasional beds of laminated, sublithographic limestone and noncalcareous shale	450
Cassin formation	sandy limestone weathering with raised ridges overlain by sublithographic, bluish-gray-weathering limestone which is in part shaly	210
Covered interval	probably like lower Bascom of southeast Shoreham	200
Cutting dolostone	medium and finely crystalline dolostones with sandy horizon and characteristic intraformational breccia at base	440
Whitehall dolostone	medium and coarsely crystalline dolostone, local intraformational breccias, locally sandy; local limestone horizon	210

TABLE 1 *continued*

BEDROCK FORMATIONS OF THE CENTRAL CHAMPLAIN VALLEY

	General Lithology	Avg. Thick. Feet
CAMBRIAN—Croixian Series		
Trempealeauian Stage		
Ticonderoga dolostone	medium and finely crystalline dark dolostone, moderate- to thick-bedded, local abundance of chert and sand	200–300
CAMBRIAN—Waucoban Series: Outcrops along eastern margin of area where these formations are in fault contact with the rocks of the autochthonous sequence.		
Winooski dolostone	light-colored, sandy dolostone	
Monkton quartzite	red, thin- to medium-bedded quartzite and thick-bedded, massive, light-colored quartzites; yellowish-orange and pinkish dolostones in lower part of formation with light-colored quartzites	
Dunham dolostone	massively bedded, buff- and yellowish-orange-weathering, locally sandy	

Champlain Valley, did provide a basis for study of the fauna of the Chazy group within the area.

Ruedemann (1921a, 1921b) from studies of the outcrops at Panton and elsewhere in the Champlain Valley recognized the correlation of the shales overlying the Glens Falls limestone with the Canajoharie shales of the Mohawk Valley. He failed to distinguish the noncalcareous Iberville shales from the calcareous Stony Point shales and the underlying transition sequence, which he termed the Cumberland Head formation from its outcrops at Cumberland Head, New York. More recently, Hawley (1957) has mapped the shales of the northern Champlain Valley and shown the existence of the two types first noted in the 1861 report.

Reports by Gordon (1921, 1923) and by Foyles (1923, 1924, 1926a, 1928a) discussed the areal geology. Foyles attempted to prove that the Fort Cassin rocks were actually Chazy and that a significant unconformity exists at the top of the sequence at Fort Cassin. His one contribution seems to have been the recognition that cross-faults offset the Champlain Thrust (1928a, map). He also proposed the term "Addison formation" for the shales and limestones of the central part of the area, feeling that they could not be differentiated into separate formations and mapped. Gordon (1921) suggested that reverse and normal faulting preceded the overthrusting.

Quinn (1931, 1933) discussed the high-angle faulting of the region. Cushman (1941) mapped in a 6-weeks period most of the area covered in this report. However, he did not recognize any of the cross-faults nor did he differentiate the Stony Point and Iberville shales from one another. Neither did he recognize the Day Point and Valcour formations, having lumped them with the Crown Point. Four years later Cady (1945) published a significant paper on the geology of the area east of the Champlain Thrust. In it he discussed the regional stratigraphy extensively and provided names for some of the previously unnamed formations of the Beekmantown group. He also interpreted some of the structures found west of the thrust belt.

Most recently Kay and Oxley (1959) have discussed the distribution and character of the Chazy group within the Central Champlain Valley and adjacent areas. Kay (1958) has also discussed the regional relations of the Highgate sequence to the north of the Central Champlain Valley. Erwin (1957) has described the limestones of the islands at the north end of the lake and worked out details of their stratigraphy.

Text-figure 2 is a generalized columnar section of the autochthonous sequence as now understood, and Table 1 briefly describes the several formations.

STRATIGRAPHY

Lower Cambrian Series

Formations representing the Lower Cambrian are successively the Dunham dolostone, the Monkton quartzite, and the Winooski dolostone. All outcrop along or east of the Champlain Thrust and are present in the area only along this feature or in slivers beneath it. For the correlations of these formations, the reader is referred to Cady's paper (1945) on West-Central Vermont.

DUNHAM DOLOSTONE (Clark, 1934)

The oldest beds exposed in the area mapped are part of the Cambrian Dunham dolostone. These are found outcropping in two small blocks 1.25 miles south of Buck Mountain and on the southern and western slopes of the hill 2.3 miles south of Buck Mountain and adjacent to State Route 17. In the last-mentioned locality the Dunham is exposed from the alluvial cover adjacent to Route 17 northward to the northwest corner of the hill. Its western boundary is a thrust fault which brings the Dunham over the Bridport dolostone; to the east lies the Monkton quartzite. A down-to-the-east fault terminates the Dunham outcrop at the northwest corner of the hill and brings it into contact with the Monkton. Along the south slope the contact between the Monkton and the Dunham is obscured by soil cover.

A depositional contact between the Dunham and the Monkton can be observed in the cliffs of the northwest corner of the hill. The massive beds of the Dunham dolostone near the top of the cliffs give way abruptly to the white, massively bedded quartzite of the lower part of the Monkton.

The two exposures of the Dunham in the area approximately 1.25 miles south of Buck Mountain represent blocks of dolostone which have been limited at either end by cross-faults whose movements appear to have been primarily dip-slip. Both outcrop areas consist of steep, cliffed exposures in which the eastward-dipping Dunham beds may be seen lying on beds of the Crown Point limestone in a thrust relationship. The eastern margins of the blocks are high-angle faults which are obscured by the cover of the 30- to 50-foot interval between the Dunham and the Crown Point limestones outcropping to the east.

The klippe of Dunham mapped by Cady (1945, Plate 10) in the general vicinity of the Dunham blocks is not present; at the locality shown on his map Crown Point beds outcrop.

Weathered surfaces of Dunham dolostones are commonly buff- or light-cream-colored (10YR7/6). Some beds are grayish-white on weathered surfaces. Fresh surfaces of the dolostones are dominantly shades of gray to black, but cream-colored varieties are also present. The average grain-size varies from .05 mm to .1 mm, but many of the dolostones are finer grained than .05 mm. The rocks of the formation in all cases are well-knit, hard, and resistant. Bedding is massive, and 3- to 4-foot beds are common. In the cliffed exposures at the northwest corner of the hill immediately north of Route 17, the dolostones show no bedding planes for thicknesses of 20 feet or more; stratification is shown by very thin laminations within the dolostones. Fine-grained sandstone lentils approximately 1 inch thick are irregularly distributed through the rocks, extending laterally for distances of 6 to 12 inches.

Patchwork masses of sandy or silty material appear as more or less smooth-weathering, nodular-like, raised areas on weathered surfaces. Thin section study of the silty-sandy materials shows them to be composed of .05 mm or less, angular to subangular grains of quartz. The individual grains can be recognized only under the crossed nicols of a polarizing microscope. Most of the quartz grains possess undulatory extinction which attests to the stress to which they have been subjected. The dolostone associated with some of these masses is dark-gray to bluish-gray with a smooth, conchoidal fracture similar to that of chert. The sand and silt does not occur in well-defined beds but usually as irregular masses and lentils within the predominant dolomite of the formation.

White calcite veinlets within the rock give rise to a scored appearance on weathered surfaces since they weather as depressions. White quartz veinlets are also present and stand up on weathered surfaces as ridges .1 inch thick.

West of the outcrop of Dunham on the hill adjacent to Route 17 lies the Bridport dolostone. Cady (1945, Plate 10) showed all of this area to be Dunham. The two formations are differentiated from one another by the more massive character of the Dunham, the thicker bedding of the Dunham, its general "brecciated" appearance on weathered surfaces where irregular masses of sand stand up, by the absence of the light-gray, 1- to 2-foot beds of sheared limestone with shaly partings which characterize the Bridport, and the presence of black sandy chert in the Dunham. Generally the intensity of the scoring of the dolostone beds is greater in the Bridport, and these beds also generally weather more toward a yellowish-orange color than do the dolostone beds of the Dunham.

Monkton Quartzite (Keith, 1923; Cady, 1945)

Forming the overthrust body above the Champlain Thrust and marking the eastern margin of the Central Champlain Valley, the beds of the Monkton formation lie exposed in westward-facing escarpments. The sandstones and dolostones of this formation cap the Red Sandrock Range from its northern limits at Jones Hill in Charlotte to the southern end of Snake Mountain in the Port Henry quadrangle. Viewed from the floor of the valley, the escarpments seem to rise from the lower, less steep slopes like the vertical faces of blocks composed of alternating light-red, dark-red, and pinkish layers might rise from a table top. Viewed longitudinally from south to north the escarpments seem to mark the western edges of a series of gigantic blocks which have been offset successively to the east to the latitude of North Ferrisburg and then offset to the west from Mt. Philo to Jones Hill to form a crude semi-circular rampart overlooking the valley below. The eastern declivities of the hills and mountains capped by the Monkton are dip slopes.

North of Jones Hill, the Monkton crops out in low ridges and as isolated exposures and, with the exception of the hill at the southwest corner of Shelburne Bay, does not form any steep escarpments. The hills and steep slopes in the area north of Jones Hill are underlain by the shales of the autochthonous sequence.

Study of the Monkton has been restricted to that portion of the formation which lies immediately above the Champlain Thrust, and no attempt has been made to give the formation the comprehensive study that it seems to warrant.

The Monkton has been divided into two lithofacies: (1) a lower dolostone-white quartzite unit and (2) an upper thin-bedded, red and and purplish-red quartzite with interbeds of dolostone and occasional white quartzites. The second type is the typical Monkton lithology as described by Keith (1923) and Cady (1945). These two general lithologies have not been formally recognized as members of the Monkton, but they are mappable within the area covered by this report. The two-fold subdivision of the Monkton proved particularly useful in recognizing the faults that cut the Champlain Thrust.

Dolostone-White Quartzite Unit

The beds comprising the lower part of the Monkton lack the characteristic brick red and purplish-red color of the upper beds, although they weather various shades of red and may be mistaken for the red quartzites of the upper unit from a distance.

The lower unit, whose northernmost exposure is on the hill at the southwest corner of Shelburne Bay and on the islet a quarter of a mile to the north, changes from a predominant dolomitic lithology in the northern part of the area to a quartzitic lithology south of Vergennes. The southernmost exposure is near the southern edge of the Port Henry quadrangle immediately above the Champlain Thrust.

The dolomitic part of the lower unit is composed of 1- and 2-foot beds of dolostone which generally weather yellowish-orange (10YR6/4 to 10YR8/6) or pale yellowish-orange (10YR8/2) and are scored where small calcite veinlets cut the rock. Thin shale partings from .25 to 1 inch thick separate individual beds of dolostone. The partings are commonly red, but dark-gray and black partings are common also. The dolostones are fine to very finely crystalline and most frequently are light-colored, white, light-pink, and shades of light-gray being the most common. Dark-gray and black dolostones form part of the sequence also.

The change from the lower unit to the upper one is gradational. Where the lower unit is largely dolostone, the transition takes the form of an upward increase in the amount of shale and a thickening of the individual shale layers within the dominantly dolomitic sequence. Some fine sandstone appears in the upper part of the unit, gradually increasing in proportion toward the top. In the uppermost part of the dolostone sequence red quartzite beds appear and gradually form an increasingly larger proportion of the section toward the top. Since the change from the dolomitic to the quartzitic lithology is gradational, the contact has been placed where the red quartzite beds become the dominant element in the section, and the relative percentage of dolostone beds decreases sharply. A short distance above the contact the dolostone beds comprise only about 10 to 20 percent of a given interval. Immediately below the contact they comprise nearly 75 percent of the section.

South of the latitude of Vergennes the lower unit is composed of massive quartzite beds 1 to 10 feet thick. The quartzites are reddish- or pinkish-weathering, but on the fresh break they are light-colored; most common are shades of pink, light-red, green, and brown. From a distance the weathered surfaces are easily mistaken for those of the upper unit. Many of the quartzites lack argillaceous matter and are cemented with silica. There are also fine-grained quartzites which contain as much as 25 percent green argillaceous material which is distributed irregularly through them. Cross-bedding is common in many of the more massive quartzites, and care must be exercised in measurement of attitudes on glaciated surfaces where the cross-bedding may easily be mistaken for bedding.

The dolostone beds are of lesser importance in the lower unit south of Vergennes than in the area to the north; they are interbedded with the quartzites and sometimes occur only as small pods or small lenses completely surrounded by the clastics. Generally the dolostones resemble the yellowish-orange-weathering, light-gray and pinkish dolostones exposed along the thrust north of Vergennes. Many appear to be silty.

Accompanying the quartzites of the lower unit are thin seams of argillaceous-appearing material which are not prominent except near the surface of the Champlain Thrust. Bedding plane shears formed in conjunction with the faulting have localized along these seams, and they have been transformed into slickensided, phyllitic masses. Seldom are the seams more than a few inches thick, but they characterize the under-surfaces of many of the massive quartzite beds. Unsheared pieces appear fibrous; microscopic examination discloses the presence of subangular .1- to .2-mm quartz grains as well as silt-size quartz fragments. The greenish material is soft, is scattered irregularly through the quartz fragments, and seems to be argillaceous or chloritic.

Red Quartzite Unit

The dusky-red (10R2/4) coloration of the rocks comprising this unit is characteristic, although lighter reds are common as are purplish tints. Many cliffed exposures are typically banded; pinkish and very light-red quartzites alternate with the darker red quartzites. Light-red-weathering quartzites found in this unit are red-colored on the fresh break in contrast to the paler colors of similar-weathering quartzites of the lower unit. The red coloration is associated with thin films of argillaceous material that pervade, in varying degree, all of the dark-red rocks.

The rocks are fine- to coarse-grained quartzites composed of rounded to angular quartz fragments set in a siliceous matrix and cemented by silica. In some of the quartzites red argillaceous material and silt-size fragments of quartz form the matrix. Individual beds vary from 6 inches to 2 feet in thickness, though beds up to 3 feet thick are not uncommon. Many of the quartzite beds have a thin film of argillaceous matter on their upper surface, and some of the quartzites contain angular feldspar fragments. Ripple-marks, interference ripples, mud-cracks, cross-bedding and cross-lamination, and questionable worm trails are found throughout this Monkton unit, attesting to the probable shallow-water origin of this part of the formation.

North of Vergennes dolostones are interbedded with the red quartzites immediately above the contact with the lower unit, emphasizing the gradational nature of the change in lithology. South of Vergennes dolostones are not so prominent above the contact, and the contrast between the white quartzites of the lower unit and the red and purplish quartzites of the upper unit is marked. Dolostones and white quartzites occur well up in the upper unit of the Monkton south of Vergennes, but immediately above the dolostone-white quartzite unit the red quartzites dominate the section.

The only place that the dolostone-white quartzite unit is completely exposed is on the northwest corner of the hill approximately 2.25 miles south of Buck Mountain and immediately north of Route 17. At this site is the only exposure of the base of the Monkton in the area mapped; the sequence is complete from the Dunham into the upper unit of the

Monkton. Elsewhere the base of the Monkton has been cut out by the Champlain Thrust.

At this locality the lower unit weathers whitish or faintly pink and is composed of greenish and brownish-tinted, fine- to medium-grained quartzites. The rocks are massively bedded with few recognizable bedding planes. On the northeast corner of the hill the change from the whitish-weathering, light-colored, massive quartzite of the lower unit to the red-weathering, dark-red beds of the upper unit is sharp, and the two units are well defined and easily differentiated.

The dolostone beds on the hill at the southwest corner of Shelburne Bay are yellowish-orange (10YR6/6 to 10YR8/6)-weathering. A fresh surface of the dolostone is pink-colored or light-gray with a pinkish tint; a large portion of the dolostone is medium-gray in color. The massive dolostones are finely crystalline, siliceous-appearing, and beds are 2 to 3 feet in thickness. Between the dolostone beds are reddish shale layers and some fine-grained sand layers averaging about an inch in thickness. Nowhere on the hill does the upper unit of the Monkton crop out.

A low ridge of dolostone outcrops about 3500 feet southwest of the hill at the southwest corner of Shelburne Bay. The dolostone is yellowish-orange (10YR7/6)-weathering and scored, and most fresh surfaces are white or pink; irregularly distributed veinlets of white quartz stand up on the weathered surfaces. Some dark-gray and black, fine-grained dolostones outcrop on the eastern slope of the ridge.

The dolostones exposed on the ridge are siliceous in appearance, hard, and very fine- to fine-grained. Many seem to be silty, and the average grain-size is from .05 to .1 mm. Rounded quartz grains up to 1 mm in diameter are scattered through many of the dolostone beds. The transition from the dolostone of the lower unit to the overlying red quartzite beds exposed to the east is obscured by alluvium.

The northernmost exposure of the transition from the lower unit to the red quartzite unit is on the eastern side of the low ridge approximately .75 mile west of Shelburne village. White and light-gray dolostones of the lower unit outcrop from the west face of the low ridge eastward to its base. Thin, .25- to 1-inch red shale layers lie between the individual 2- to 3-foot beds of dolostone. The red shale increases in abundance upward in the section. Accompanying the increase in red shale is the appearance and gradual upward increase of red quartzite beds until at the base of the hill the clastics form over 50 percent of the section. The contact between the lower and upper units is placed where the clastics become the dominant part of the section. Above the upper boundary of the dolostone-white quartzite unit the fine- and medium-grained red quartzites replace the dolostone so that in the upper unit the dolostone forms only a minor portion of the sequence. The dolostone with red shale partings underlying the typical red quartzites of the Monkton can be traced more or less continuously from the area west of Shelburne southward to the vicinity of the Charlotte-Shelburne town line where the Monkton is covered by alluvium.

Approximately .5 mile northeast of Intersection 428, Mutton Hill, Charlotte, the transition from the lower sequence of dolostones to the upper quartzite sequence crops out. Here the pink-colored dolomite weathers a dark-buff or brownish-cream color. Thin, .25-inch, dark-red shale layers and some 1-inch reddish sand layers separate the individual massive dolostone beds. In about the middle of the ridge the dolomitic sequence is replaced by the red quartzite sequence.

The dolostone unit with thin, red shaly partings outcrops from the north side of Jones Hill to the south edge of Pease Mountain where it is covered by alluvium. On the ridge immediately south and slightly east of Pease Mountain the quartzites of the upper unit seem to lie directly on the shales of the Ordovician sequence. The exact contact is covered, and it is possible, although improbable, that the dolostone sequence is present beneath the cover. The lower unit appears above the thrust on Mt. Philo, disappearing near the middle of the south face; the unit outcrops along the front of Shellhouse Mountain from a short distance south of the north end, where the contact between the two Monkton units intersects the Champlain Thrust Fault, southward to the cover at the south end of the mountain.

At the north end of Snake Mountain the thrust fault is overlain directly by one or the other of the two units, depending upon the effects of the cross-faulting. In this area the lowest part of the lower unit exposed is a yellowish-orange-weathering, medium-gray, medium- to fine-grained dolostone. The thickness of the dolostone exposed above the fault and below the first white quartzite bed varies from 5 to 25 feet. A similar dolomitic horizon appears sporadically at the base of the quartzite section between the north end of Snake Mountain and Vergennes. Southward along the west face of Snake Mountain the dolostone is consistently present between the thrust fault and the base of the quartzite beds, although disappearing occasionally for short distances. In most places it is less than 10 feet thick. Near the Addison-Bridport town line the light-colored quartzites disappear beneath the alluvial cover, but they reappear about a mile farther south with the dolostone at their base.

On Snake Mountain the change from the lower unit of more massive, lighter colored quartzites to the thinner bedded, dark-red and purplish quartzites of the upper unit is gradational. Red quartzites appear 25 to 50 feet below the contact alternating with the light-colored quartzites, increasing in relative importance as the contact is approached. Arbitrarily the contact has been mapped where the red quartzites first comprise more than half of the section. The lighter quartzites are present above the contact where they comprise less than 50 per cent of the total section; they are commonly more thinly bedded than below. Fifty feet above the contact the light-colored quartzites are represented by only an occasional bed. The change from a section in which the white quartzite is characteristic to the red quartzite sequence takes place within a stratigraphic thickness of approximately 25 to 50 feet. The banded, cliffed exposures that are seen at the south end of Snake Mountain, adjacent to Route 125, belong to the upper unit.

The dolomitic portion of the dolostone-white quartzite unit north of Vergennes could be interpreted as being part of the Dunham formation. However, the dolostones associated with the lower unit are not so sandy as the known Dunham that is exposed within the area, does not exhibit quite the same pink coloration as the Dunham exposed to the north and east of the Central Champlain Valley, and is intimately associated with the clastic portions of the Monkton on a regional scale. Hence, the conclusion is reached that the dolostones are part of the Monkton.

Approximately 2100 feet S. 70° E. from the top of Mt. Philo there crops out a sheared, medium blue-gray-weathering, dark bluish-gray, sublithographic limestone. It seems interbedded with the dolostones and silts of the Monkton. A similar limestone outcrops near the contact of the Monkton with the Crown Point on the low knoll about a mile east of Intersection 287, south-southeast of Willmarth School in Addison. From the relations observed at both of these localities it appears that the limestones are part of the Monkton and not small slivers of younger limestone dragged up along the thrust.

The Monkton has been assigned a Lower Cambrian age (Cady, 1945, p. 534). Three hundred feet of the dolostone-white quartzite unit are exposed between the Dunham and the upper unit on the hill approximately 2.25 miles south of Buck Mountain. Approximately 250 feet of the lower unit are exposed on Buck Mountain. The maximum thickness of the lower unit appears near the south end of Snake Mountain, S. 65° E. of Crane School where an estimated 400 to 450 feet of it lie between the thrust and the upper unit. The upper unit is estimated to be 700 feet thick at this locality, but the lower and upper contacts can be approximated only. On Mt. Philo the lower unit is between 50 and 75 feet thick; north of Mt. Philo between 50 and 100 feet of the unit lie above the thrust fault, the actual thickness varying from place to place.

Winooski Dolostone (Cady, 1945)

Attention was focused on the Winooski dolostone at only two places during the course of this study. The northern locality lies east of Mt. Philo where stratigraphic relations within the Winooski proved useful in recognizing one of the major cross-faults of the area. The Winooski was studied also at the south end of Snake Mountain where the nature of the gradational contact, described by Cady (1945), makes the differentiation of the Monkton and the Winooski difficult. The base of the Winooski in this area was placed where beds of dolostone 3 feet or more thick, or a sequence of thinner beds totaling 3 feet or more in thickness appear over the red quartzites of the Monkton or interbedded with Monkton-type quartzites. This interpretation approximates the contact as shown by Cady (1945, Plate 10). However, over the first massive dolostone beds are thick, red, gray, and whitish, medium-grained quartzites similar to those found in the underlying Monkton.

East of Mt. Philo two lithofacies may be recognized in the Winooski, the change from one to the other being gradational. The lower part of the formation consists of fine-grained pink and reddish dolostone in 1- to 2-foot beds. On weathered surfaces the dolomitic material is usually pink-tinted, buff, or cream-colored and smooth. Separating the individual beds and within the beds are silty and shaly red and black partings or laminae. These often stand up on the weathered surface. Occasional red quartzite beds are present also, increasing in number downward in the section as the underlying Monkton is approached. Their distribution within the dolostones is irregular, and on the weathered surface their branching and anastomosing pattern suggests the links of a chain. This part of the Winooski is best seen on the west face of the ridge approximately 1.1 miles N. 20° E. of Intersection 305 at the southeast corner of Mt. Philo. Cady (1945) has mapped part of this area as Monkton, but all the exposures seem to fit the Winooski lithology better.

The pink and red lower horizons are exposed on the knob approximately .25 mile N. 45° E. of Scott Pond. Here the dolostone of the Winooski is light-red to pink (5R6/4) on the fresh break. The transition from the Monkton to the Winooski takes place in the small valley between the knobs. The ridge approximately .6 mile east of Intersection 368 at the northeast corner of Mt. Philo is also composed of the typical pink Winooski dolostone. There are quartz grains distributed through the pink dolostone, and some medium-grained red quartzite similar to that found in the Monkton is interbedded.

Stratigraphically above the pink horizon of the Winooski lies a series of gray, fine-grained dolostones with thin, ± 1 inch thick, quartzose silty layers. Interbedded with the dolostones are layers of fine- and medium-grained sand, the individual layers seldom exceeding 1 inch. Scattered through the dolostone beds are rounded quartz grains. Also, interbedded with the gray dolostones is an occasional pinkish dolostone bed similar to those found lower in the section. Infrequent white quartzose sandstone beds, 1 foot thick, are intercalcated between the thicker bedded dolostones. About a quarter of a mile north of Scott Pond the dolostone is gray also, and a traverse from the stream westward demonstrates the gradual change from the gray dolostone of the upper part of the Winooski to the pink beds of the lower part.

The upper lithofacies outcrops on the hills east of the Scott Pond-East Charlotte road and north of the stream flowing into Scott Pond. Several beds of cross-laminated, coarse-grained quartzose sandstone crop out in this area along with the gray dolostones.

Based on the average dip and the outcrop width, the lower pink horizon in the vicinity of Mt. Philo has a thickness of approximately 100 feet. No estimate is made for the thickness of the upper horizon.

Upper Cambrian Series[1]

TICONDEROGA DOLOSTONE (Rodgers, 1955)

Since the type area of the Clarendon Springs formation (Keith, 1932) is some distance from the Central Champlain Valley and east of the belt of thrusting and since lateral variations in the formation exist (Cady, 1945, p. 536–537), making long-distance correlation on the basis of general stratigraphic position suspect, the beds designated "Cal-

[1] Beneath the Ticonderoga dolostone is the Potsdam formation, a white and pinkish, generally massively bedded quartzite. It outcrops in the southern part of the Ticonderoga quadrangle in Shoreham and on the southern edge of Mt. Independence in Orwell.

ciferous A" by Brainerd and Seely (1890b) seem to warrant a new formation name in the Champlain Valley. The Little Falls dolomite of the Mohawk Valley has been correlated with dolostones in the same stratigraphic position at the southern end of the Champlain Valley (Rodgers, 1937), but Rodgers (personal communication, January, 1959) considers that these beds are sufficiently different from the Little Falls to warrant a different appellation. Hence, he has defined a new formation, the Ticonderoga, whose type section is located on Mount Hope at Ticonderoga, New York. The description of the type section as supplied by Rodgers (personal communication, February, 1959) and used with his permission is given as Section 1 in Appendix I.

Comparison of the type Ticonderoga section and the section at Thompson Point shows that the Thompson Point section is less sandy and more cherty as a whole. Furthermore, the exposures at Thompson Point lack the well-developed sandstone beds that are found in the Ticonderoga section; the latter contains a few limestone beds that are not found farther north. Otherwise the bulk lithologies of the two sections are very similar.

Exposures of the Ticonderoga (Clarendon Springs of Cady, 1945) at Delano Hill and Mutton Hill in Shoreham resemble in their gross aspects the Ticonderoga at Thompson Point. Common to all three localities is a tendency toward a decrease in average bed thickness together with an increase in the sand and silt content of the rocks toward the top of the formation.

The Ticonderoga dolostone forms the lowest part of the continuous sequence exposed on Thompson Point in Charlotte. As the lowest autochthonous formation exposed in the Central Champlain Valley, it forms the base on which the overlying Ordovician sequence has been deposited. Small outcrops of the upper portion of the Ticonderoga appear south of Vergennes, east and west of Route 22A, but the most complete exposures are in the bluffs along the west side of Thompson Point.

The formation is composed of dark-gray (N3), bluish-gray (5B5/1)- and yellowish-gray (5Y8/1)-weathering dolostone and calcitic dolostone (Dunbar and Rodgers, 1957); many beds contain sand- or silt-size quartz grains that are either concentrated in thin laminae or scattered erratically through a bed. Quartz grains outline cross-laminations and swirl-like structures within many of the dolostones. Insoluble residues indicate that the carbonate rocks may contain as much as 15 per cent quartz silt whose presence is not readily apparent in a hand specimen;

the finer grained dolostones have the greater concentration of the detrital matter. Individual beds range from 1 to 4 feet in thickness, although there are a few sandy layers which are less than 1 foot thick. Knots of white quartz and some crystals characterize parts of the formation, and locally they aid in its recognition. Insoluble residues contain minute quartz crystals in addition to the angular silt-size fragments of detrital quartz. Sandstone beds and well-lithified silt beds form minor elements of the formation.

The dolostones are fine- and medium-grained, range from light- to dark-gray in color, exhibit a dull to subvitreous luster on a fresh surface, and have a crystalline texture formed by closely interlocked carbonate crystals. Most of the rocks fail to react with cold dilute hydrochloric acid unless scratched, or they have only a weak reaction. Stains confirm that the rocks are dolostones; weak reactions with dilute hydrochloric acid are confined to the calcitic dolostones and to the very finely crystalline rocks. Fresh surfaces of some dolostones exhibit a vitreous luster which suggests that these rocks contain significant percentages of silt. Insoluble residues, which have a vesicular-like appearance after the removal of the carbonate grains, are comprised of 1-mm masses composed of silt-size quartz particles cemented together by secondary silica.

The two units noted by Rodgers, a lower darker colored one and an upper lighter colored one, at Ticonderoga (1955; also Section 1, Appendix I) are found at Thompson Point (see Section 2, Appendix I). The difference in color is most apparent on the weathered surfaces, for the lower half of the formation weathers to darker shades of gray than does the upper half. Part of the color difference may be related to the subtle increase in sand and silt content of the higher beds, but it is also apparently related to a subtle increase in the calcite associated with some of the dolostones and with the sandy beds. Rodgers (1955) also notes that the two units may be found in the Whitehall and Fort Ann, New York, areas as well as in the exposures of southeast Shoreham (Brainerd and Seely, 1890b; Cady, 1945).

The overall sand content of the formation increases in the upper one-third to one-quarter of the formation. Sandstone beds, generally absent in the lower exposures of the Thompson Point area appear in the upper part, and the sand content of the dolostones increases. The sand- and silt-rich beds frequently weather yellowish-gray to grayish-yellow (5Y8/1 to 5Y8/4), the light-colored sandy beds being more calcareous than the darker colored ones.

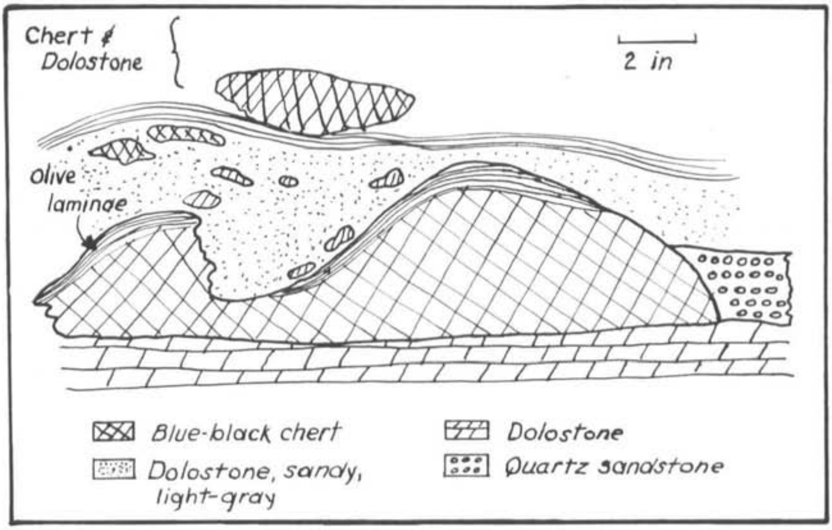
The bulk of the sandstones are calcareous, reacting readily with dilute hydrochloric acid, and the rounded, frosted quartz grains comprise slightly more than half of the rocks, although sandstones with a higher percentage of quartz do exist. It is believed that the frosting of the sand grains represents an earlier cycle of deposition.

Dark, blue-black chert is distributed irregularly through the formation as thin beds of limited lateral extent, as small lenses, and as isolated nodules. Long-weathered chert nodules are scoriaceous or fibrous appearing. The chert increases in abundance toward the top of the formation in the Thompson Point exposures. Near the top of the formation here, at a location approximately S. 72° E. of the center of Garden Island, a short distance east of the crest of the bluff, a 3-foot bed of chert outcrops for a distance of 30 to 40 yards. Intimately associated with the chert is pyrite. It is found scattered through the dolostones, but it seems to be concentrated in chert-rich areas. Its presence is indicated by rusty stains on the weathered surfaces of the chert.

Apparently some of the chert precipitated during the formation of the main rock body and was subsequently transported as pebbles. Thin layers of rounded chert pebbles that are surrounded by rounded quartz grains .25 to 1 mm in diameter occur in several of the carbonate beds. The chert of the pebbles may have been derived from a pre-Ticonderoga source, but its general similarity to the chert nodules and lenses of the formation infers its derivation from chert precipitated penecontemporaneously with the carbonate minerals. The rims of quartz grains strongly support the idea that the chert pebbles were transported after forming. Some of the chert occurs as angular fragments in thin calcareous quartzitic layers in which the detrital matrix is less than .06 mm.

These two occurrences imply that the chert was subjected to brecciation and transportation as it and the carbonates were forming. The chert fragments were transported and deposited, forming intraformational conglomerates and breccias much in the same way that carbonate materials formed intraformational conglomerates and breccias within this and other formations.

A chert boulder with a channel-like depression on its upper surface and a flat surface on its lower side lies in sandy dolostone S. 22° E. of the center of Garden Island. Depression of laminae adjacent to the "channel" suggests that the feature formed while the chert was still soft. Light-gray sandy dolostone with a few angular and subrounded chert pebbles fills the depression. The relations suggest that the chert



Text-fig. 3. Penecontemporaneous, channeled chert, Ticonderoga dolostone. Smaller fragments of chert are angular and slightly lighter colored than larger chert mass; up to 20% ± .75-mm, rounded, frosted quartz grains in sandy dolostone. Location about 30 yards south of bostonite dike which is S. 30° E. of Garden Island, 4 feet above lake level.

boulder formed prior to the formation of the overlying dolostone; its flat bottom conforms to the bedding below. The rounding points to its transportation while still in a gelatinous or plastic state. The presence of the chert pebbles in the "channel" points to their being moved into position by currents. The relations observed support a penecontemporaneous origin for the chert and the surrounding dolostone. They also point to the transportation of the chert and possible brecciation of some of it during or prior to transportation. The diagram of Text-figure 3 illustrates this feature.

Nearby, quartz-rich dolostone and chert are interlaminated in very thin layers fractions of an inch thick. The relations seen here point to the primary origin of the chert.

Abundant evidence for current activity during the formation of the Ticonderoga dolostones exists. Channels cut into laminae within the massive dolostones have been back-filled, and thin cross-laminated zones are apparent in many of the laminae. Intraformational conglomerates and breccias, most only a few inches thick, attest further to the presence of currents. The distribution of quartz grains into patterns of

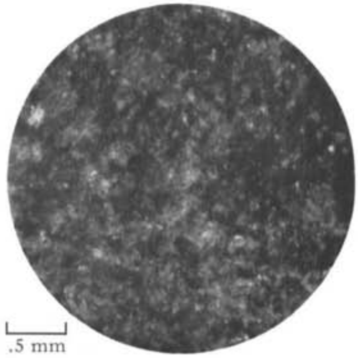


PLATE 5

Figure 1. Pellet structure in Ticonderoga dolostone. Etched polished surface in reflected light. Note darker, subcircular, raised masses of .03-mm dolomite crystals set in lighter colored, etched-down matrix; Deer Point, west shore of Thompson Point.

cross-lamination, of loops, and of swirls within the massive dolostones together with the distribution of carbonate grains in laminae and lines provide the evidence for current activity on the ocean bottom.

The polished surfaces of two specimens together with thin sections cut from them show the presence of aggregate or pellet-like structures such as described by Dunbar and Rodgers (1957, p. 232 and fig. 114). The aggregates consist of dark, .5-mm subspherical masses of dolomite crystals; these are set in a lighter colored dolomite matrix. The crystals of both the matrix and the rounded masses average .03 mm in diameter. Figure 1, Plate 5 is a photomicrograph of one of the polished surfaces.

The darker rounded masses consist of interlocked carbonate crystals. A dusty-appearing material is distributed through the masses, but it is concentrated at the borders of the round masses, marking off these structures from the lighter colored carbonate crystals of the matrix. In several instances gradations from the crystals of the rounded masses to the crystals of the matrix exist, but only a very faint dusty border surrounds the masses in these cases. No actual rounding or abrasion of the grains at the borders of the round masses has been detected. On the other hand, while the matrix material and the crystals of the masses are interlocked at the boundaries of the masses, penetration of one group of crystals into the other seems lacking. Rather the dusty-appearing borders apparently mark sharp boundaries between the two groups of carbonate crystals.

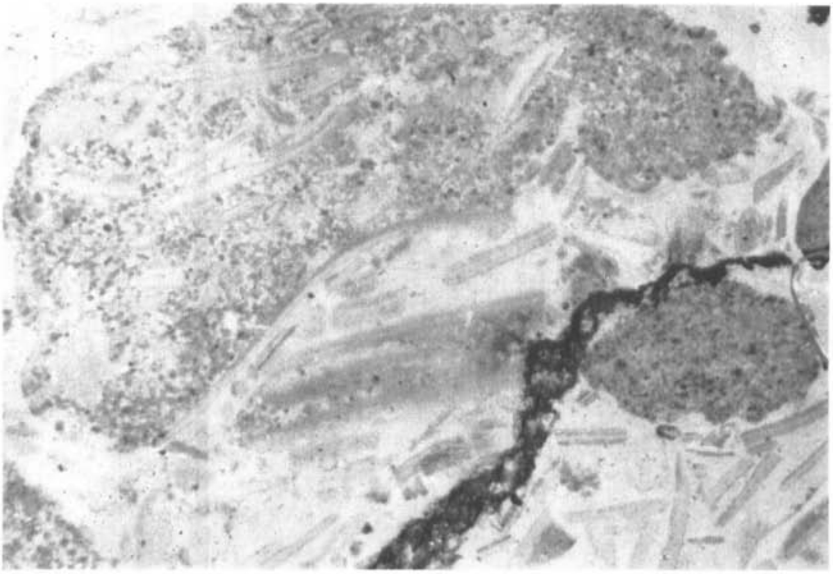


PLATE 5

Figure 2. Trilobite-bearing conglomerate from Thorp Point member of Cassin formation. Dolomitic sandy pebble with trilobite fragments set in crystalline mush of calcite; reflected light on slightly etched surface; Thorp Point, Charlotte.

Small (.1 to .2 mm) quartz grains are included within some of the subspherical masses. The boundaries between the quartz grains and the carbonate are sharp, being marked by the presence of the dusty material. In addition the carbonate grains appear to be smaller immediately adjacent to the quartz grains than elsewhere in the circular masses.

One specimen was found in which the rounded, dusty-bordered masses form one lamina a fraction of a millimeter thick while the next lamina consists of short streaks of the dusty material and its associated carbonate grains alternating in a direction normal to the bedding with layers composed of the lighter colored carbonate grains.

Many of the dolostone beds contain thin laminae composed of rounded quartz grains. Most commonly the grains are in the medium and coarse size-range, and the laminae are only one grain diameter thick. Other instances may be found in which the quartz grains are sufficiently concentrated to form laminae and layers up to 1 inch thick, and these might more appropriately be termed sandstone laminae. The various layers are integral parts of the thicker dolostone and calcitic dolostone beds,

PLATE 5

Figure 3. Whitehall dolostone breccia, small point approximately 700 feet N. 70° E. of Flat Rock, Thompson Point. Map near hammer handle indicates general attitude of dolostone beds; notebook lies parallel to bed of breccia which is inclined to the bedding above and below; hammer head lies near juncture of inclined breccia and overlying bed. Breccia blocks faintly discernible as lighter, block-like areas beneath notebook.

and they do not persist laterally for more than a few feet. Channel features and cross-lamination are common associates of these layers. Not uncommonly lines on the weathered surfaces of the dolostones reflect some of the current structures found in the adjacent quartz-rich laminae.

The broken material of the intraformational conglomerates and breccias weathers to a lighter gray color than the matrix material, but on a fresh surface it is often impossible to differentiate the two. Pebbles of the conglomerates are commonly flat and lenticular; yet equidimensional shapes are not rare. Edges and corners of the clasts are subrounded. Some of the broken and worn material resembles the yellowish-gray (5Y8/1) arenaceous layers common in the upper part of the formation.

The composition of the matrix varies from calcitic dolostone to medium-grained calcareous quartz sandstones which are dark- or medium-gray in color. Quartz forms from 40 to 60 per cent of the matrix in most of the conglomerates and breccias, but in a few the quartz content is somewhat less and in a few somewhat more. Sandy matrices are more prominent in the upper one-third of the formation.

One conglomerate found close to the top of the formation near the south tip of Thompson Point consists of brown-tinted, cream-colored lenticular carbonate masses cemented by a matrix composed of approximately equal amounts of frosted, rounded quartz grains and dolomite. Maximum diameter of the light-colored carbonate masses is about .5 inch. They lie both at an angle and parallel to the laminae of the matrix. Angular quartz fragments approximately .05 mm in diameter are present in the carbonate clasts. The sand grains of the dolomitic matrix are from .5 to .75 mm in diameter, and the average carbonate grain-size is .1 to .15 mm.

Iron oxide distributed through the carbonate masses tints them, but it is concentrated at the outer rims of the masses, delineating them from the matrix. This relationship suggests that the carbonate accumulations have been rolled or exposed to submarine weathering prior to their final deposition. Iron stain in the matrix material is restricted to the surface of an occasional quartz grain.

Measurement of a section of the Ticonderoga beginning at the small point S. 55° E. of the center of Garden Island (Deer Point), described in detail in Section 2, Appendix I, discloses that the Ticonderoga formation is approximately 88 feet thick in this area. This thickness contrasts with the measurement of 40 to 50 feet given by Brainerd and Seely (1890b) for the "Calciferous A" in this area. Their limited discussion does not allow determination of the exact position of the contact between the "Calciferous A" and "B" as they placed it.

The type section of the formation is 185 feet thick; Rodgers (1955) records approximately 300 feet at Whitehall and possibly more than 200 feet at Putnam, New York. Cady (1945, p. 537) notes 230 feet of Clarendon Springs (Ticonderoga) at Shoreham and points out that the dolostones at this horizon thin eastward. Brainerd and Seely (1890b) give a thickness of 310 feet for their "Division A" at Shoreham.

On the western side of Lake Champlain, Kemp and Ruedemann (1910) record the presence of the Division A beds at Cold Spring Bay, near Westport, and near Port Henry. They assign a thickness of over 300 feet to the formation in the Port Henry quadrangle. Buddington and Whitcomb (1941) do not record the Division A beds in the Willsboro quadrangle.

Average outcrop width of the formation south of Vergennes implies that the Ticonderoga is in excess of 300 feet thick and probably closer to 400 feet. However, unrecognized faults may give rise to misleading values. The implication from the thickness of the upper, lighter colored unit at Thompson Point is that the formation is approximately 200 feet thick here.

In the current work the top of the Ticonderoga is placed where the dolomitic and calcareous sandstones and sandy dolostones at the top of the Ticonderoga are replaced by dark-gray (N3) finely to coarsely crystalline dolostones which are characterized by a dirty- and earthy-appearing, dull-lustered, matrix material. The fresh surfaces of the Whitehall dolostones near the contact are dull-lustered, frequently possess a brownish-tint, and appear to the eye as if the rock should be friable. Only the weathered surfaces are easily broken in the fingers, and this feature contrasts with the well-lithified appearance and nature of the weathered surfaces of the bulk of the Ticonderoga dolostones. The change from the arenaceous beds of the Ticonderoga to the dolostones of the Whitehall formation seems well defined, and the two units are separable at this horizon. Brainerd and Seely (1890b, p. 15) show the contact between their Divisions A and B extending from the northwest corner of Thompson Point southward to the cove approximately 4500 feet S. 20° W. from the center of Garden Island where the contact disappears beneath the lake. In contrast, the author believes that the Ticonderoga underlies the western half of Flat Rock and that the contact extends the length of Thompson Point.

Data available at the south end of Thompson Point and at the northwest corner (S. 70° E. from the center of Garden Island) support the concept of a gradational contact between the Ticonderoga and the overlying Whitehall formation, as do the relations seen in the outcrops south of Vergennes. At the northwest corner of Thompson Point there are in the beds near the top of the Ticonderoga a few small 6- to 12-inch blocks that have been tilted at an angle to the bedding and cemented with the same type of sandy dolostone. Medium to coarse, rounded quartz grains comprise from 25 to 50 per cent of the rock. The horizon containing this breccia is overlain by sandy dolostone which is succeeded by a brownish-tinted, gray-colored, medium crystalline dolostone, a lithology typical of the lower part of the Whitehall formation. The sandy dolostones change from grayish-yellow (5Y8/4) to a medium-gray near the contact.

At this locality there seems to be no suggestion of an erosional break between the two formations, and similar relations may be observed at the southern tip of Thompson Point where sandy dolostones are found in the Whitehall within a few feet of the contact. The presence of the breccia near the contact might be taken as evidence supporting a disconformity, but several similar breccias have been observed in the Whitehall at different horizons. Furthermore, the deposition of lithologically similar materials near the southern end of Thompson Point and south of Vergennes without any apparent break is believed to be stronger evidence in support of a continuous sequence of rocks with only minor breaks in the sedimentary record.

The section measured from the northwest corner of Thompson Point southeastward to the small knoll approximately 900 feet from the shore (Section 4, Appendix I) describes the upper part of the Ticonderoga and illustrates the nature of the change from this formation to the Whitehall. The contact may also be observed approximately S. 15° E. of Deer Point where a medium crystalline, dirty-appearing dolostone of the Whitehall rests on a sandy, light-gray dolostone which is thought to be the uppermost Ticonderoga bed.

Silty and sandy beds of the Ticonderoga formation are exposed along the west side of the ridge southeast of the southwest corner of Vergennes, and beds of the Ticonderoga outcrop at several places on the west side of Route 22A south of Vergennes. The outcrop of the Ticonderoga at the southwest corner of Vergennes contains carbonate beds with a high percentage of medium- and coarse-grained, rounded quartz. The beds are thought to be near the top of the formation since there is a persistent sandstone bed interbedded with the earthy-appearing dolostones. Southward, approximately a half mile north of the Addison-Panton line on Route 22A, a medium-grained dolomitic quartz sandstone outcrops. A small outcrop of dolostone appears from beneath the Champlain Thrust near the south end of Shellhouse Mountain, approximately 1.3 miles east-northeast of Ferrisburg. It has been mapped as Ticonderoga on the basis of lithology alone, although it could belong to one of several of the Beekmantown units.

In the area south of Vergennes Ticonderoga dolostones containing irregular masses of white quartz and quartz crystals grade upward into dolostones of the Whitehall formation. Where the sandy and silty beds are not prominent in the Ticonderoga, the contact between it and the Whitehall is difficult to pinpoint. However, a subtle change from a dull luster (Ticonderoga) to a subvitreous luster (Whitehall) on a fresh break combined with an accompanying change from grayish-weathering beds to beds weathering with a more bluish coloration above has been utilized in separating the two formations and placing the contact.

Age and Correlation

Aside from a questionable *Cryptozoön* found at Deer Point, no fossils have been discovered in the Ticonderoga dolostone in the Central Champlain Valley. Rodgers (1955) places the age of the formation in its type area as Upper Cambrian, correlating the limestone lenses found in the upper unit with the Hoyt limestone of the Saratoga region on a lithologic basis. Ulrich and Cushing (1910) made a similar correlation.

Fisher and Hanson (1951) demonstrate that the Hoyt limestone overlies the Little Falls dolostone, or is, perhaps, correlative with parts of it. Fossils from the Galway formation beneath the Hoyt limestone indicate a Franconian through lower Trempealeauian age (Fisher and Hanson, 1951, p. 802). The uppermost part of the Potsdam equivalent, the Danby, at Whitehall is Franconian (Cady, 1945, p. 536). Wheeler (1942) reports Trempealeauian Stage fossils from the upper member of the Ticonderoga on Skene Mountain at Whitehall.

It thus appears that the Ticonderoga formation may be correlated in a general way with the Little Falls dolostone of the Mohawk Valley, but the boundaries of the two formations are not isochronous, and for that matter, the base of each may vary in age from locality to locality, depending upon the fortuities of deposition. The Ticonderoga may range locally down to the top of the Dresbachian. The gradational nature of the change from the sandstones of the Potsdam-Danby type through the sandstones, sandy dolostones, and dolostones of the Galway-Wallingford-"Theresa"-type (Fisher and Hanson, 1951; Cady, 1945) emphasizes this possibility. On the other hand, the change from the Danby sandstones to the Ticonderoga (Clarendon Springs) dolostones is abrupt in southeast Shoreham and at Mutton Hill north of Shoreham.

The age of the Ticonderoga formation within the Central Champlain Valley is taken as essentially upper Franconian and Trempealeauian; most of the exposed rocks are probably Trempealeauian, and the formation may record Lower Ordovician deposition in its uppermost layers.

Ordovician—Canadian Series

Beekmantown Group—General

The term Beekmantown was first applied by Clarke and Schuchert (1899, p. 877) as a replacement for the older term Calciferous Sandrock or Calciferous. In 1890 Brainerd and Seely (1890b, p. 2–3) divided the rocks normally included within the Calciferous into five units, giving them letter designations. Subsequent work beginning with Clarke's (1903) has restricted the term to the beds of "Division B" through

"Division E" (Brainerd and Seely, 1890b). Various modifications have been made in the usage of the term through the years, but it is currently used within the Champlain Valley as a group term for the several formations that record Lower Ordovician history (Twenhofel and others, 1954). Formational names have been given to the units set out by Brainerd and Seely. Cady (1945, p. 539) adequately reviews the distribution of the beds placed within this group and the history of the restrictions applied to the term Beekmantown.

Movement of the base of the Whitehall formation (Rodgers, 1937) on Skene Mountain at Whitehall, New York, upward 110 feet (Rodgers, 1955) makes the base of the Beekmantown group correspond with the base of Brainerd and Seely's "Division B." Top of the group is placed at the top of the Bridport dolostone. The total thickness of the group is about 1500 feet.

While it is possible to recognize and map the several formations ranging from the Cambrian Ticonderoga to the Cutting dolostone, each contains individual beds and horizons which closely resemble beds in one or another of the other formations. Thus stratigraphic position is important in placing isolated outcrops in the proper formation. Marked changes in lithology do not appear until after the deposition of the Cutting.

On a lithologic basis, at least, the Cambrian Ticonderoga dolostone is more closely related to the overlying dolostones of the Beekmantown group than to the underlying Potsdam. The Cambrian-Ordovician contact apparently lies in the conformable sequence from the Ticonderoga to the Whitehall; the contact is gradational.

Within the Central Champlain Valley and adjacent areas the dolostones and limestones comprising the Beekmantown have not been intensively studied with the single exception of the beds called "Division D, 3 and 4" by Brainerd and Seely (1890b). The classic Fort Cassin locality with its extensive fauna lies within the area mapped. All previous reports on the area written in terms of the areal geology have been overly generalized and in many respects erroneous (Perkins, 1910; Seely, 1910; Gordon, 1921; Foyles, 1924, 1926a, 1928a; Cushman, 1941). For the most part the Beekmantown rocks were simply lumped together under this term or where one of the four units was given a name, it was misidentified.

On the New York side of Lake Champlain the several units have been recognized in the Port Henry quadrangle (Kemp and Ruedemann, 1910), although they have not been mapped separately. Buddington and Whitcomb (1941) cited the probable existence of several of the units but did not separate them. Cushing (1905) in discussing the geology of Clinton County did not map the several units separately, devoting most of his discussion to the Cassin formation. Describing Clinton County geology, Cushing (1894) noted that the exposures near Beekmantown are chiefly "Divisions C and D."

Uppermost Beekmantown rocks outcrop on the islands at the north end of Lake Champlain, and recently Shaw (1958) has described from the St. Albans area limestones and shales which fit into the time span represented by the beds of the Beekmantown group.

WHITEHALL DOLOSTONE (Rodgers, 1937; *revised*, Rodgers, 1955)

The type section of the Whitehall dolostone located on Skene Mountain in Whitehall, New York, has been described briefly by Rodgers (1937). In his original description Rodgers included within the formation the upper 35 feet of the beds called "Calciferous Division A" by Brainerd and Seely (1890b). Subsequent work (Rodgers, 1955; personal communication, January, 1959) indicates that at the type locality the base of the Whitehall should be placed at the base of "Division B," the 35 feet of dolostone below belonging to the Ticonderoga formation and containing Upper Cambrian fossils (Wheeler, 1942). At Thompson Point the contact between the Ticonderoga and the Whitehall is gradational, and the change of lithologies occurs at the horizon noted elsewhere by Brainerd and Seely as the boundary between "Divisions A and B" of the Calciferous. Cushman (1941) placed the "unconformity" between the "Little Falls" and the Whitehall at a sandstone horizon near the top of the Ticonderoga beds at Thompson Point and correlated this horizon with the "unconformity" at the base of the Whitehall as originally defined by Rodgers. Brainerd and Seely (1890b) did not recognize an erosional interval between these two formations in any of the sections they studied.

Cady (1945, p. 540) uses the term Shelburne marble for the Division B sequence east of the Champlain Thrust where the beds at this horizon are largely limestone and marble. There is no marble west of the Champlain Thrust, and the limestone-dolostone sequence described from the Shoreham section by Brainerd and Seely (1890b) lacks the marbleization seen farther to the east. Hence the name Shelburne marble is inappropriate for use within the Central Champlain Valley area.

The discontinuous exposures of this formation at Thompson Point and near Vergennes are inadequate for the definition of a new formation, and since the Whitehall locality provides adequate exposures for the definition of this mapping unit, Rodgers' (1937) terminology is followed with the modification of the base of the formation as noted.

Correlation and Age

The Whitehall formation is believed to represent the lowest Ordovician formation in the Champlain Valley. Rodgers (1937, p. 1577) reports fossils from Whitehall outcrops in Shoreham, Vermont, which Ulrich indicated could be correlated with fossils from the Strites Ponds beds of the Phillipsburg, Quebec, sequence and with the fauna of the Gasconade formation. Wheeler (1942) studied faunas collected from the southern end of the Champlain Valley and the Saratoga region and placed a Cambian age on the beds at Whitehall. Subsequently Fisher and Hanson (1951) have demonstrated that Wheeler (1942) mistook the Gailor formation (Ordovician) at Saratoga for the Little Falls, placing the Hoyt with its Upper Cambrian fossils over the Little Falls. Fisher and Hanson (1951) have demonstrated that the Hoyt underlies the Ordovician Gailor formation of the Saratoga region. Furthermore they point out that the Galway formation, part of the Potsdam, and possibly part of the Hoyt can be correlated with the Little Falls of the Mohawk Valley. They place the Cambrian-Ordovician contact in the Saratoga region at an unconformity between the Ritchie formation and the thin Mosherville sandstone. The Gailor formation, a cherty dolostone, overlies the Mosherville and contains fossils associated with the *Helicotoma uniangulata* fauna of the lowest Ordovician. Ulrich (1911, p. 631, p. 639) referred to a similar fauna from the "Little Falls dolomite" at Whitehall which he correlated with the fauna found in the Gasconde formation of the Ozark region.

While Cady (1945, p. 541) presumed that the fossils from Whitehall mentioned by Ulrich (1911) came from the "lower part" of the Whitehall formation as defined by Rodgers (1937), there seems to be no printed description of the stratigraphic position of these fossils available. In view of Wheeler's (1942) discoveries, it seems that they came from higher in the section, from within the Whitehall as now defined.

Fossils have been found at only one locality in the Central Champlain Valley, in massive, oölitic, blue-gray limestones west of the East Branch of Dead Creek, approximately 2.5 miles west-southwest of the airway beacon at the north end of Snake Mountain. The fauna from this locality is described in Appendix II, localities 467, 468, and 469. While not clearly a Lower Canadian fauna, it seems more closely allied to faunas from this part of the geologic column than to any other.

On the basis of the information available the conclusion is reached that the Whitehall formation represents the lowest Ordovician, the base of the Canadian Series, of the Champlain Valley region. It is correlated with the Shelburne marble of the area east of the Champlain Thrust on the basis of a similar stratigraphic position between two widely distributed formations. It may also be correlated with the Tribes Hill formation of the Mohawk Valley. The lowest part of the formation is correlated with the Gailor formation of the Saratoga region. Fisher (1954, p. 85) proves that part of the Fort Johnson, lowest member of the Tribes Hill formation, can be correlated with the Gailor. The lower part of the limestone- and slate-bearing Highgate formation of the St. Albans area is roughly equivalent to the Whitehall, being correlated with the Gasconade formation. The upper, *Leiostegium*-bearing beds may represent middle Canadian (Shaw, 1958, p. 552). The author correlates the Whitehall as defined herein with the "Baldwin Corner formation" of the Fort Ann, New York, area (Billings and others, 1952). The Whitehall and the "Baldwin Corner" resemble one another in many respects and both occur at about the same position in the dolostone sequence of the Lower Ordovician.

Lithology

Brainerd and Seely (1890b, p. 2) based their description of the "Calciferous Division B" on exposures approximately 2 miles east of Shoreham Center and described it as follows:

> "Dove-colored limestone, intermingled with light grey dolomite, in massive beds; sometimes for a thickness of twelve or fifteen feet no planes of stratification are discernible. In the lower beds, and in those just above the middle, the dolomite predominates; the middle and upper beds are nearly pure limestone; other beds show on their weathered surfaces, raised reticulating lines of grey dolomite. Thickness 295 feet."

They recognized that the unit crops out along with other divisions in the Thompson Point area and indicated that it is composed of "light-grey massive dolomites." No mention is made of the presence of limestone in the Thompson Point section.

The Whitehall formation outcrops along the western shore of the small bay separating the two prongs of Thompson Point. While the shore exposures are more or less continuous, away from the shore the outcrops are scattered. A more or less continuous section is exposed from the northwest corner of Thompson Point to the small knoll approximately 950 feet to the southeast. This section, including the upper 17 feet of the Ticonderoga, is described in Section 4, Appendix I.

In the Thompson Point area the Whitehall consists of massive dolostones with a few interbedded dolomitic limestones. The two limestone bands found by Brainerd and Seely (1890b) near the middle and in the upper portion of the formation at Shoreham are absent at Thompson Point. A detailed description of the uppermost 25 feet of the Whitehall given as Section 5, Appendix I, shows that the top of the formation is dolostone.

The dolostones of the Whitehall range from finely to coarsely crystalline, are siliceous-appearing to dull-lustered and earthy-appearing on a fresh surface. Both the fresh and weathered surfaces exhibit various shades of gray. The dirty, earthy-appearing dolostones are medium and coarsely crystalline, dark brownish-gray to dark olive-gray (5YR5/1 to 5Y5/1), and present a loosely cemented appearance on the fresh surface even though they are actually non-friable. In these rocks the carbonate crystals are set in a brownish, earthy-appearing matrix, and the rocks emit a strong fetid odor when freshly broken. Some of the rocks possess a significant percentage of calcite in the matrix.

The finely crystalline dolostones also emit a fetid odor, but they are more siliceous in appearance and are medium light-gray to light-gray (N6 to N7) on both the weathered and fresh surfaces. Medium- to light-gray, mottled dolostones represent a minor portion of the Whitehall beds and are usually found near the middle of the formation. The few dolomitic limestones resemble the dolostones in general appearance, but are lighter shades of gray on the fresh surface, and some weather very light-gray to almost white. In composition they border on calcitic dolostone.

The bedding of the formation is massive. The average bed thickness is between 2 and 3 feet, but many exposures contain no well-defined bedding planes for thicknesses of 10 to 15 feet. However, fine lines and laminations formed through slight variations in grain size, presence of silt, and differential weathering of the carbonate grains indicate bedding. Toward the top of the formation the bedding is less massive than in the lower part where silty, finely and very finely crystalline dolostones predominate.

Most of the dolostones in the lower quarter of the formation are very finely crystalline with the carbonate crystals ranging in size from .05 to .1 mm. Yellowish-colored silica, in part probably secondary, is found associated with many of the finer grained dolostones as irregularly distributed .01-mm films and as .1- to .5-mm masses. Many of the tenacious, finer grained silty dolostones near the base possess a higher specific gravity than the coarser grained ones higher in the section.

The lower portion of the Whitehall is sandy. Rounded, .5- to 2-mm, frosted quartz grains are scattered randomly through the carbonate beds; in some places they are concentrated sufficiently to make thin layers of sandstone within the more massive carbonate beds. Interbedded with the sandy beds are the earthy-appearing, strongly fetid, medium and coarsely crystalline dolostones whose appearance above the sandy horizons of the Ticonderoga mark the contact between the Ticonderoga and the Whitehall formations.

In some of the sandy dolostones the dolomite crystals are molded around the quartz grains, indicating that the dolomite crystallized after the introduction of the quartz. The suggestion is that the dolomite crystals were forming as the quartz was deposited. Where the crystallizing dolomite encountered a quartz grain, it adapted itself to the quartz shape. The fact that not all of the dolomite crystals in contact with the quartz grains conform to the quartz grain shape suggests that some formed prior to the deposition of the quartz.

Blue-black chert nodules and somewhat larger masses are distributed throughout the formation. The chert is of more frequent occurrence in the lower 50 to 75 feet of the formation and in the upper quarter than in the middle part.

Calcite (.005- to .01-mm) occupies spaces between the dolomite crystals and forms thin layers or films between individual dolomite crystals in many of those medium crystalline dolostones which react moderately with dilute hydrochloric acid. A few of the calcite crystals are comparable in size to the dolomite grains, but these large calcite crystals are undoubtedly of secondary origin as they are often associated with calcite veinlets.

The origin of the smaller crystals is a matter of conjecture, but the relations observed suggest that the dolomite grains formed first and that their formation was followed by the crystallization of the calcite grains in the spaces between the dolomite crystals. An analogous relationship is that seen in a granite where the anhedral quartz fills the openings between subhedral feldspar crystals which formed earlier. Whether the difference in time of crystallization of the two carbonates represents a relatively long time lag or whether the two carbonates formed essentially simultaneously with but a short time lag is not clear on the basis of the evidence at hand. The author believes that the two formed penecontemporaneously.

Thin films of brownish material separate the two carbonates where they are juxtaposed, and as far as can be discerned, the brownish material was deposited as a film on the dolomite crystals.

In other dolostones there appear to be thin, .1- to .2-mm, laminae composed of very small calcite crystals which alternate with thicker laminae of dolomite crystals. On weathered surfaces the laminae with dolomite crystals are raised slightly. Some of the raised lines or laminae seen on weathered surfaces are concentrations of quartz grains and quartz grains with some minute pyrite cubes. The lines are recognizable on a fresh surface by their color which is slightly darker than the overall color of the rock.

Secondary quartz is present also. Its later origin is demonstrated by the fact that the shape of the quartz is controlled by the rhombohedral faces of the dolomite crystals, and instead of being anhedral or crystallizing as subhedral or euhedral quartz crystals many of the quartz grains have faces which reflect the angles of the rhombohedrons with which they are in contact. (See detailed descriptions in Section 5.)

Many of the dolostones contain up to 5 per cent .01-mm angular quartz grains distributed more or less evenly throughout the rock or concentrated in small patches. Final deposition of the quartz seems to have been later than the formation of the dolomite grains; the faces of the dolomite crystals are impressed upon the small masses of angular quartz where the grains are cemented together by silica. The angular quartz grains apparently coagulated into small masses as the sediment was forming, and the earlier-formed (or penecontemporaneously forming) dolomite crystals impressed themselves upon the soft mass of quartz.

Some of the quartz concentrations are minute and stringer-like. Calcite is intermixed with the silica, but the minute calcite rhombs seem to be more abundant between the masses of silica-cemented quartz and the dolomite crystals. The structure of the quartz masses in the insoluble residues and the nature of the distribution of some of the angular quartz fragments suggest that in part at least silt-size particles of quartz were deposited simultaneously with the accumulating dolomite grains as thin, dust-like layers on the dolomite rhombohedrons. Not all of the quartz associated with the small masses is detrital however.

The outcrops of the medium to light bluish-gray (5B7/1)-weathering

Whitehall dolostones at Vergennes and southward have been mapped previously as Beekmantown (Seely, 1901, 1910), Chazy (Foyles, 1926a, p. 115), and Calciferous (Beekmantown) E (Cushman, 1941). However, the general appearance of the rocks on both weathered and fresh surfaces indicates that they belong to the Whitehall formation. This conclusion is lent strong support by the presence of the basal Cutting breccia and sandstone near Prospect Cemetery in Vergennes. On the basis of the exposures on either side of Otter Creek and behind the Vergennes Post Office these beds might be included with the Cutting, or possibly within the light bluish-gray-weathering lithology of the Bridport. However, the latter generally lacks the sandy zones and current structures found in the exposures of the Whitehall in Vergennes; also the prominent deep scoring of the Bridport is absent in the Vergennes exposures. Chert, prominent in the upper unit of the Cutting, is not so abundant in the Whitehall exposures at Vergennes as in the upper Cutting, and the Vergennes lithology does not resemble the lithologies of the lower three units of the Cutting formation.

The outcrop of the Cutting basal breccia and the outcrops of the overlying members of the Cutting in normal stratigraphic sequence approximately a half mile N. 70° E. of Prospect Cemetery support the correlation of the beds at Vergennes Falls and those which form the ridge extending northward and southeastward from the falls with the Whitehall formation in the Thompson Point area. Furthermore, the exposures from the southern city limits of Vergennes southward to the latitude of the East Panton School are typical dolostones of the Whitehall.

The outcrops within the city limits resemble the Whitehall beds exposed along the southern edge of Converse Bay. Medium and finely crystalline dolostones of various shades of gray and bluish-gray which weather olive- and brownish-gray (5YR6/1 and 5Y6/1) to bluish-gray (5B7/1) comprise the Whitehall in this vicinity. Many beds are silty, and some contain enough silt to be properly termed dolomitic siltstones. Others have rounded, .5- to 1-mm quartz grains scattered through them. The bedding is massive, and the cliffed exposures lack well-defined bedding planes for vertical distances of 10 to 15 feet. Small intraformational conglomerates are common in the dolostones underlying the ridge southwest of the waterfall in Vergennes, and most of the beds emit a fetid odor when struck with a hammer. Blue-black chert nodules and irregular larger masses are present in several places. The medium and finely crystalline, bluish-gray (5B6/1) to very light-gray (N8)-weathering dolostones of the Whitehall exposed east of Route 22A south of Vergennes contain chert in masses up to 1 foot in diameter as well as thin 1 to 2 inch thick stringers and lenses.

The presence of sandy dolostones and calcareous sandstones in the exposures within Vergennes from near the Rutland Railroad tracks southwestward along the bluffs and ridge to Prospect Cemetery suggest strongly that the lowest exposed beds are near the base of the Whitehall. This suggestion receives support from the appearance of Ticonderoga beds south of Vergennes.

Limestone appears in quantity in only one area, approximately 2.5 miles west-southwest of the airway beacon on Snake Mountain. The fossiliferous limestones are psuedo-oölitic in that they are composed of 70 to 75 per cent subspherical, dark-rimmed, rounded masses up to 1.5 mm in diameter. The masses are composed of .005- to .01-mm calcite with a few dolomite rhombs up to .05-mm and are in general darker colored than the surrounding, finer grained calcite matrix. Each of the subspherical bodies has a dark rim separating its interior from the matrix. Such a relationship leads to the inference that the bodies have been rolled around prior to final deposition. Underlying the limestones are medium to finely crystalline silty dolostones and silty calcitic dolostones typical of the Whitehall.

Diamond Island, west of Grosse Point, consists of medium to coarsely crystalline light-gray dolostone belonging to the Whitehall sequence. The rocks weather yellowish-gray (5Y6/1), and distinct bedding planes are lacking.

The Whitehall contains several sedimentary breccias. These are best exposed along the shore at the southern tip of Thompson Point; others have been found in various scattered outcrops away from the shore, and a number of small breccias are apparent on the weathered surfaces of the Whitehall southwest of Vergennes Falls.

Figure 3, Plate 5 illustrates one of the breccias located on the small point approximately 700 feet N. 70° E. from Flat Rock. In another breccia, blocks up to 18 inches long and 6 inches thick are mixed in a calcitic dolostone matrix with fragments 1 to 2 inches long. The blocks and smaller fragments are light to medium light-gray (N7 to N6) and are lighter colored than the surrounding dolostone matrix material. The brecciated material is both silty, very finely crystalline dolostone and finely crystalline dolostone. The smaller angular fragments exhibit fine raised lines on the weathered surface, and this feature contrasts sharply with the smooth-weathered aspect of the larger blocks.

The long dimensions of the larger blocks parallel the dip direction of the bed. Within the same brecciated zone are smaller pieces oriented so that their long dimension is at an angle of 45 degrees to the strike direction of the beds. The planes of stratification of these blocks are approximately parallel to the bedding planes as if the blocks had been simply broken loose from the underlying material and rotated about a vertical axis. Other small pieces are tilted so that their stratification planes are at an angle to the general bedding.

On the east side of the small point 1200 feet N. 70° E. of Flat Rock large blocks of yellowish-brown (10YR5/6)-weathering sandy or silty, finely crystalline dolostone and calcareous silt with fine raised lines on the weathered surface form another breccia. A fresh surface of the broken material is medium light-gray (N6). Some of the blocks in the breccia are as much as 3 feet long and 6 inches thick. The bulk of these pieces are tilted in a westerly direction so that the angle between the bedding surface of the underlying dolostone and the tilted surface of the block is approximately 90 degrees.

A bed composed of calcareous silt and silty dolostone resembling the blocks of this breccia lies beneath it in an exposure a few yards to the northeast. While the first impression is that this bed could be a possible source for the blocks, closer examination of the weathered bedding surface discloses that the bed itself is a breccia. However, the blocks are not tilted as in the breccia to the south. Within this bed are cross-laminated layers, and lying immediately over it is a coarsely crystalline, medium light-gray to medium-gray (N6 to N5) calcitic dolostone.

A third breccia of large blocks is obscurely outlined on the weathered surface of outcrops approximately 1800 feet N. 50° E. of Flat Rock. It is associated with interbedded dolostones and calcitic dolostones. There seems to be no correlation with the breccias exposed on the shore to the south.

Near the northwest corner of the bay bifurcating Thompson Point, about 50 yards north of the lamprophyre dike still another breccia appears. This particular one is near the top of the formation, for to the south it is overlain by the basal Cutting breccia. Faint suggestions of channeling are present in the breccia. It appears from the exposures that the breccia fills channels cut in the underlying medium and finely crystalline dolostone. The brecciated material is silty dolostone.

Near the base of the Whitehall, on the southern and northern shores of the first small cove northeast of Flat Rock, is a breccia composed of 6- to 12-inch pieces of sandy, finely crystalline dolostone. The blocks comprise 60 to 70 percent of the sediment and are in a matrix of dark-gray to dark brownish-gray (N3 to 5YR3/1) dolostone. Under the breccia are beds of calcareous sandstone resembling those exposed at the northwest corner of Thompson Point. Dark-gray dolostones overlie the breccia. The relationships here suggest that part of the Ticonderoga dolostone may be exposed. However, the attitude of the Ticonderoga to the west requires that the top of the formation lie below this outcrop. Small intraformational breccias outcrop on the tip of the point at Flat Rock in what has been called Whitehall, and it is believed that the breccia in the small cove is one of the several that are found throughout the formation. Insofar as can be discerned the blocks forming the breccia were derived from the Whitehall. On the other hand, it may indicate that there is an erosional break between the Ticonderoga and the Whitehall, or it may correlate with the breccia located in the Ticonderoga near the contact with the Whitehall at the northwest corner of Thompson Point. The latter explanation would require the presence of a small fault to the west of the shore, and no positive evidence exists for such a feature.

Thin zones of intraformational breccias and conglomerates are found throughout the Whitehall. At the most northerly small point in the southeast corner of Converse Bay one of these zones overlies a 6-inch layer of black argillaceous material. The angular fragments and the matrix are of the same type of dolostone and recognition of the breccia depends upon the weathering of a surface at an angle to the bedding planes. Some of the brecciated zones are only a few inches thick; others are as much as 3 feet thick.

Brainerd and Seely (1890b) measured a thickness of 295 feet for the Whitehall ("Division B") at the southeastern Shoreham locality. Cady (1945, p. 541) gives a thickness of 275 to 300 feet for the nondolomitic limestones of the Shelburne marble on the west limb of the Middlebury Synclinorium. The thickness at Whitehall is about 300 feet (Rodgers, 1955). Brainerd and Seely (1890b) also estimate 250 to 275 feet for the formation in the vicinity of Mount Independence and Fort Ticonderoga. On Thompson Point the thickness determined in the measured section (Section 4) is 209 feet. South of Vergennes an estimated 225 feet are exposed at the north end of Prospect Cemetery, and 250 to 275 feet are estimated to be present east of the East Panton School where the top of the formation is covered by alluvial material.

While the Whitehall is predominantly dolostone within the Central Champlain Valley, lateral variations do occur elsewhere. Rodgers (1955) points to a rapid lateral change at Whitehall where the dolostones change to limestones in a comparatively short distance. Similar changes have been noted by him at Cutting Hill in southeastern Shoreham where Brainerd and Seely noted the presence of limestone in the middle and upper parts of the formation. The "Baldwin Corner" formation, 120 feet thick, in the Fort Ann area (Billings and others, 1952) possesses persistent limestones near the middle and base. Where the author has seen the unit, near Comstock, New York, it looks much like the lower part of the Whitehall in the Thompson Point area, the resemblance applying to the breccias also.

Petrographic evidence from the Whitehall within the Central Champlain Valley suggests rather strongly that most of the dolostones of the formation are primary, or at least that the original carbonate was converted to dolomite within a very short time after deposition. The presence of the limestones west of Snake Mountain is taken to be a primary lithologic variation. They are thought to have formed contemporaneously with the associated dolostones of the formation. It is suggested that the dolostone-limestone variations seen elsewhere in the formation are primary features of the Whitehall sequence. The fact that the beds of the Lower Canadian seem to grade eastward into a limestone sequence, the Shelburne marble, would lend some support to the concept of a primary origin for both the dolostones and the limestones. Furthermore, evidence at hand concerning the relative ages of the Whitehall at its various outcrops does not preclude the fact that in some localities it may be slightly older or younger than at others. Thus it is conceivable that some of the variations in lithology may be associated with depositional environment changes through geologic time as well as with facies changes.

Cutting Dolostone (Cady, 1945)

The type area of the Cutting dolostone, named by Cady (1945, p. 541), lies in the southeastern part of Shoreham in the classic section described by Brainerd and Seely (1890b). The limits of the formation correspond with "Division C" of the "Calciferous," and Cady (1945, p. 542) used Brainerd and Seely's description as the type description of the Cutting. This description of the 350 feet of sandstone and dolostone from top to bottom is given below (Brainerd and Seely, 1890b, p. 2):

"4. Magnesian limestone like No. 2, frequently containing patches of black chert	120 ft.
3. Sandstones, sometimes pure and firm, but usually calciferous or dolomitic	70 ft.

2. Magnesian limestone in thick beds, weathering drab . . 100 ft.
1. Grey, thin bedded, fine grained, calciferous sandstone, on the edges often weathering in fine lines, forty or fifty to the inch, and resembling coarse grained wood. Weathered fragments are frequently riddled with small holes called *Scolithus minutus* by Mr. Wing . . . . 60 ft."

In the Central Champlain Valley of Vermont all four units can be recognized. Since they can be mapped over a considerable area, they are treated as members of the formation and designated by C-1, C-2, C-3, and C-4 to correspond with the numbers in the original description. No formal names are proposed for the several members of the formation since exposures within the Central Champlain Valley are inadequate for the necessary detailed description.

The most prominent and extensive exposure of the formation lies at Thompson Point where the Cutting is underlain conformably by the Whitehall formation and is probably overlain by the equivalent to the lower part of the Bacsom formation (Cady, 1945). In Vergennes the basal breccia of the formation is exposed a few yards north and south of the road junction at the northeast corner of Prospect Cemetery; the upper part of the lowest member and the next succeeding members are exposed approximately 1000 feet east of the junction of Route 22A and the road to Panton. The isolated hill approximately .65 mile east-southeast of the East Panton School is formed of sandstones and dolostones which belong to the lowest member of the Cutting.

Foyles (1923, p. 79; 1926a, p. 115) failed to recognize the presence of the Cutting, or any of the other formations of the Beekmantown group in Panton, stating that he found no true Beekmantown strata in Panton and calling the outcrops at the Vergennes waterfall Chazy. Seely (1901; 1910, map) noted that the beds at the Vergennes waterfall were Beekmantown although he did not record the outcrops south of Vergennes. However, in the 1861 report on the geology of Vermont (Hitchcock, E. and others, p. 268), the outcrops south of Vergennes were recognized as belonging to the Calciferous. Cushman (1941) mapped all of the beds in this area as "Beekmantown E".

Nowhere within the Central Champlain Valley is the top of the Cutting exposed. At the type locality the formation totals 350 feet (Brainerd and Seely, 1890b, p. 2); in the Thompson Point area there are approximately 400 to 450 feet exposed. Table 2 lists the thicknesses of the several members at the type locality, Thompson Point, and Vergennes.

TABLE 2

THICKNESS OF CUTTING DOLOSTONE

Member	Approximate thickness—Feet		
	Thompson Pt.	Vergennes	Shoreham
C-1	115	115	60
C-2	110	110	100
C-3	95	100+	70
C-4	120+	not exposed	120

Brainerd and Seely (1890b, p. 16) assumed that the lake beds which lie to the east of the uppermost exposure of the Cutting covered 150 feet of the overlying formation, and they apparently felt that the last exposure of the uppermost member of the Cutting ("Division C") represented a horizon nearly at its top. However, the information gathered in the present work shows that closer to 200 feet of the equivalent to the lower Bascom (Cady, 1945) are covered in this area. The inference is that the contact between the lower part of "Division D" and the Cutting is probably 20 or 30 feet above the stratigraphically highest exposure of the Cutting. Furthermore, there may be a small fault lying between the last exposure of the Cutting and the eastern edge of Thorp Point, as is indicated on the map (Plate 1), a happenstance which would make estimates of the thickness of the covered parts of the two formations unreliable. At Vergennes the total exposed thickness is approximately 300 feet.

Comparison of the thickness data indicates that the C-1 member of the Cutting thickens northward at the expense of the dolostones of the C-2 member. It is possible that the choice of a different horizon from that used by Brainerd and Seely as the boundary between the lowest and C-2 members has been made in the present work; if so the discrepancies may be explained. Nonetheless, all of the horizons show a greater thickness at Thompson Point when compared with the Shoreham section.

C-1 Member

The lowest member of the Cutting is a sandy and silty sequence of thin-bedded, fine-grained dolomitic sandstones and thick-bedded, silty and sandy massive dolostones. Within the two areas of exposure the most characteristic single feature of the member is the breccia at the base; another striking feature is the cross-bedding associated with the sandstones at the base, a feature which has been widely recognized as a characteristic of the lowest part of the Cutting (Brainerd and Seely, 1890b; Rodgers, 1937, 1955; Wheeler, 1941c, 1942; Cady, 1945).

The breccia crops out on the western shore of the bay splitting Thompson Point, approximately 1000 feet from the head of the bay where it lies conformably on the dolostone of the upper part of the Whitehall. Dolomitic sandstone and very finely crystalline sandy light-gray (N7) dolostone which weather in shades of gray and yellowish-gray (5Y8/1) are the components of the breccia, forming blocks which average less than 6 inches in length, though larger ones are present.

Characteristically the edges and corners of the blocks are rounded to a greater or lesser extent. Rounding is more prominent on the smaller fragments than on those in excess of 3 or 4 inches. Raised lines ± .5 mm thick representing concentrations of quartz silt typify weathered surfaces of the very fine-textured material. The individual subrounded to angular, clear quartz grains of the lined blocks are from ± .05 mm to .1 mm in diameter; occasional, scattered, rounded, frosted quartz grains occur in the fragments.

Most of the breccia's matrix is similar in texture and composition to the blocks, but calcareous sandstone composed of 1.0- to 1.5-mm, rounded, frosted quartz grains in a matrix of .1-mm calcite rhombs cements part of the breccia. The quartz content of the coarse-grained sediment varies between 50 and 75 percent. Silty and sandy limestones of medium crystallinity serve as part of the matrix also. In this material very thin films of angular silt-size quartz particles separate individual carbonate rhombs and masses of carbonate rhombs. Most grains of the sand-size fraction are less than .1 mm, but scattered .1- to .2-mm, rounded quartz grains are also present.

At the small point a thickness of 4 to 5 feet is exposed. The actual thickness may be more, for the bed dips eastward beneath the lake, and its top is obscured in a landward direction by the accouterments of a summer cottage.

No systematic orientation of the breccia blocks has been discerned. Rather, they seem to represent a jumbled mass deposited on a smooth, presumably flat, surface.

Brainerd and Seely (1890b) indicate on their map of the southwest Charlotte area that all the beds along the west side of the bay are part of the Whitehall (Division B"). Apparently they did not recognize the breccia as forming the base of the Cutting ("Division C"), nor for that matter do they mention its presence at all. Underlying the breccia are massive, medium crystalline, gray dolostones which are believed to be the uppermost beds of the Whitehall.

The most extensive single outcrop of the basal C-1 breccia lies on the small ridge approximately 3500 feet south of Cedar Island. The largest blocks in the breccia are 9 inches long, though the average block size is under 6 inches and many are only 2 to 3 inches long. Weathered surfaces of the blocks display the typical fine, raised lines and weather from light-gray to yellowish-brown (10YR5/4); some are almost white. The thinly laminated nature of the breccia, both of the blocks and the matrix, is clearly shown on the weathered surfaces where layers 1 mm thick weather in an irregular outline with each upward succeeding layer being slightly smaller in areal extent that the one below it. The results suggest a series of sheets of paper cut to represent contour horizons of a topographic map which have been laid upon one another in proper sequence.

The blocks vary from very fine-grained dolomitic sandstone (.05- to .1-mm quartz grains) to finely crystalline sandy dolostone in which the carbonate grains range from .05 to .1 mm in size. In any given specimen the quartz and carbonate grains are of comparable dimensions. The cementing material of the breccia is much like the blocks, although it does not generally possess the raised lines on a weathered surface. Its weathered color is more yellowish-brown, reflecting a generally larger carbonate fraction, and it contrasts sharply with the lighter shades of the blocks.

Taken as a whole, the breccia averages about 40 percent carbonate and 60 percent very fine-grained quartz. Some of the blocks are 75 to 90 percent quartz; in others the quartz comprises only about 30 percent of the rock.

Individual beds within the breccia at this locality are between 1 and 2 feet thick; the total thickness is probably of the order of 5 feet. No systematic arrangement of the blocks exists; the sandy matrix seems to have filled the openings between the broken and tilted blocks. Below the breccia on the north side of the ridge lie the dolostones of the Whitehall formation which are described in Section 5, Appendix I.

A third outcrop of what appears to be the C-1 breccia is found on the southeast side of the small knob approximately .5 mile S. 25° E. of Cedar Island.

The dolostones at the top of the Whitehall are exposed along the western edge of the hill. The best exposure of the breccia occurs on the northeast corner of the hill where 3- to 4-inch chunks of the very fine-grained sandstone have been tilted so that their bedding planes now lie normal to the bedding plane of the bed. Other pieces of the breccia have been simply tilted, some only slightly as shown in the sketch of Text-figure 4. The matrix material, of composition similar to that of the blocks, fills in between the blocks; thin horizons conform to the irregular surfaces presented by the jumble of blocks at the time of deposition. One such horizon is shown in the sketch of Text-figure 4.

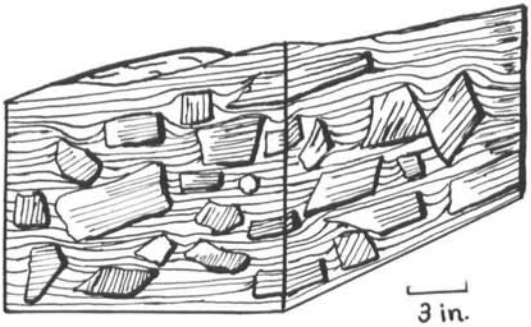
On the south shore of Garden Island a small patch of yellowish-brown-weathering, lined breccia lies on the light-gray-weathering finely to coarsely crystalline, fetid dolostones of the Whitehall. Because of its similarity to the breccias at the base of the C-1 unit, this breccia is correlated with them. It could be a breccia within the Whitehall, but it appears to resemble the breccia near the center of Thompson Point more than the breccias found within the Whitehall.

The exposures of the breccia adjacent to Route 22A near Prospect Cemetery in Vergennes are low and for the most part can be seen only in the horizontal dimension. In the exposure south of the road intersection at the northeast corner of Prospect Cemetery a few "*Scolithus*" borings may be seen in a 1-foot ledge of the breccia. Figure 1, Plate 6 is a photograph of the breccia at Thompson Point.

Although it is possible to recognize the breccia on a vertical surface in some places, it seems necessary to have it exposed on a bedding surface for incontrovertible identification because of the manner in which the breccia weathers and the manner in which the cementing material fills in between the blocks. While there are somewhat similar breccias in the Whitehall formation they seem to be more dolomitic and to lack the great concentration of lined material which typifies the Cutting breccias.

The sandy horizon at the base of the Cutting is reported from a number of localities. Rodgers (1937, 1955) recognized its presence in the Whitehall area; it has been described from Shoreham by Brainerd and Seely (1890b, p. 2), and Cady (1945, p. 542) notes its eastward disappearance in the Middlebury Synclinorium. Robert Cushman (personal communication, October, 1959) reports finding the sandy, dolomitic breccia in several places in Washington County, New York. The basal sandstone and breccia of the "Great Meadows formation" (Billings and others, 1952) of the Whitehall and Fort Ann, New York, areas is lithologically almost identical with the basal Cutting sandstone and breccia; the term "Great Meadows formation" has been applied to the sequence of rocks overlying the Whitehall dolostone on Skene Mountain at Whitehall (Billings and others, 1952).

All lines of evidence indicate that the breccia formed in place and that



Text-fig. 4 Basal Cutting breccia, small knob approximately .5 mile S. 25° E. of Cedar Island. Diagrammatic, based on field notes and sketches. Note how the thin sandy laminae or lines fill in between blocks and warp around them.

the blocks and smaller fragments comprising the breccia have been transported only very short distances. The breccia seems to represent the deposition of the sandy dolostones and dolomitic sandstones followed by disruption of the beds. The associated cross-bedded and cross-laminated sandy dolostones and dolomitic sandstones suggest the nature of the current activity. Many of the larger blocks seem to have been simply tilted, and their edges lack evidence of abrasion. The smaller blocks and fragments obviously have been rolled around and have had their edges abraded and rounded. Whether the breccia represents a shoreline feature or only a shallow-water environment can not be definitely stated. Nonetheless, it is believed that the shoreline of the sea in which the sediments were forming was not far from the site of deposition of the broken material. Furthermore, it is believed that the blocks were formed and transported while they were still moderately soft and that the currents moving them were not excessively vigorous.

Above the breccia the C-1 unit consists of thin- and thick-bedded, generally massive dolomitic sandstones. Dolostones are interbedded in the lower part of the member, but they replace the sandstones in the upper half or third of the unit. Most of the beds typically weather with the fine lines noted by Brainerd and Seely (1890b, p. 2), and on weathered vertical surfaces there is often a reddish or pinkish-gray (5YR8/1) tint which aids in the recognition of the member.

Dolostones, sandy dolostones, and dolomitic sandstones of the C-1 member are exposed in the west face of the ridge approximately .5 mile southeast of Cedar Island. Some of the sandy beds are brownish-gray (5Y6/1); others are pinkish-gray (5YR8/1). Most of the dolostones are dark-gray to medium dark-gray. Fine-grained, tenacious, dolomitic quartz sandstones are prominent and have on weathered vertical surfaces the raised lines that are typical of the member. At the northernmost exposure of the member, the sandstones are extensively cross-laminated. The basal breccia, if present, is not exposed here.

Dolostone beds 4 to 6 inches thick and separated by shaly partings appear near the top of the member. Reddish spots which are attributed to the oxidation of the pyrite scattered through the rock are seen on some fresh surfaces. It is believed that the oxidation predates the weathering of the dolostones and that it may have taken place soon after deposition of the dolomite.

The quartz grains of the rocks are generally angular, clear, and between .02 and .1 mm in diameter. In many of the sandy and silty dolostones the quartz grains lie between .02 and .05 mm, and they form small ($\pm$ .5 mm) isolated masses within the carbonate framework of the sediment, as well as the films described below. Average grain-size for both the angular quartz and the carbonate rhombs of the dolostones is between .02 and .05 mm. The quartz grains and the carbonate rhombs are of comparable size in all the rocks of the member, coarser quartz grains accompanying larger dolomite rhombs.

Throughout the member silty and sandy horizons predominate, with many of the beds exhibiting small-scale cross-laminations and small intraformational conglomerates and breccias. Occasional very fine-grained sandstone layers, 1 or 2 inches thick, are interbedded with the thicker bedded sediments. The quartz of the sandstones is clear and angular and averages about .05 mm in size.

The upper half of the member is dominantly dolostone and silty dolostone (see Section 6, Appendix I). Much of the silt in the dolostones occurs as .01 to .02 mm thick films between individual carbonate rhombohedra and as isolated lenticular spots averaging .1 to .2 mm in length, but up to .5 mm thick. The films conform to the rhombohedral outlines of the carbonate grains. Insoluble residues of these rocks consist of clear, angular quartz grains with an average size between .005 and .01 mm. The relationships seem to suggest that the quartz was trapped between the carbonate grains during precipitation or shortly after but before final lithification. Additional support for this concept comes from the fact that similar quartz fragments, well cemented with silica, form the laminae which are expressed as fine raised lines on weathered surfaces of some of the rocks.

Generally the dolostones are very finely to finely crystalline (.02 to

.06 mm), and some have .1- to .2-mm rounded, frosted quartz grains scattered randomly through them in addition to the silt-size quartz. In many the quartz content approaches 50 percent of the rock.

Along the east shore of the bay which separates the two prongs of Thompson Point and in the bluffs above the shore, the C-1 member outcrops as beds 1 to 3 feet thick. Many of these beds are dolomitic siltstone or very fine-grained sandstone, while others are finely to medium crystalline dolostone and sandy dolostone. Sandy, medium and finely crystalline dolomitic limestones also crop out. A few of the beds contain scattered masses of blue-black calcite which may represent recrystallized fossil fragments. Vugs containing white calcite rhombs and quartz also occur. Small-scale cross-laminations and thin intraformational breccias may be observed in a number of places.

The measured section from the upper part of the C-1 member into the lower part of the C-2 member at Cartmell Point (Section 6, Appendix I), is presented to describe the change from the C-1 to the C-2 member as well as part of the lithologies of each of these beds.

On the small bulge at the northeast corner of Thompson Point the C-1 member beds consist of finely and medium crystalline sandy dolostone and dolomitic sandstone. Rounded, frosted quartz grains up to .25 mm in diameter form the sand component of these beds. On some of the bedding surfaces of the thick (1 to 3 feet), massive, beds are thin layers of silt-size material which appear to contain dessication cracks while within the beds are thin zones of cross-lamination and intraformational conglomerates.

Cedar Island represents an outcrop of the lowest member of the Cutting formation. Fine-grained sandstones with the pinkish-gray (5YR8/1) weathered surfaces often found in this unit crop out as well as light-gray dolomitic sandstones which weather grayish-orange (10YR7/4) to yellow-gray (5Y8/1). Irregular bedding surfaces are brought out by weathering of the vertical faces of the outcrops. A "ribbed" sequence similar in appearance to the calcareous sandstones of the Cassin formation underlies the eastern third of the island. Rusty-colored ridges 1 to 2 inches thick separate slightly lower gray-colored areas. It is in this part of the member that the "*Ophileta*-like" fossils were found by Brainerd and Seely (1890b, p. 16). Outlines of the fossil may be seen on most bedding surfaces in the "ribbed" horizon, but they are particularly abundant near the dock. Donald W. Fisher, State Paleontologist of New York, kindly identified one of the specimens as *Ophileta* (oral communication, May, 1959). This locality is the only place that fossils other than

"*Scolithus*" have been found in the Cutting exposures of the Central Champlain Valley.

At Vergennes the C-1 member is exposed on the west face of the two hills approximately 1000 feet northeast and east of the Prospect Cemetery. The upper part of the C-1 unit is sandy, generally massive, moderately thick-bedded dolostone. South of Vergennes the isolated hill approximately .65 mile east of the East Panton School is dominantly 1- to 2-foot, medium- and dark-gray, fine-grained dolomitic sandstone. On the north slope of the hill a sedimentary breccia composed of silty dolostone is exposed. The blocks and fragments vary from 2 mm to 1 cm in size, and many have a rusty rim on them while others have a rim of quartz silt. The corners and edges of many of the larger fragments have been worn and slightly rounded. The material of the blocks is finely crystalline, silty dolostone, and much of it is reddish-orange (10R6/6) or brownish (5YR5/6). The blocks were apparently rolled around prior to final deposition, and in the process picked up the rusty and silty coatings. The dolomitic material of the blocks is similar to much found in the formations beneath the Cutting and to beds within the Cutting itself.

Tilted blocks approximately 2 feet long and 6 to 10 inches thick occur in a fine- to very fine-grained, light-gray sandstone on the west face of the hill. Black chert blocks and fragments which seem to be detrital are scattered through some of the dolostones. At the base of the hill the sediments are tough, thin-bedded (4 to 6 inches), very fine-grained dolomitic sandstones and siltstones. The abundance of the fine sand at this locality suggests that the beds represent a horizon near the base of the formation.

C-2 Member

An abundance of blue-black chert masses distributed through the dolostones characterizes this member. On an individual basis many of the dolostones can be easily confused with the dolostones of the other members of the Cutting and with dolostones of the Whitehall. Hence the rather abrupt increase in the amount of chert and the stratigraphic position of the unit are important criteria for recognition of the member.

The dolostones of the C-2 member vary from medium-gray-weathering medium and coarsely crystalline, relatively pure rocks to finely crystalline, slightly silty rocks. The fresh surfaces range from medium-gray (N5) to dark olive-gray (5Y3/1) in color, and the fresh surfaces of the coarser grained dolostones are often dull-lustered. As with similar rocks in the Whitehall, the dull luster is associated with rocks in which earthy-appearing material lies between the individual dolomite crystals. The maximum amount of the earthy matrix material seems to be about 10 percent, and it usually comprises a much smaller proportion of the rocks. In thin sections the earthy matter is seen as a brownish, dust-like film on the dolomite rhombs. Quartz silt is absent or forms only a very small percentage of these sediments.

When freshly broken the dull-lustered rocks emit a strong fetid odor as is the case with like rocks of the Whitehall. The odor is less strong in the finer grained, more silty carbonates.

Differentiation of the C-1 and C-2 members can be made on the basis of the upward disappearance of the fine-textured, silty, somewhat vitreous-lustered dolostones of the lower sequence and their replacement by the coarser grained, less silty, dull-lustered, chert-bearing dolostones which represent the C-2 member. In contrast to the finely crystalline texture and vitreous luster of the C-1 rocks, the dolostones of the C-2 member often provide fresh breaks on which the dolomite rhombs stick up as individual whitish grains set in a dull background. Taken as a whole the dolostones of the C-2 member are thicker bedded than those of the upper part of the lowest member of the Cutting.

The general impression gained from exposures, based on luster and grain size among other criteria, is that the C-2 dolostones are less silty than those of the lower member; this idea is borne out by laboratory study, and, furthermore, the insoluble residue analyses (see Section 6) suggest that they might be a useful tool in recognizing the unit in areas where the chert is not so well developed as at Thompson Point.

The chert which typifies the C-2 member occurs as irregular masses 1 foot thick distributed randomly through the carbonates; in some places it is found plastered on joint surfaces, and elsewhere it occurs as lenses parallel to the bedding. Some of the chert is bedded, or reflects pre-existing bedding if it is a replacement product. Variations in coloration and the distribution of silt grains through it point up its bedded aspect. Undulating laminae suggest that the precipitating silica was strung out by currents. In the small, isolated accumulations of dolomite crystals in the chert, the rhombs are often separated from the chert by thin films of silt-size quartz which follow the configuration of the rhomb faces. This relationship would seem to indicate that the dolomite and chert formed as primary precipitation products in the Ordovician seas.

Interbedded with the coarser grained, dull-lustered dolostones are finely and medium crystalline, slightly silty dolostones. On the northeast corner of Thompson Point a thin (3 to 4 inches) quartz siltstone lies between two massive slightly silty dolostones along an undulating surface. The quartz grains of the siltstone are similar to those which form the quartz films and minute masses in the dolostones and the siltstones and very fine-grained sandstones of the C-1 member.

In the Vergennes area the C-2 member consists of light-gray (N7)- to very light-gray (N8)-weathering, dark olive-gray (5Y3/1) to blackish (N2), medium and coarsely crystalline dolostones with the typical dull luster or earthy appearance. Presence of a few chert masses aid in the recognition of the unit.

C-3 Member

A yellowish-orange coloration characterizes many of the weathered dolostones of the C-3 member. However, the color may be observed only on a fresh break where weathering effects have penetrated into the rock. This coloration is particularly useful in separating the unit from the overlying and underlying dolostones in the ridge .5 mile southeast of Cedar Island.

Along the east coast of Thompson Point the C-3 member is represented by a series of very finely crystalline silty dolostones. Most of the rocks are light- to very light-gray (N8) on a fresh break, and the beds contain isolated masses of blue-black chert. Grain size of these dolostones varies from .05-mm to .1-mm.

Thirty percent of one specimen from the C-3 member at the northeast corner of Thompson Point is composed of oval-shaped brownish areas representing accumulations of .01– to .05-mm carbonate grains. The brown pigment is distributed between and on the individual crystals and as a film .001 mm thick around the several ellipsoidal masses of carbonate grains. Each film delineates sharply a boundary between the .5-mm masses and the more coarsely crystalline carbonate grains of the cement. Individual crystals of the surrounding material average about .1 mm in size. Penetration of the matrix crystals through the brown line into the oval-shaped masses is absent, and the contact between the two sets of crystals is along the brown line.

In contrast to the dull luster of many of the C-2 dolostones, the C-3 dolostones exhibit a vitreous or "siliceous" luster which is attributed in part to a slightly higher content of quartz silt and to a finer grained texture. Rounded, frosted quartz grains are found more or less randomly distributed through some of the C-3 rocks. Generally speaking, the C-3 dolostones are more finely crystalline than those of the C-2 unit, are lighter in color on the fresh break, and while containing chert masses, the chert is found only locally and does not seem to typify the member as a whole. The C-2 and C-3 members are much alike in their bedding characteristics. The C-3 member has some sand similar to that found at the base of the Cutting poorly exposed at the north end of the outcrop area at Thompson Point.

That some of the carbonate sediments represent a mechanical mixture of calcite and dolomite is a possibility; however, because of the extremely fine grain-size of those rocks in which the mixture may exist, the work done on these rocks has given only inconclusive answers.

C-4 Member

The outcrop of the C-4 member is restricted to the east edge of the ridge southeast of Cedar Island and to the headland into Converse Bay northeast of Cedar Island. The best exposures of the C-4 member are along the shore of the headland.

The uppermost member of the Cutting is typically massive, yellowish-gray (5Y8/1) and very light- to medium light-gray (N8 to N6)-weathering dolostone of a general drab appearance. Thin raised lines emphasize minor current-formed structures. The fresh break of a typical rock discloses a very finely crystalline to finely crystalline dark-gray (N3) to medium-gray (N5) lithology in most cases. In thin sections and on polished surfaces some of the dolostones may be seen to possess small (.05 to .1 mm) oval-shaped areas surrounded by carbonate of lighter color. The matrix is lighter colored and on etched surfaces is attacked more readily by dilute acid—whether acetic or hydrochloric. The grains comprising the oval-shaped areas are from .01 to .05 mm in diameter in contrast to the .05 to .75 mm range for grains of the matrix material.

Many of the dolostones are silty. The quartz silt forms films between the dolomite rhombohedrons, although some quartz grains up to .05-mm are scattered through the rock. The average silt content is about 10 per cent, but may be as much as 25 per cent. A few of the rocks are dolomitic siltstones.

While the dolostones of the C-4 member are generally finely crystalline, some of them are medium crystalline, but these do not show the dull, earthy luster which characterizes the coarser dolostones of the lower members. Abundant evidence of penecontemporaneous deformation, graded bedding, and local erosion of laminae before deposition of the succeeding laminae exists in the massive beds. Figure 2, Plate 6 illustrates some of the features seen on the weathered surfaces of the dolostones but not readily recognized on fresh surfaces. Similar

PLATE 6

Figure 1. Breccia at base of Cutting dolostone; small point on west shore of bay bifricating Thompson Point, approximately 1600 feet northeast of Flat Rock.

primary structures may be found in many dolostones of the Beekmantown group.

The notable increase in the chert content of the dolomitic beds over the chert content of the dolostones of the C-3 member, together with stratigraphic position, aids in the recognition of the uppermost member of the Cutting. In addition the generally finer texture of its component beds helps distinguish the C-4 member from the ones beneath it. The chert occurs as nodules and as distinctly bedded lenses showing lines of stratification. Some is present in veinlike bodies cutting across the bedding.

With the exception of the basal sandstone horizons of the Cutting, the other beds of the several members can be easily confused with one another in isolated outcrops. Hence stratigraphic position is of con-

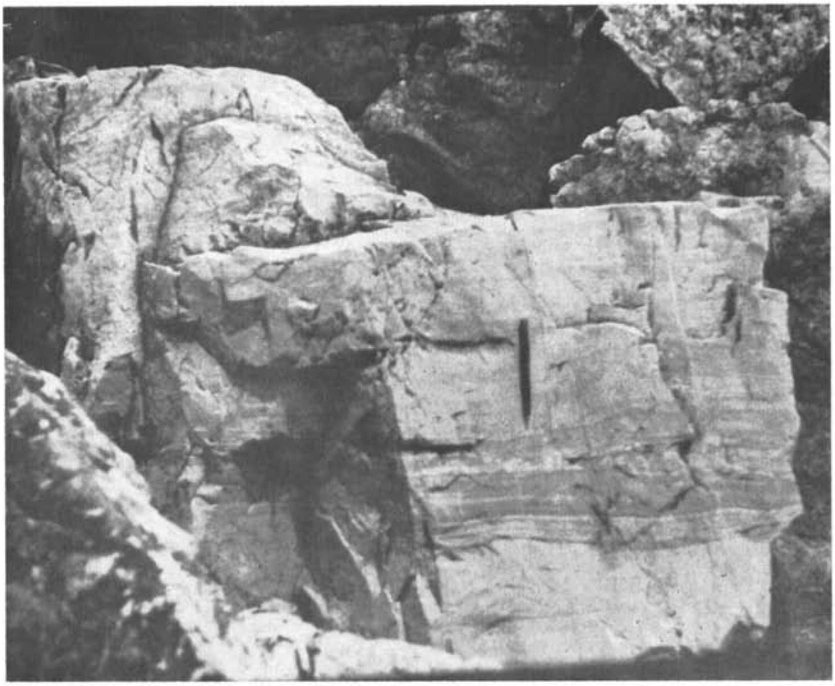


PLATE 6

Figure 2. Typical current structures in Cutting (C-4) dolostone; overturned, loose boulder, south end of headland approximately 3000 feet S. 80° E. of Picket Island, Charlotte. Pencil points toward stratigraphic top of boulder.

siderable importance in recognizing the several members, although close inspection of the rocks of an outcrop will in most cases suggest the member to which the outcrop belongs. However, recognition of each member depends upon the mass effect of a number of features rather than upon the presence or absence of any single or several features. Thus positive recognition and mapping of each depends upon variations over an area larger than a single small outcrop.

Age and Correlation

Since no fossils indicative of the exact age of the Cutting formation have been found in the Central Champlain Valley, reliance must be made upon nearby areas for the age. The ill-preserved *Ophileta* from Cedar Island can only suggest a Lower Canadian age since the genus ranges well up into the Canadian (Twenhofel and others, 1954). Rodgers (1955) reports the finding of Lower Canadian fossils in the uppermost part of the Cutting on the hill west of Route 22A, 3 miles north of Shoreham village and on the east flank of a hill a half mile south of Richville, Vermont. Wheeler (1942, p. 522) notes the presence of a fauna with "Tribes Hill affinities" in a mottled limestone just above the cross-bedded basal Cutting sandstone at Whitehall. Earlier he had reported the presence of "Tribes Hill and *Lecanospira* faunas" above the cross-bedded sandstone (1941b; Cady, 1945, p. 541).

Wing (Dana, 1877, p. 342) noted that the "dolomitic limestone" above the cross-bedded sandstones which are now considered the basal Cutting contained *"Ophileta compacta"* and *"Ophileta complanata,"* noting a difference in the two forms. Unfortunately he did not fix the stratigraphic position of each, and he lumped the dolostones above the cross-bedded sandstone with the sandy limestones which form the lower part of the Bascom east of the thrust belt.

From the evidence at hand it seems most likely that the Cutting represents the upper part of the Lower Canadian in the Central Champlain Valley, being approximately equivalent to the upper part of the Gasconade formation of Missouri and possibly extending into the time represented by the lower part of the Roubidoux formation of the same region. The evidence implies that the formation is the local representative of the *Ophileta complanata* zone. While it is quite possible that the upper part of the formation may be of different ages at widely separated localities, the basal part is inferred to be of approximately the same age throughout the area in which the Cutting and its equivalents are known. The widesparead distribution of the cross-bedded sandstone with the *Scolithus* and of the rather distinctive basal breccia would seem to argue for this interpretation. The breccia is known from the Fort Ann-Whitehall region (Billings and others, 1952; R. Cushman, oral communication, October, 1959), west of Saratoga Springs, New York, at Rock City Falls (R. Cushman, oral communication, October, 1959), and in the Central Champlain Valley. The breccias and sandstones seem to mark a change from the deposition of the dolostones forming the upper part of the Whitehall in the Central Champlain Valley and elsewhere to sediments of a more clastic nature. The fact that the breccias are intraformational in origin would seem significant. Whether the breccias reflect the diastrophic activity recorded in the unconformity between the Tribes Hill and the Chuctanunda formations in the Mohawk Valley (Fisher, 1954, p. 91) or not is unclear. Their full meaning can be discovered only by careful and detailed study of this particular horizon over its whole outcrop area.

The presence of the basal Cutting breccia at Rock City Falls just below the falls (R. Cushman, oral communication, October, 1959) suggests that the Cutting may be in all or part equivalent to the Chuctanunda Creek formation (Fisher, 1954, p. 90) of the Mohawk Valley to which a Lower Canadian age has been assigned. In the Whitehall area the interbedded dolostones and limestones overlying the basal cross-bedded sandstones on the northeast corner of Skene Mountain and called the "Great Meadows formation" (Billings and others, 1952) are believed to be equivalent to the Cutting, for it is possible to recognize four distinctive units in the sequence from the basal sandstone through the "Fort Ann limestone," the uppermost unit of the "Great Meadows." Whether these are exactly comparable to the members of the Cutting found in the Central Champlain Valley or not is a moot question.

Cady (1945, p. 542) has noted that the sandy C-1 and C-3 units of the Cutting become less prominent in an eastward direction. The dolostones of the formation grade southeastward from Shoreham into "curdled" limestones in the Middlebury Synclinorium. Kemp and Ruedemann (1910, p. 65) note the presence of intraformational breccias in the C-2 unit where it is exposed in the Coll Bay area north of Port Henry. They also note that the C-3 unit in this area is a sandstone.

CASSIN FORMATION (Cushing, 1905) (*restricted*)[1]

The author has chosen to use the name Cassin formation for those beds of the Calciferous Division D (Brainerd and Seely, 1890b) which outcrop in the Central Champlain Valley. More specifically the term is restricted to the "D-3" and "D-4" beds, (p. 3). Given below is their description from southeastern Shoreham:

"4. Blue limestone in thin beds, separated from each other by very thin tough slaty layers, which protrude on the weathered edges in undulating lines. The limestone often appears to be a conglomerate, the small enclosed pebbles being somewhat angular and arenaceous . . . . 100 ft.

[1] South of the latitude of West Bridport the lower part of the Bascom formation (Cady, 1945) seems to predominate and has been mapped (1960) as Bascom undifferentiated. Most of the outcrops of this formation lie on the upper plate of the Orwell thrust. South of Chipman Point in Orwell the Thorp Point member of the Cassin formation may be seen in the bluffs overlooking the lake.

3. Sandy limestone in thin beds, weathering on edges in horizontal ridges one or two inches apart, giving to the escarpments a peculiar banded appearance. A few thin beds of pure limestone are interstratified with the siliceous limestones. . . . . 120 ft."

The name Cassin formation has not been formally recognized by the United States Geological Survey as a valid formational name (Wilmarth, 1938; Wilson, D. and others, 1957), but restricted as it is in the present report, it is a useful term for describing a valid cartographic unit occurring within the Central Champlain Valley. Its type locality is at Fort Cassin at the mouth of Otter Creek in Ferrisburg.

The formation name was first formally proposed by Cushing (1905, p. 362–363), but he included within the unit beds of the "Beekmantown (Calciferous) E" even though the massive dolostones and dolostones with thin limestone beds do not appear in the outcrops on Fort Cassin. To the north, in exposures east of Thompson Point, the top of the formation is exposed and seen to be conformable with the overlying Bridport. The nearest outcrops of the beds overlying the Cassin formation near the type area are a half mile southwest on Summer Point. Nowhere in the Central Champlain Valley of Vermont is the base of the formation exposed. The measurements of the type section (Section 7, Appendix I) across the north end of the Fort Cassin headland indicate that the exposures at this locality represent slightly more than a quarter of the total thickness of the formation. Exposures at Fort Cassin represent mostly the upper part of the formation. Section 8 from near the center of the Fort Cassin headland is a supplemental section describing the change from the lower silty and sandy limestone sequence to the upper member. Sections described from the Thompson Point area (Sections 9, 10) are supplemental to the type section.

The Cassin formation is the same general lithofacies as the upper 220 feet of Cady's (1945, p. 542) Bascom formation exposed in southeastern Shoreham. Brainerd and Seely (1890b, p. 14) gave a thickness of 200 feet for the beds of their D-3 and D-4 horizons in these southwest Charlotte exposures. The value obtained for the thickness in the present work is between 200 and 210 feet.

Cady (1945, Plate 10) mapped part of the "D-4" sequence as "Crown Point." Later Kay and Cady (1947) applied the name "Burchards" to the limestone which lies beneath the Beldens formation and which Cady had mapped as "Crown Point." Subsequent work in the vicinity of Ellsworth Ledge in Cornwall (Cady, oral communication, November, 1957; Kay, 1958, p. 79–80; Twenhofel and others, 1954) and in the area north and east of Middlebury shows that the "Burchards" or "Crown Point" of the Ellsworth Ledge area in Cornwall (Wing in Dana, 1877a) is in reality the uppermost limestone of the "Division D" sequence of Brainerd and Seely (1890b). The correct relationships were recognized by Wing (Dana, 1877a, p. 344–345).

Kay and Cady (1947) point out that the "Burchards" and Beldens in the Cornwall village-Ledges outcrop belt form a unit which contrasts with the overlying Middlebury limestone, and they place them together in the "Chipman Group." Apparently Cushing felt similarly about the rocks exposed at Fort Cassin and the dolostones of the overlying "Division E" (Bridport dolostone), for he included the D-3 and D-4 beds with the "Division E" beds in his Cassin formation. It is the contention of the author that the sequence of dolostones and thin-bedded limestones of the Bridport is sufficiently distinct to warrant their separation from the underlying Cassin formation. Furthermore, it is felt that the Cassin formation is more closely related to the underlying rocks than to the Bridport, making the term "Chipman Group" superfluous. Within the Central Champlain Valley the silty limestones of the upper member of the Cassin formation are unlike anything found in the Bridport. The change from the limestone and sandy limestones of the Cassin formation to the dolostones of the Bridport records a marked change in the conditions of deposition.

The Bascom formation of Cady (1945) might well be broken down into two formations. The lower should include the lower two units of "Division D" (Brainerd and Seely, 1890b), the blue limestones at the base and the "magnesian limestone" above them; the upper should include the "D-3" and "D-4" beds. Wing (Dana, 1877a, p. 344–345) apparently included the lower part of the Bascom (Brainerd and Seely's "D-1" and "D-2" horizons) with beds that are now included in the Cutting formation, recognizing a clear difference in lithology between the upper part of the Bascom and its lower part and seeing a closer lithologic relationship between the lower part of the Bascom and the beds of the Cutting than between the lower and upper parts of the Bascom. It is the upper sequence, then, to which the name Cassin is applied.

Two members may be recognized and mapped; these correspond to the two divisions differentiated by Brainerd and Seely. The names are taken from geographic features in the area of Thompson Point where the Cassin formation is better exposed and more accessible than at the type locality.

The lower member is composed of sandy and silty, ribbed or banded limestone with abundant intraformational breccias, beds composed of trilobite fragments and a few light bluish-gray weathering sublithographic limestones; the upper lithology is chiefly bluish-gray, very finely crystalline to sublithographic limestone with thin, black, irregular, encrusting shale and silt partings. While on a general basis the two units are distinctive and might properly be of formational rank, the fact that the upper unit contains important thicknesses of ribbed, sandy limestone beds and the lower unit has a few light bluish-gray-weathering, sublithographic limestones suggests that the two should be grouped together as one formation and the two lithologies regarded as members of the formation. It is viewed as quite plausible that one of the lithofacies may expand vertically replacing the other; also it is not improbable that a lateral gradation of one lithology into the other occurs. The upper and lower boundaries of the Cassin are based on lithology; the separation of the two members is on a lithologic basis and controlled by the faunal associations only insofar as the fauna preserved in the rocks can be considered as indicative of the lithology.

It is because the two lithologies are so intimately related that the author has chosen to use the name Cassin as the cartographic unit instead of expanding the term Burchards, whose original definition (Kay and Cady, 1947) included only the upper limestones with silty partings, to include the lower more sandy beds. The original inadequate definition of the Cassin included both the lower sandy beds and the upper bluish limestones and thus seems to be a more apt name for the sequence. On the other hand, the Bridport dolostones ("Beekmantown E") are so unlike any of the beds of the underlying Beekmantown sequence that it seems advisable to recognize them as a distinct cartographic unit and to separate them from the Cassin formation.

Lateral variations in the Bascom formation are discussed by Cady (1945, p. 543), who indicates that east and north of Shoreham, in the Hinesburg Synclinorium, the "D-3" and "D-4" units change to "curdled" limestone and thin-bedded slaty quartzites and sandstones respectively. He also demonstrates the lateral and vertical gradations within the "D-3" in the northward direction, with the ribbed sandy limestones of the Shoreham section giving way to the "curdled" limestones. He thinks that a thickness approximating that of the Bascom in the Shoreham area is present in the Hinesburg exposures.

Rodgers (1955; personal communication, March, 1959) found that he could not make the twofold division in the New York portion of the Ticonderoga quadrangle. He noted (1955) that the Bascom can be divided into two units in the Shoreham area. A twofold division of the "Division D" beds has been made in the Fort Ann-Whitehall area (Billings and others, 1952). Rodgers (1955) assigns a thickness of about 250 feet to the Ticonderoga quadrangle exposures which consist of a heterogeneous mixture of gray dolostone, siliceous to cherty dolostone, fine-grained sandstone similar to the sandstones in the Cutting, and silty and sandy limestone and dolostone in thin alternating layers.

On the western side of Lake Champlain, in the vicinity of Cold Spring Bay, Kemp and Ruedemann (1910, p. 65–66) noted that rocks of "Division D" like those exposed at Shoreham appear along the shore northeast of Coll Island and southward. They described the "D-4" beds here as consisting of thin, tough, slaty layers of limestone. This is the typical lithology of the uppermost portion of the Emerson School member. In the northern Adirondack region in the type area of the Beekmantown, the beds of the Cassin formation are not exposed according to Cushing (1905, p. 363). Buddington and Whitcomb report both the lower part, or "*Lecanospira* zone" and beds containing the Cassin fauna from the New York portion of the Willsboro quadrangle (1941, p. 72–73). The presence of the Cassin formation on Providence Island has already been noted, but the description by Brainerd and Seely (1890, p. 17) does not permit the exact placement of the boundary between the two members; conveniently it can be placed at the top of the *Calaurops*-bearing, 28-foot interval.

Thorp Point Member (new name)

The small point protruding into Town Farm Bay[1] about half way between the eastern shore of Thompson Point and the mouth of Thorp Brook is known locally as Thorp Point, and a small cemetery near the end of the point contains headstones indicating that members of the Thorp family are buried here. The name of the point is given to the lower member of the Cassin, the type section being located along the western shore of the point. The lowest exposed beds of the section are found about 20 yards north of the large bostonite dike cropping out at the northwest corner of the point, and the section extends southward

[1] Town Farm Bay is the name currently used for Balls Bay of the earlier papers while Dean Island is the current name for the Cove Islands of the earlier works.

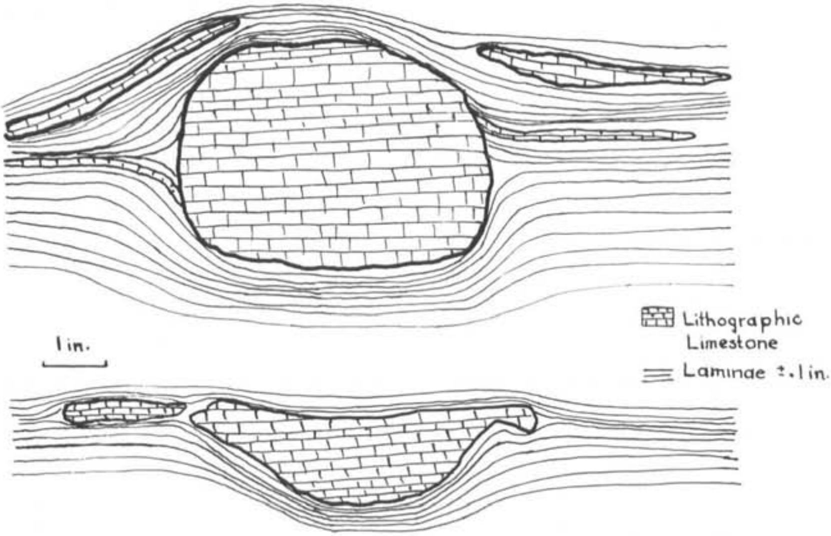
to a horizon near the top of the bluff on the south side of the small cove approximately 300 yards south of the dike. A detailed description of the section is given as Section 9, Appendix I. Total exposed thickness of the member here is 82.7 feet. In the supplemental section just south of the Thompson Point road a 105-foot interval is exposed, indicating that the supplementary section begins about 20 feet lower in the Thorp Point than the type section. The exposures at the base of the bluffs a few yards south of the Thompson Point road are thought to be near the contact with the underlying dolomitic "D-2" sequence.

The bedding of the limestones is moderately thick, averaging between 1 and 2 feet, and massive; thinner beds, especially siltstones and shales are present between the thicker limestones. The overall bedding thickness is to be distinguished from the lenses, lentils, small channels, layers of pebbles, and other sedimentary features that are found within the individual beds. In some exposures of the ribbed material the bedding thickness is seen to be comparable to the thickness of the ribs and the intervening areas.

Composition of the Thorp Point member is rather uniformly dark-gray and dark bluish-gray (5B3/1), silty and sandy limestone and calcareous sandstones whose most characteristic feature is the ribbing which forms on the weathered surfaces. Faces at right angles to the bedding weather so that brownish ridges of very fine-grained calcareous quartz sandstone stand higher than the dark-gray (N3) sandy and silty limestone between. The ridges are approximately .1 to .25 inches thick and are from .5 to 2 inches apart, this relationship giving the "peculiar banded appearance" noted (Brainerd and Seely, 1890b, p. 3) as being characteristic of this particular horizon.

Whether the deposition of the sandy, brownish laminae was rhythmic or not is a moot question; there is some suggestion that cyclic or rhythmic deposition may have taken place, but concrete evidence is lacking. Minor amounts of penecontemporaneous slumping and faulting are reflected in the offsets and variations of some of the ridges.

Nodules of light-gray-weathering limestone have been observed in some of the dark bluish-gray sandy limestones of the Thorp Point. At one locality about 20 yards south of the small cove on the west side of Thorp Point, the .1-inch silty laminae surround such a nodule; the lower laminae are depressed downward, suggesting that the nodule was transported to its depositional site rather than precipitated in place. Text-figure 5 illustrates this particular feature. In the same general area a 1-foot silt and shale band contains similar nodules; the 1- and 2-inch

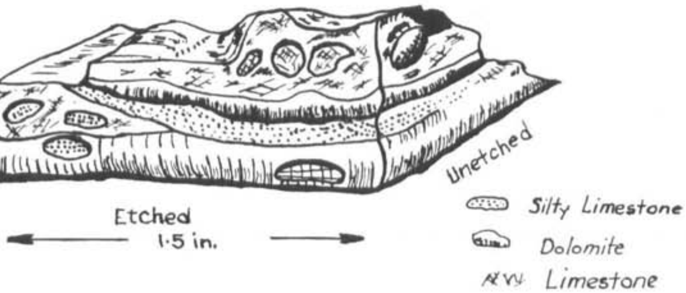


Text-fig. 5. Blue, lithographic, penecontemporaneously formed limestone cobbles or nodules in fine-grained, sandy limestone of Thorp Point member of Cassin formation, showing depression of subjacent laminae and warping of superjacent ones. Location on small point west and slightly south of house, Thorp Point, Charlotte. Based on field sketch.

beds of the shaly material are wrapped around the isolated nodules.

Texture of the rock is uniform, grain-size averaging approximately .05 mm for both the clear angular quartz and the carbonate grains of the limestone. Well-formed .05-mm dolomite rhombs are common in some of the silty and sandy laminae. The ridges have an average carbonate content of from 10 to 15 per cent while the sandy and silty limestones comprising the bulk of the rock contain an average of approximately 35 per cent clear angular quartz in the silt and very fine sand size-ranges. Some of the beds lacking ribs but with an abundance of fossil fragments contain closer to 50 per cent quartz, and in some cases they are actually calcareous sandstones. Brownish iron oxide rims surround many of the carbonate and quartz grains of the ridges. Within the less quartz-rich parts of the beds contacts between the quartz and carbonate grains follow the shape of the quartz grains, indicating that the carbonate matrix has adapted itself to the shape of the quartz.

Many of the sandy limestones of the member are composed almost entirely of trilobite fragments and recrystallized fossil fragments. This statement is particularly true of the limestones in the upper part of



Text-fig. 6. Sandy limestone pebbles in limestone matrix with laminae of dolomite (raised on etched surface). Note also pebbles of sublithographic limestone. Thorp Point member Cassin formation at Thorp Point, Charlotte.

the member. Dark-gray, sandy, trilobite-bearing limestones may contain several per cent of brassy yellow ± .1-mm pyrite cubes. The larger quantity of pyrite in these layers contrasts with the traces of pyrite found in the lower sediments. The high sand and silt content of the trilobite-rich beds together with the fact that they tend to be fine-grained makes differentiating between silt-rich limestone and calcareous sandstone difficult.

Seely (1906, p. 178) described the "sponge" *Wingia* from beds of this member; his specimens apparently came from beds along the west shore of Thorp Point. However, examination of the pebbles shows them to be silty, finely crystalline limestone or calcareous siltstone and hence inorganic in origin. Wing recognized the conglomerate beds as such and separated them from the "trilobite beds" (Dana, 1877, p. 343). Conglomerate beds are well developed on the small protuberance of the west shore of Thorp Point, and the pebbles seem to have formed penecontemporaneously with the sedimentary materials in which they are found. The pebbles are discoidal in shape; most lie parallel or subparallel to the general bedding, but some are tilted. The silt-size material of the pebbles occurs in laminae up to .5 mm thick. Text-figure 6 is a sketch of a portion of one of these conglomerates.

Associated with the pebble-bearing horizons both laterally and vertically are horizons in which silty material similar to that found in the pebbles is distributed through the rock in such a manner as to form a meshwork of raised laminae on vertical weathered surfaces. The meshworks attest to the contemporaneity of the pebbles and their enclosing matrix. Some of the intraformational conglomerates grade laterally into sandy, ribbed limestones.

The matrix materials of the conglomerate beds range from microcrystalline calcite averaging .005 mm to calcite crystals as large as .1 mm. Generally, the coarser grain-size is associated with a great abundance of trilobite fragments, even though the finer grained matrix contains many fragments also. Pods or pockets of trilobite fragments lie between some of the pebbles, and fossil-fragmental material forms cement in some instances.

Trilobite fragments border a number of the pebbles, the phenomenon suggesting that the silty material filled the concave side of the fragment which was then rolled around by water currents. Other pebbles are bordered by a rusty rim, and a few of the pebbles seem to have black, opaque rims which are thought to be composed of pyrite since the rim material is similar to the opaque black, square-shaped specks which are observed in thin sections of some of the limestones and which are believed to be pyrite.

Some of the beds within the Thorp Point member are dolomitic, varying from silty, calcitic dolostones to silty dolomitic limestones. Because of the very fine grain-size of these rocks, they are difficult to recognize without utilization of an etched polished surface. Thin, probably lenticular, ill-defined, horizons of dolostone occur in the limestones. These horizons are only a few millimeters thick, or a centimeter at the maximum, and can be recognized on a fresh break by their olive-gray (5Y5/1) or greenish-gray (5GY4/1) color which contrasts with the medium dark-gray to dark-gray (N4 to N3) or dark bluish-gray (5B3/1) color of the rest of the rock. Microscopic isolated rhombs and clusters of rhombs of dolomite are common in many of the limestones of the Thorp Point.

Near the top of the member light bluish-gray-weathering, sublithographic and finely crystalline limestones appear. They resemble the limestones that make up the upper part of the formation, but seem to be of limited thickness, and probably do not extend far laterally. These limestones carry the cephalopod and gastropod fauna of the Thorp Point while the darker sandy beds carry trilobite and brachiopod remains almost exclusively. Outlines of small gastropods may be observed on weathered surfaces of silty and shale laminae between the massive limestone beds.

The member is well displayed adjacent to the Thompson Point road at the north end of Thorp Point where the west-facing bluffs of the ridge are formed by the "ribbed" limestones. The ribbing is not so prominent along the west shore of Thorp Point, but it is present to a greater or

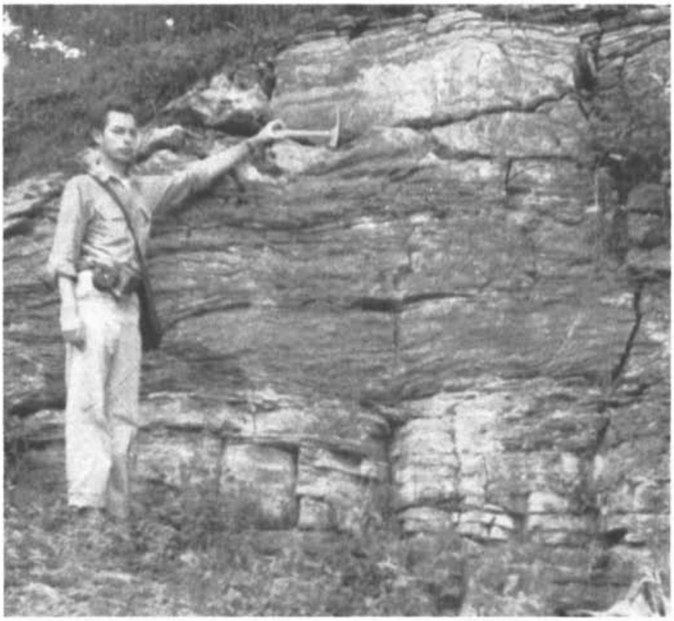


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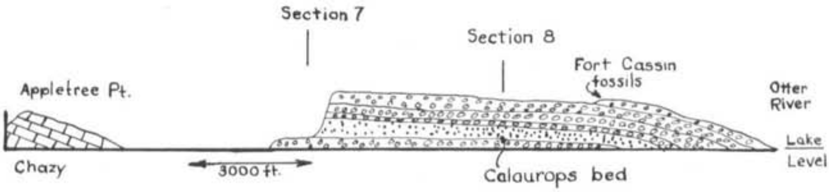
PLATE 7

Figure 1. Cassin formation, contact between Thorp Point and Emerson School members. Hammer rests on contact. South side small cove in west shore Thorp Point, approximately 5750 feet S. 37° E. of Cedar Island.

Figure 2. Typical sandy limestone of Thorp Point member, Cassin formation; Thorp Point, approximately 5500 feet S. 70° E. of Cedar Island.



Text-fig. 7. Fort Cassin headland viewed from lake (after Whitfield, 1890), showing position of measured sections.

lesser degree, depending upon the vagaries of weathering. Figure 2, Plate 7 illustrates the typical outcrop adjacent to the Thompson Point road.

The only other known outcrop of the Thorp Point member is at the type locality of the Cassin formation. On the northwest corner of the point the ribbed limestones are prominent and can be traced southward until they disappear beneath the lake midway between the north and south ends of the headland. The ribbed limestones farther south on the headland are recurrences of the ribbed limestone in the overlying member.

The top of the Thorp Point has been placed at the base of the *Calaurops*-bed (Whitfield, 1890) in the Fort Cassin area, for the bed containing the outlines of *Calaurops lituiformis* Whitfield seems to mark cessation of important sand and silt deposition and the beginning of predominant limestone and dolostone deposition. The *Calaurops*-bed has not been recognized as such at Thorp Point, although *Calaurops* is reported by Brainerd and Seely (1890b, p. 17) in the sandy, ribbed limestones on Providence Island to the north. *Calaurops* has been found at Thorp Point at localities 81 and 350. The former locality is within the Emerson School member and the latter is in the Thorp Point member.

Text-figure 7 is based on Whitfield's sketch (1890) and is a view of the Fort Cassin area seen when one looks eastward from the lake to the west face of the headland. The Fort Cassin collections described by Whitfield (1889; 1897) came from about 15 feet above the *Calaurops*-bed. The author has placed on the sketch the positions of the two measured sections given in this report.

Emerson School Member (new name)

The name of the member is taken from the abandoned school at the intersection slightly over a mile S. 75° E. of Cedar Island. The type section, displaying a total of 101 feet of limestones, is at the north end of the ridge running northeastward from Thorp Point proper, about 50 yards south of the Thompson Point road. The base of the member is about a quarter of the distance from the crest of the ridge to the adjacent low area on the east side of the ridge. Details of the type section are given as Section 10, Appendix I. Section 9 is considered a supplemental section.

While the exposures of the lower part of the member in the area chosen for the type section are somewhat less perfect than the exposures at the lake shore to the south, the top of the formation, or beds near the top, crop out north and east of the Emerson School Intersection and are overlain by the lowest dolostones of the Bridport formation. The contact between the Thorp Point and Emerson School members on the south side of the small cove on the west shore of Thorp Point (Section 9) is illustrated in Figure 1, Plate 7.

Away from the lake shore the only outcrop of the Cassin formation is on the small hill approximately 2 miles west-southwest of Buck Mountain where ribbed sandstones interbedded with fossiliferous, light bluish-gray limestones crop out. The lithology suggests that the beds belong to the Emerson School member, and the ribbed sandy limestones of the outcrop suggest a position low in the member.

The light bluish-gray (5B8/1)-weathering shaly and silty limestones of the Emerson School member contrast sharply with the underlying silty and sandy limestones of the Thorp Point. Generally the upper limestones are dark-gray (N3) to dark bluish-gray (5B3/1), sublithographic with a conchoidal, chert-like fracture. Many contain macerated fossil fragments, if not well-preserved forms. In beds with abundant fragmental material the texture is usually fine- to coarse-grained, and the fossil fragments are held together by a cryptocrystalline "mush" of calcite crystals. Cellulose peels and etched surfaces of the limestones reveal that many of these rocks are composed of recrystallized fossil fragments up to .25 mm and ovoid or subspherical masses composed of .001- to .005-mm calcite grains. Many of the masses have iron-stained rims; others possess rims lighter in color than the interior. None of these masses exhibit an oölitic structure, but rather each seems to represent an aggregation of minute carbonate crystals which was moved around the ocean floor prior to deposition. The color difference between the masses and the surrounding matrix sets them apart, even when the cementing material is of like composition.

If the fragmental material has been comminuted or is not abundant, the texture is very finely crystalline to lithographic. In these latter limestones the bulk of the rock is composed of .001- to .005-mm calcite grains. Isolated, irregular-shaped masses composed of the ± .005-mm grains may be set between coarser grains, but the bulk of the rock is composed of very fine grains with the coarser grains occurring either as isolated crystals or in small clusters. Dolomite rhombs up to .25 mm are scattered through this rock type and are also concentrated in areas up to 4 to 5 mm long and 1 to 2 mm thick. Films of silt-size quartz particles ± .02 mm thick often separate individual dolomite rhombs in the clusters and small masses. Rounded, frosted quartz grains .1 to .2 mm in diameter appear in some of the limestones, and a few of the larger quartz grains are coated with .002- to .003-mm angular pieces of quartz.

Irregularly distributed through the massive limestones are black, .1-inch laminae composed of angular, silt-size quartz grains. The laminae protrude on weathered vertical surfaces. Individual laminae branch and anastomose so as to convey the impression of a series of irregular chain links. On a bedding surface the silty laminae are interrupted by upward protrusions of limestone through them. It would seem that the surfaces on which the silty laminae were deposited were irregular and that in most instances the deposition of the limestone and silty laminae was essentially simultaneous with brief periods when the detrital material predominated.

The distribution of the silty laminations in the limestones and the general appearance of the limestones themselves combine to make these beds very similar to some beds of the Crown Point formation. Without the aid of fossils and/or stratigraphic position, the Emerson School member and the Crown Point can easily be mistaken for one another.

Thin bands of intraformational conglomerates are occasionally found where the bluish-gray lithographic and sublithographic limestones are replaced by finely crystalline, silty and sandy limestones, but these conglomerates are less prominent in the Emerson School member than in the Thorp Point member. Black chert is a common component in some of the lithographic and sublithographic, conchoidal-fracturing limestones, occurring as irregularly shaped nodules and larger masses. As far as has been determined the chert is a primary constituent of the rock.

Dolostone, generally calcitic, is another rock type found in the Emerson School member. The dolostones display a vitreous luster on a fresh break and may on occasion be easily mistaken for a very fine-grained sandstone. One specimen from near the end of Thorp Point consists of .1- to .15-mm rhombs of dolomite with films of quartz silt separating some of the rhombs and with quartz silt irregularly distributed through the rock. The quartz forms darker "splotches" on whitish, acid-etched surfaces of the rock. In general appearance this particular dolostone resembles many of the slightly silty dolostones of the Whitehall and Cutting formations.

On the northeast corner of the Fort Cassin headland the shaly and silty, light bluish-gray-weathering limestones of the Emerson School member overlie and are interbedded with limestones containing less detrital material and with dolostones (Section 7). Several local disconformities are exposed along the north shore. One of these is figured by Foyles (1923) who considered that it represented the "unconformity" between the Chazy and the Trenton. He assigned the black shaly limestone to the Trenton and the underlying beds to the Chazy on the basis of a "restudy" of the fossils. This particular surface is an erosion surface as is demonstrated by close examination of the very fine lines in the dolostone (top is at 61.6 feet in Section 7) beneath the limestone. However, the interruption in deposition was apparently only local and short-lived, being of diastemic proportions. The irregular surface is reflected by the apparent warping of the silty limestone overlying the surface. However, it can be demonstrated that the apparent warping is in fact the initial dip of the limestone, the inclination being developed as the lime-rich sediments came to rest on the irregular surface. A similar irregular surface separates the dolostone from the underlying limestone.

Outlines of small nautiloids may be observed on the weathered surface of limestone with black silty partings. Casual observation suggests that they are gastropods, but close examination discloses the presence of septa.

The contact between the two members of the Cassin formation is gradational and is placed where the light bluish-gray-weathering beds typical of the Emerson School first appear, although the light coloration seems in part a function of the nature of the exposure in the lower part of the member. The sections from Thorp Point and from the center of the headland at Fort Cassin (Sections 8, 9, 10) provide details of the transition. The base of the Emerson School member is placed about 2 to 3 feet below the top of the bluff which marks the south boundary of the small cove on the west side of Thorp Point (Figure 1, Plate 7). The choice of the exact location of the contact is somewhat arbitrary, and the contact might almost as well be located about 3 feet lower.

Comparison of the sections from Thorp Point and from the center of the Fort Cassin headland indicates that the change from the Thorp Point member to the Emerson School member is marked by changes in lithology, changes which can not be correlated on a bed for bed basis. Light-weathering lithographic limestones do not seem to be generally present in the Thorp Point member, but ribbed silty and sandy limestones like those characteristic of the Thorp Point appear in the Emerson School member.

While the typical lithographic and sublithographic limestones of the Emerson School do not always appear immediately above the contact, the weathering characteristics of the beds comprising the two members seem to delineate the contact. The Thorp Point beds generally weather in shades of dark-gray or dark bluish-gray. These colors contrast with the lighter bluish-gray tints of the weathered surfaces of the Emerson School beds. The contrast is not in all instances sharp or well delineated, but it is, rather, one of a mass effect of the surfaces at or adjacent to the contact.

As shown by the several measured sections, there lies between the ribbed limestones of the Thorp Point and the shaly or silty laminated limestones of the upper part of the Emerson School member a sequence in which dolostones, ribbed, silty and sandy limestones, and light-gray lithographic to sublithographic limestones appear. Study of the Emerson School member on the west face of Fort Cassin point demonstrates the rapid lateral variations of lithology which are present in the lower part of the unit. For example, near the south end of Fort Cassin point à ribbed limestone resembling beds found in the Thorp Point member passes northward into limestone lacking ribbing and into nodular-weathering limestone. This bed lies above the *Calaurops*-bearing bed. Also dolostones grade laterally into relatively pure limestones of various textures, and some of the thicker, more massive dolostone beds have within their boundaries layers of blue-gray, fossiliferous limestone 2 to 4 inches thick. Many similar features are present in the sequence from above the *Calaurops*-bed, and while less conspicuous in the Thorp Point area, the lateral changes are present nonetheless.

Fauna

While the fauna found in the Cassin formation is known chiefly from the Fort Cassin locality, it does occur elsewhere. It is found at Thorp Point, and Brainerd and Seely (1890b, p. 14) list a few forms from this locality. Forms found at Thorp Point during the present investigation are given in the faunal lists of Appendix II. The writer made no collections in the Fort Cassin area. The isolated outcrop approximately 2 miles west-southwest of Buck Mountain has yielded a fauna like that found in the Fort Cassin and Thorp Point localities (locality 455). Brainerd and Seely (1890b, p. 17) also report the existence of the Fort Cassin-type fauna on Providence Island.

Ecology has played its role in the distribution of the faunas. Trilobite remains are concentrated in the dark-gray-weathering, more sandy limestones of both members while the cephalopods and gastropods are more closely associated with the light bluish-gray-weathering sublithographic to lithographic relatively pure or slightly silty limestones. Aside from ecologic control on distribution, there is no readily discernible difference in the faunas of the two members.

Butts (1941, p. 118–119) points out the wide geographic distribution of the fossils that are used to define the *Lecanospira* zone and the younger *Ceratopea* zone, the top of which seems to be characterized by the Cassin-type fauna. The two zones are inferred to be present in Scotland, Newfoundland, Quebec, and the Champlain Valley, central Pennsylvania, and Virginia, and also westward in Missouri and Arkansas. Beds containing *Lecanospira* do not outcrop in the Central Champlain Valley. The zone is thought to range through the limestones and dolostones of the lower half of the Bascom (Brainerd and Seely's "D-1" and "D-2") (1890b; Cady, 1945, p. 547), the Cutting below falling into the *Ophileta complanata* zone as noted before.

Theoretically the *Ceratopea* zone overlies the *Lecanospira* zone (Butts, 1941), but the fact that the upper part of the Ogdensburg formation seems to contain forms that correlate it with the Cotter fauna which seems to fall within the *Ceratopea* zone (Cady, 1945, p. 546) suggests that the two zones may overlap to some extent or that their "index fossils" may have longer ranges than currently thought.

The *Eurystomites kellogi* zone (Cady, 1945, p. 545), forming the upper part of the more widely conceived *Ceratopea* zone, is represented in the Cassin formation of the Central Champlain Valley and the upper part of the Bascom formation (Cady, 1945). Within the Central Champlain Valley evidence concerning the possible upward extension of the zone into the Bridport as suggested by Cady (1945, p. 547) is not known. The answer may lie to the east in the limestones of the Beldens formation which are equivalent to the dolostones and limestones of the Bridport.

Part of the fauna found in the Cassin formation has been obtained from the Smithville formation of Arkansas and the upper part of the underlying Powell, in all or part (Schuchert, 1943, p. 844). Butts (1941, p. 118–119) correlates the Cassin with the uppermost part of the Beekmantown group in the Appalachian Valley of Virginia. The Ogdensburg formation north of the Adirondacks seems to lie somewhat lower than the Cassin formation, correlating roughly with the lower part of the Bascom of West-Central Vermont (Cady, 1945, p. 546; Twenhofel and others, 1954). Fisher (1954, p. 92) notes the possible equivalence of the Ogdensburg formation with the Cranesville formation of the Mohawk Valley, suggesting that the two may correlate with the Jefferson City formation of Missouri. Such a correlation places the Cranesville beneath the Cassin formation. Finally Cady (1945, p. 546) correlates the Emerson School member of the Cassin formation, or the upper Bascom ("D-4"), with the Solomons Corner beds of the Phillipsburg slice in southern Quebec.

Adjacent to the area covered in this report *Lecanospira*-bearing beds have been reported from the Willsboro quadrangle as has the Cassin formation, both as restricted here and in the broader sense of Cushing (1905) (Buddington and Whitcomb, 1941, p. 72–73). Kemp and Ruedemann (1910, p. 66) report the presence of the sequence found at Shoreham from the Port Henry quadrangle, although they do not give any thickness data. Beds apparently containing elements of the Cassin fauna, lithologically similar to those in the Central Champlain Valley, and in a similar stratigraphic position outcrop in the Fort Ann and Whitehall areas, being approximately 150 feet thick (Billings and others, 1952).

Beds containing the *Eurystomites kellogi* fauna are approximately 200 feet thick in southeastern Shoreham (Brainerd and Seely, 1890b). At Ellsworth Ledge in Cornwall (Dana, 1877, p. 344) measurements indicate a thickness of approximately 100 to 120 feet for the Thorp Point member and a value possibly exceeding 150 feet for the Emerson School member equivalent of the Bascom formation (see Section 11, Appendix I). Wing's (Dana, 1877, p. 66) "*Ophileta*" beds include the Cutting and the lower two units of the Bascom; beds "5a" and "5b" are the ribbed sandstone of the Thorp Point member, and the "5c" beds are the Emerson School member equivalent. In this general region the uppermost, slaty and silty limestone beds of the Bascom grade into the Bridport without a break; there is simply a change from the limestone to the dolostone. Below, the section seems uninterrupted from the C-2 unit of the Cutting through the uppermost unit of the Bascom. At Thompson Point the beds of the zone are 207 feet thick; this value may be low since the base of the Cassin formation has not been recognized. On Providence Island the exposed thickness of the Cassin formation is 179 feet (Brainerd and Seely, 1890b). An estimated 200 to 250 feet of the Cassin formation is exposed on the coast of Willsboro Point, S. 25° E. of Ligonier Point. Both the Thorp Point and the Emerson School members are represented, and a Cassin-type fauna is present south of the neck of Willsboro Point (Buddington and Whitcomb, 1941).

Rocks representing the *Lecanospira* zone thin north-northwestward to less than 100 feet on the north side of the Adirondacks (Cady, 1945, p. 547; Chadwick, 1920, p. 238–243). However in the Canton, New York quadrangle they are overlain disconformably by the succeeding Beekmantown rocks (Chadwick, 1920). In the Whitehall-Fort Ann area rocks of this time ("Great Meadows" and "Smith Basin" formations) total 200 feet (Billings and others, 1952). If all the Cutting at Shoreham, and elsewhere, be viewed as belonging in this zone, then it is 350 feet thick here (Brainerd and Seely, 1890b). At Ellsworth Ledge in Cornwall the incomplete section (Section 11) exposes more than 350 feet of beds assigned to this zone; the top of the C-1 unit of the Cutting is exposed possibly at the base of the west-facing slope up which the lower portion of the section was measured. In the Central Champlain Valley the estimated thickness of the zone is 640 feet, including an estimated 200 feet of covered beds which are correlated with the lower Bascom east of the thrust belt and 440 feet of Cutting at Thompson Point. The thickness is somewhat less if the lower part of the Cutting cannot be assigned to the zone.

Bridport Dolostone (Cady, 1945)

The name Bridport was assigned to the exposures of dolostone and smaller amounts of limestone that lie in the southeastern part of the town of Bridport, Vermont (Cady, 1945, p. 540); this formation corresponds to the "Division E" sequence of the "Calciferous" as defined by Brainerd and Seely (1890b, p. 3). Ulrich (in Ulrich and Cooper, 1938, p. 26) applied the name Providence Island limestone to equivalent beds exposed on Providence Island south of South Hero Island in northern Lake Champlain. Since only about 57 feet of the unit is exposed here (Brainerd and Seely, 1890b), it seems better to use the name Bridport for the exposures in the Central Champlain Valley as the formation is more typically exposed in Bridport than on Providence Island.

Within the Central Champlain Valley the Bridport is easily differentiated on the basis of its weathered surfaces, general massive, moderately thick (1 to 3 feet) beds, and the thin to moderately thick laminated limestones that are interbedded with the dolostones. Black, noncalcareous shale is also present within the formation in beds up to several feet thick; black calcareous shale is locally present.

Some variations of the formation are described in Section 12, Appendix I. Weathered surfaces range in color from dark yellowish-orange (10YR7/6) to pale-orange (10YR8/2) to yellowish-gray (5Y8/1) and light bluish-gray (5B7/1 to 5B8/1). Characteristic of the weathered surfaces of the dolostone beds are the minute grooves which cut across the surface of the rock, sometimes in a rectangular pattern, sometimes in a haphazard manner. Where the dolostones are darker weathering, Wing's description of the beds as "thread-scored bees wax" (letter to James Hall, cited in Cady, 1945, p. 550) is particularly apt. The scoring is always a prominent feature of the yellowish-gray or pale-orange beds, but it seems less prominent in the bluish-gray-weathering dolostones.

The Bridport dolostones are for the most part unlike any of those comprising the lower formations of the Beekmantown group. Not only are the weathered surfaces of the beds of this formation distinctive, but fresh surfaces differ from those of the rocks in the lower sequence. The lower beds usually exhibit a more "friable" and/or earthy appearance compared to the dense, somewhat vitreous appearance of the Bridport dolostones. Moreover, the dolostones of the Bridport seem to be finer grained and seem to lack the light, grayish films of quartz silt found between the dolomite rhombs of many of the lower dolostones. The textures of the weathered surfaces differ also; the Bridport seems characterized by weathering textures which remind one of the very finest grade of sandpaper while the textures of the lower Beekmantown dolostones appear more like that of fine to medium grades of sandpaper. A more common and intense scoring of many of the Bridport dolostones is another differentiating factor. Weathered surfaces of some of the bluish-gray-weathering dolostones may be aptly described by the term "elephant-skin."

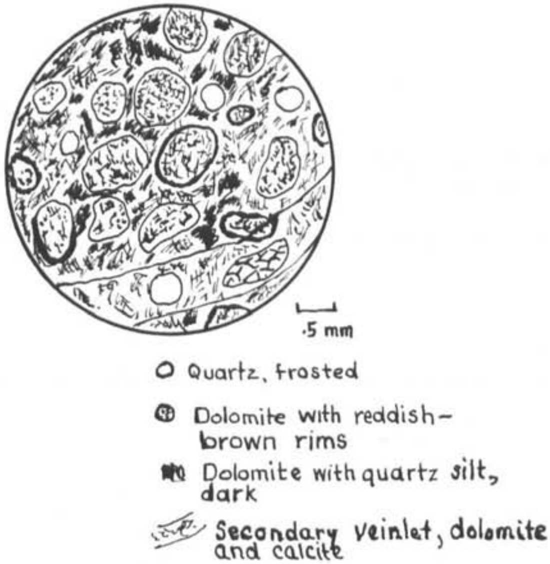
Bridport dolostones are characteristically dark-gray to black and very finely crystalline to sublithographic. Average grain-size is of the order of .01 mm; some of the dolostones are coarser, but many are composed of dolomite rhombs between .005 and .01 mm. Many of the beds are extremely silty; both silty dolostones and dolomitic siltstones are important components of the formation. In those rocks with only a very small percentage of silt, the silt is distributed in fine wisps and .1-mm laminae. White quartz veinlets are common. Like the other dolostones of the Beekmantown group those of the Bridport are fetid, although not as strongly so perhaps as the older ones.

Small amounts of clear, angular, .05-mm quartz grains are scattered evenly through some of the dolostones. The very finely crystalline dolostones exposed approximately 1.7 miles S. 60° W. of the airway beacon on Snake Mountain contain rounded, frosted .5- to 1.0-mm quartz grains both as small bands approximately 1 inch thick and as scattered grains. Associated with the larger quartz grains are clear, angular .02- to .05 mm grains of quartz similar to those found in other dolostones. These beds also contain .5- to 1.0-mm rounded areas of dolomite rhombs with quartz silt rims (Text-figure 8), a relationship suggesting the precipitation and subsequent coagulation or aggregation of the carbonate rhombs into clusters followed by rolling of the aggregation along the bottom.

The light bluish-gray-weathering, scored dolostones are pure, very finely crystalline to sublithographic, and are usually light-gray or light bluish-gray on a fresh surface. Most display a vitreous or sparkling luster on a freshly broken surface. Typically many of these dolostones possess small (± .25 inch) very light buff-weathering dolomitic patches and small masses which stand slightly above the bluish-weathering material on a weathered surface. A few thin intraformational conglomerates have been observed in the lighter weathering beds of the Bridport.

Forming an important component of the Bridport formation are beds whose fresh surface is mottled in shades of dark- and medium-gray. Microscopic examination of several samples of this type of material revealed that the darker gray, angular-appearing areas are surrounded by a lighter colored matrix. The angular-appearing areas range in size up to 5 mm, but the average size is somewhat less. Etched samples showed that the corners of the angular-appearing pieces are rounded in many instances and that the smaller ones display a circular or elliptical cross-section. In some instances the darker areas are slightly more silty than the matrix material, and some are surrounded by thin films of quartz silt. Also the darker bodies appear to be slightly more coarsely grained than the matrix, even though the average grain-size of both is nearly the same.

The dark, angular and subrounded pieces may comprise up to 60 per cent of a handspecimen. Differential weathering leaves the darker areas slightly higher than the matrix areas. The gash-like and longer veinlets which give rise to the brecciated appearance of the weathered



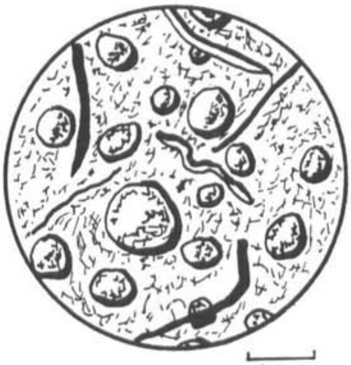
Text-fig. 8. Bridport dolostone. Subspherical masses of .01- to .05-mm dolomite grains; some of masses are coated with reddish-brown rims; dark-gray matrix of .01- to .05-mm dolomite grains with up to 10% quartz silt. Sketched from etched surface. Bridport outcrop approximately 1.5 miles southwest of airway beacon on Snake Mountain.

surface of the mottled as well as some of the unmottled, light-weathering dolostones cut indiscriminately across both the lighter and darker areas. On a weathered surface it is difficult to differentiate the mottled rocks from those which have been broken by tectonic activity. In both cases there are slightly raised areas which in the case of the mottled material correspond to the darker component.

From the relationships observed it seems most likely that the mottled rocks represent conditions in which partly consolidated dolostone was broken by currents or other submarine phenomena and then cemented with similar material. These rocks can then be looked upon as sedimentary breccias.

Some of the silty dolostones occasionally contain small circular areas with a mass of dolomite rhombs in the center surrounded by a layer of brownish silt (Text-figure 9).

The mottled beds generally weather pale yellowish-gray (5Y9/1) to very light bluish-gray (5B8/1), whereas the dark-gray to black beds weather in shades of yellowish-orange or yellowish-brown. Associated



Text-fig. 9. Etched surface of Bridport dolostone showing raised, subspherical, silt-rimmed, silty masses of dolomite crystals set in slightly finer grained dolomite. Veinlets of secondary calcite and quartz. Knob 1.75 miles N. 85° E. of Cedar Island.

with these latter beds are black, platy laminae and films of quartz silt. Where these quartzitic layers are more than a few tenths of a millimeter thick, they stand up on the weathered surfaces. The lighter weathering beds of the formation seem to lack the detrital material represented by the black laminae. Clear, angular quartz grains up to .03-mm occur scattered through some of the other dolostones.

The silt distributed through the dolostones is at the lower end of the silt-size range, and in many cases the fine material is in the clay-size range. This detrital component of the dolostones provides the yellowish-orange pigment of the weathered surfaces, a higher silt content being accompanied by a darker or deeper yellowish-orange coloration. On surfaces etched with dilute hydrochloric acid the silt appears as dark honey-colored raised areas. The silt may be distributed through the rock more or less uniformly or may be in definite laminae a few tenths of a millimeter thick. Insoluble residues of these dolostones are composed of ± .005-mm quartz. They are medium dark-gray to olive-gray (N4 to 5Y4/1) and are barely palpable when rubbed between the fingers.

Black, thin-bedded, easily cleaved, noncalcareous shale is interbedded with the dolostone beds. In places the shale beds are as much as 3 feet thick; however, individual shale layers are more commonly only a few inches thick. The shales are composed of very fine silt-size and clay-size quartz fragments, and argillaceous material seems to be at a minimum. The material of the shales is like that forming the black, platy partings and irregular laminae within the dolostone beds. A few of the shales are calcareous. Most of these are associated with the limestones of the formation.

Dolostones closely associated with the shales weather yellowish-orange and pale-orange (10YR7/2) and are black and silty as well as moderately to heavily scored. Some of the associated beds are actually dolomitic siltstones, but because of the very fine grain-size and dark color of the dolostones, the determination can be made only by etching a fresh surface with dilute hydrocholoric acid. The massive, thick-bedded dolostones usually do not exhibit cleavage, but where there are a number of thin shale interbeds or a large amount of the shale distributed through the dolostone beds, fracture cleavage appears, and bedding is obscured. Moreover, the dolostone in these circumstances is thin-bedded.

While the exposures and the nature of their distribution do not permit positive conclusions regarding the distribution of the shales and silt in the Bridport, there does seem to be a tendency for the clastic material to increase in relative importance toward the top of the formation. The trend is not clear-cut, but in the exposures approximately a mile N. 70° E. of Cedar Island, in Charlotte, and again in the exposures approximately 2 miles S. 20° W. of Buck Mountain, there seems to be a definite increase in the silt content of the Bridport toward the top of the formation. Elsewhere the shale content increases toward the top of the formation. Similarly in the exposures south of the mouth of Kimball Brook in Charlotte, the upper dolostones are more silty than those below the middle of the section; thin shale horizons are more abundant towards the formation's top also.

The thin-laminated limestones interbedded with the dolostones of the Bridport weather a distinctive bluish-gray color (5B8/1 to 5B5/1). Most of the limestone beds are only a foot thick, and individual limestones are separated from one another by dolostone beds. In the area south of Kimball Brook in Charlotte, limestone bed sequences several feet thick lie exposed between the massive beds of the drab-weathering dolostones. Elsewhere the limestones occur not only as well-defined beds extending some distance laterally, but also as small pods completely enclosed by dolostone.

Even in localities where the formation has not been intensely sheared, many of the limestones present a sheared and slightly marbleized aspect. The limestones are for the most part black to dark bluish-gray and are sublithographic to lithographic with a chert-like fracture; their average grain-size appears to be in the range of .001 to .005 mm. Thin, silty, black laminae which cause a "chained" appearance on the weathered surfaces of the limestones and which are similar to those so characteristic of the Crown Point limestone are rare components of the limestones.

Many of the limestones contain fragments of brachipoods, trilobites, and gastropods, and from the overall relations observed in both the field and the laboratory, the limestones represent an abundance of fossil fragments which accumulated in a lime mud. Small channels and cross-lamination have been observed in a few of the limestones.

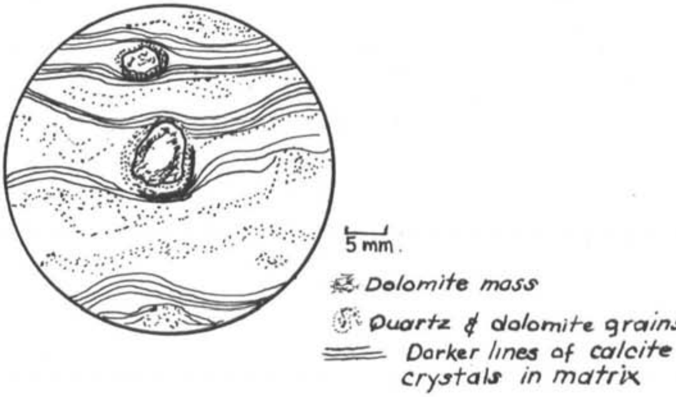
Black, silty limestones containing varying amounts of .005- to .01-mm angular quartz grains set in a matrix of .001- to .005-mm calcite grains are interbedded with the Bridport dolostones in several places. The best exposures of this type of limestone are on Sloop Island, which is west of Wings Point in Charlotte, and along the coast south of Kimball Brook. Associated with this type of limestone are the calcareous shales of the same general appearance.

Within a few of the massive dolostone beds 1-inch laminae, or bands, of bluish-weathering limestone occur. Physically there is a complete intergradation between these laminae and the surrounding dolostone, and no interruption in the massiveness of the dolostone bed is caused by their presence (see Section 12).

Small (less than 1 inch), wisp-like and irregularly shaped, buff-weathering masses are found in the typical limestones of the Bridport. On etched, polished surfaces of the limestones these masses are seen to be clusters of dolomite crystals around which the adjacent calcite crystals warp or swirl. (Text-figure 10 illustrates such an occurrence.) This relationship suggests that the dolomite crystal clusters formed first and that they were either rolled along the bottom or that the surrounding calcite crystals were moved into position around the earlier formed dolomite bodies. All of the evidence cited points to a penecomtemporaneous precipitation of the dolomite and calcite crystals.

The dolomite content is sufficiently high in some of the limestones so that the appellation dolomitic limestone is appropriate in describing them; conversely some of the lighter colored dolostones contain greater than 10 percent calcite and can then be termed calcitic dolostones. These two lithologies represent but a minor portion of the Bridport. In sections where the limestones are the dominant lithologic type, silt-rich dolostone beds may lie between limestone beds; some of the limestone beds may be separated by only .5- to 1-inch dolostone beds and laminations. Within the limestones buff-weathering, irregular masses of dolomite crystals may occur; in a few cases these are outlines of fossils.

A second general trend is an eastward increase in the limestone content



Text-fig. 10. Bridport dolostone, clusters and aggregates of dolomite crystals in .05-mm to .01-mm calcite matrix. Quartz grains form laminae around larger aggregates. Dark-and light-gray lines in calcite matrix show effects of currents in distributing the grains and the adaptation of matrix material to earlier formed, silt-rimmed dolomite aggregates. Based on cellulose peel and etched surface of specimen from 1 mile northeast of Cedar Island.

of the formation. The exposures of the formation nearest the Champlain Thrust seem to contain a higher percentage of the light bluish-gray-weathering lithographic and sublithographic limestone than the exposures farther west. Exposures of the Bridport on Pease Mountain and approximately 2 miles south-southwest contain relatively large amounts of limestone; perhaps as much as 50 percent of the formation is limestone in these localities. Significant quantities of Bridport limestone outcrop on Marsh Hill, northeast of Vergennes also. An upward as well as an eastward increase of limestone is inferred from the outcrops in the area.

All of these exposures lie in thrust slices west of the Champlain Thrust and have been transported westward an unknown distance. However, an eastward increase in limestone is to be expected in view of the fact that the Bridport and the limestone and marble-bearing Beldens are correlatives (Twenhofel and others, 1954; Kay, 1958).

It would seem then, that the easternmost outcrops of the Bridport represent a transition zone from the Bridport to the Beldens with a complex interfingering of limestone, dolostone, silty dolostone, and dolomitic silt both horizontally and vertically. Work more detailed than that undertaken in this investigation is required to provide a complete picture.

The intimate interbedding of the limestone, the dolomitic materials,

PLATE 8

Figure 1. Limestone (in foreground) and dolostone (in background) of Bridport dolostone; 5200 feet N. 5° E. of Otter Creek bridge on Route 17.

and the silts seem to preclude a secondary origin for the dolostones. Generally the contact between individual limestone and dolostone beds is sharp, although some of the contacts are slightly irregular or undulatory with an amplitude of .5 to 2 inches. In other instances the limestone and dolostone beds are separated by thin, black silt partings or thin, very fine-grained quartz sandstone. A limestone bed may be underlain by a yellowish-gray (5Y8/1)-weathering, moderately scored dolostone and overlain by a dark yellowish-orange (10YR6/6)-weathering, silty dolostone with black platy partings. The contacts of the limestone with both the overlying and underlying beds are sharp, and the limestone may contain some thin streaks or streamers of dolomite as well as black silt or shale partings. A small number of beds which seem to be an intimate mixture of limestone and dolostone were observed, although the conclusions regarding these beds have not been confirmed by laboratory

PLATE 8

Figure 2. Bridport-Day Point contact. Light-colored Bridport dolostone beneath darker, thin-bedded limestones of Day Point; approximately 4250 feet N. 8° E. of Marsh Hill, Ferrisburg.

study. Plate 8, Figure 1 illustrates a typical limestone-dolostone exposure.

The northernmost outcrop of the Bridport lies in the thrust slice of Pease Mountain in Charlotte. Southward the Bridport appears in other thrust slices beneath the main Champlain Thrust and in small blocks and belts of folding adjacent to the Champlain fault. It is easily differentiated from massive beds of the Crown Point formation outcropping adjacent to it because of its general tan- to buff-weathering nature. Where the Bridport has been intensely sheared and has an important limestone component, differentiation of the two formations is occasionally difficult.

Away from the thrust fault the Bridport outcrops north and east of Thompson Point, along the shore from the mouth of Kimball Brook south and east of Thompson Point, southward to Grosse Point. It reappears along the shore south of Kellog Bay. Isolated outcrops appear

PLATE 8

Figure 3. Upper part of Day Point, Summer Point area (Section 15); coast approximately N. 45° E. of Mile Point, Ferrisburg.

between Ferrisburg and Vergennes and west of Snake Mountain. The largest outcrop belt lies approximately 1 mile southeast of Arnold Bay.

The complete sequence from the base of the formation to its top is nowhere to be seen; the base is exposed northeast of Thorp Point (see Section 10) in western Charlotte; the top may be observed in a number of places. While the base of the formation is not exposed in the area north of Thompson Point and east of Converse Bay, this outcrop area probably represents the most complete exposure of the formation. Several minor folds within the Bridport at this locality complicate the understanding of the sequence. East of the north end of Thorp Point a large part of the formation is covered and the top can only be approximated. Exposures along the lake shore south of Hawkins Bay and those southeast of Arnold Bay are near the top of the formation. The stratigraphic position of the portions of the formation in the thrust slices can only be estimated, but many of these are near the top of the formation also.

Because of the absence of a complete, continuous sequence of the Bridport, the thickness can be estimated only. Northeast of Thorp Point the estimated minimum thickness is 400 feet.

If Dean Island is the approximate base of the formation and there is no folding between the islands and the shore, the thickness based on outcrop width and average dip is 450 feet.

Both of the figures cited above are to be regarded as minimal values; it is thought that the total thickness of the formation closely approximates the 470 feet found in the eastern Shoreham section by Brainerd and Seely (1890b, p. 3). South of the Central Champlain Valley area, in the Ticonderoga area, Rodgers (1955) reports an estimated thickness of 400 feet for the Bridport equivalent in the New York portion of the Ticonderoga quadrangle.

One characteristic of the Bridport is the minor folding associated with it in exposures away from known thrust faulting. Several small, shallow folds appear in the formation north of Thompson Point and along the lake shore south of Kimball Brook, near the Addison-Chittenden County line. The folding seems restricted to the Bridport and is not reflected in the underlying or overlying beds. Some of the fold axes strike at right angles to the regional strike of the beds while others approximately parallel the regional strike of the formation. As far as can be determined the Chazy beds overlying the Bridport in the folded areas do so with no apparent structural discordance. The formation is structurally conformable on the Cassin formation, a relationship which Cady notes also for West-Central Vermont, reporting that there is no "stratigraphic break" between the Bascom and the Bridport (1945, p. 543).

Age and Correlation

While there are a number of limestones with fossil fragments in the Bridport, material suitable for identification is extremely rare. Brainerd and Seely (1890b, p. 6) have reported *Bucania tripla* Whitfield, *Turritospira* ("*Murchisonia*") *confusa* (Whitfield) and *Isochilina seelyi* (Whitfield) from the Shoreham outcrops along with "undescribed species of *Lingula, Malcurites? Murchisonia, Orthoceras, Bathyurus, Cheirurus?*" (p. 6). Whitfield (1890a, p. 38–39) described *Bathyurus glandicephalus* from the same general locality. Brainerd and Seely reported *Isochilina gregaria* (Whitfield) and *Isochilina cristata* (Whitfield) from the Dean Island group as well as an undetermined species of "*Bathyurus*" (Brainerd and Seely, 1890b, p. 16). From Sloop Island near Wings Point the author has collected the following fossils:

Brachiopod fragments
Straparollina? sp.
cf. *Maclurites sordida* Hall
Blastoid sp. indet.
Trilobite fragments
Pelmatozoan columnals

Outlines of *Maclurites*-like gastropods and fossil fragments were noted in a section of the Bridport containing approximately 75 percent limestone and located on the south slope of the ridge approximately 2 miles S. 20° E. of Buck Mountain.

The Bridport correlates with the Beldens formation, limestone, dolostone, and marble, east of the thrust belt in the latitude of the Central Champlain Valley. The Beldens is reported in the Highgate Springs slice of northern Vermont (Kay, 1958). Outcrops of the formation appear in the Ticonderoga quadrangle, both on the New York and Vermont sides of Lake Champlain, where it is reported to be of the order of 400 feet thick (Rodgers, 1955). In the Fort Ann area beds equivalent to the Bridport are chiefly dolostone with limestone becoming more important toward the top (Billings and others, 1952); the sequence here is approximately 200 feet thick. Outcrops of the Bridport-type dolostones are reported from both the Port Henry and Willsboro quadrangles (Kemp and Ruedemann, 1910; Buddington and Whitcomb, 1941); the formation is well exposed along the eastern shore of Willsboro Point between the community of Willsboro Point and Ligonier Point. It is also exposed on Providence Island (Brainerd and Seely, 1890b, p. 17) and on the southern edge of South Hero (Erwin, 1957). The exposures of the formation on the southern tip of Isle la Motte, like those of South Hero, closely resemble much of the dolostone of the Central Champlain Valley area, although these exposures lack the silt and sand found in much of the dolostone farther south. In both regions the dolostones show much evidence of current activity, intraformational brecciation, and rapid variation in relative percentages of dolomite and calcite within individual beds.

Stratigraphic equivalents of the formation are apparently absent in the Mohawk Valley and on the north side of the Adirondacks. The formation has been correlated with the Bellefonte dolostone of central Pennsylvania (Twenhofel and others, 1954), and possibly the upper part of the Romaine formation may correlate with the Bridport (Twenhofel, 1938, p. 32; Twenhofel and others, 1954).

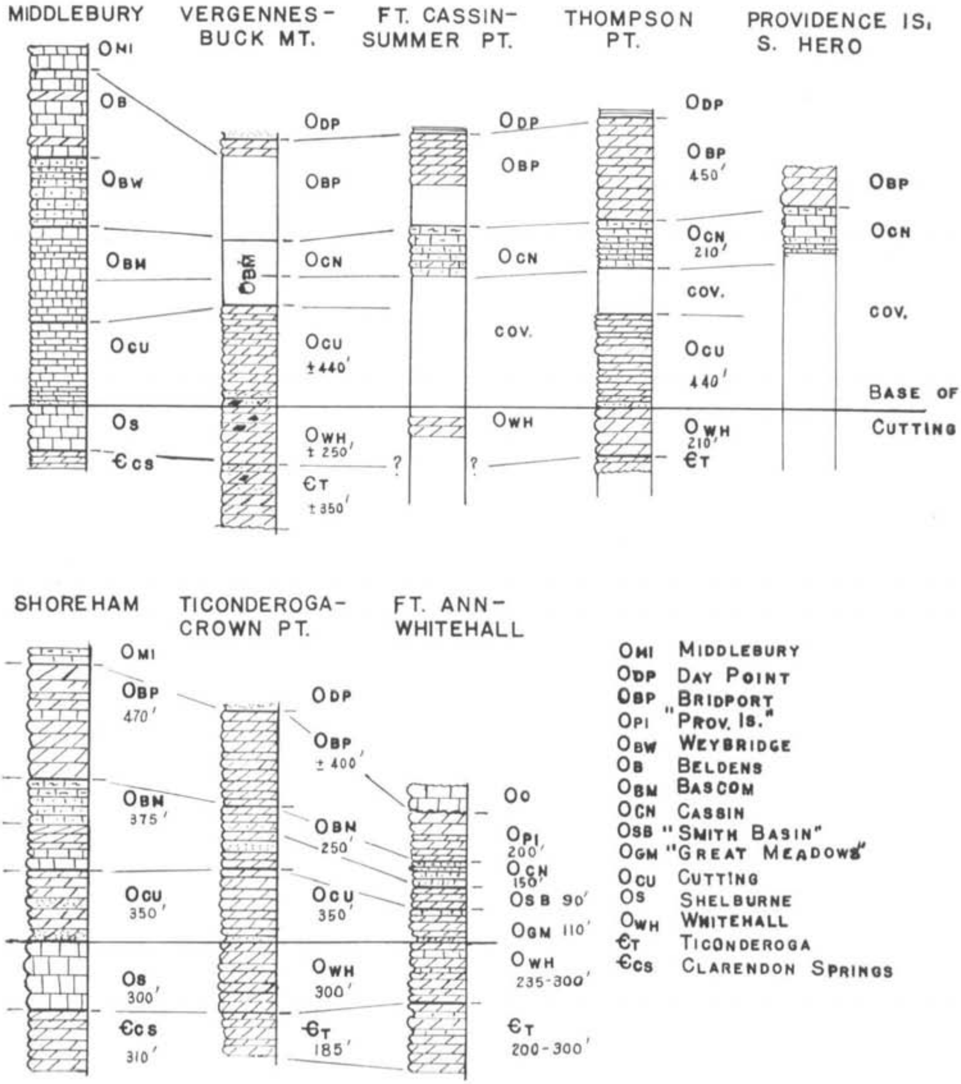
Evidence from fossils found in the formation indicates only that it is of Upper Canadian age; Cady (1945, p. 547) places the formation within the *Eurystomites kellogi* zone. Whether the formation records all of the history of the Central Champlain Valley from the time of the last Cassin-type deposition to the beginning of Chazy group deposition or not, is as yet unanswered. It is probable that it does. All local physical evidence points to continuous deposition from the lower beds into the Bridport, and the evidence along the contact between the Bridport and the Chazy beds suggests that within the Central Champlain Valley the deposition may have been continuous, or essentially so; yet no incontrovertible evidence exists.

Canadian History

Because of the apparent conformability and the general similarity of the rocks of the Ticonderoga dolostone, the history of its deposition will be included with the discussion of the history of the Beekmantown sediments although the formation is apparently of uppermost Cambrian age. However, Shaw (1958, p. 532) suggests that the upper part of its general equivalent, the Clarendon Springs dolostone, may be lowermost Lower Canadian.

Table 3 summarizes the thicknesses of the formations included within this group, and Text-figure 11 shows the regional correlations. From the values given it can be seen that the several formations of the group thin southward and that moderate variations of thickness exist for each formation. This relationship suggests that deposition in the Beekmantown and Ticonderoga seas was not uniform, and that to obtain a true picture of the sedimentation, more detailed knowledge is needed than either this work or earlier works have brought forth. However, it seems apparent that the axial region of deposition lay in the longitude of the present-day Champlain Valley; undoubtedly the axis shifted from time to time through the Canadian, as probably did the margins of the seas. The area is believed to have been moderately stable during Canadian time; the dominance of dolostones and limestones tends to support this concept. Yet the presence of numerous angular unconformities in the Highgate formation (Shaw, 1958) points to crustal instability.

It is likely that the changes in sedimentation began at different times in separate parts of the trough. For some formations the change from one to another may have taken place more or less at the same time, but for others the changes may have progressed outward from one locality



Text-fig. 11. Beekmantown correlations, Central Champlain Valley and adjacent areas. Stratigraphic datum is the base of the Cutting dolostone. Based on various authors and measurements by writer.

TABLE 3

THICKNESS OF BEEKMANTOWN GROUP AND TICONDEROGA DOLOSTONE[1]

Formation	Approximate Thickness—Feet							
	Thomp. Pt.	Whitehall	Fort Ann	S'east Shoreham	Ellsworth Ledge	Ticon-deroga area	Port Henry	Middlebury
Bridport	450		200		400			700
Bascom				375	375	250		400
Cassin	210		150		250			
Unexposed interval (="Smith Basin")	200		90					
Cutting (="Great Meadows")	425		110	350		350+		350
Whitehall (Shelburne)	210	300	120	295		300		300
Ticonderoga (Clarendon Springs)	300	300	315	310		185	300	80

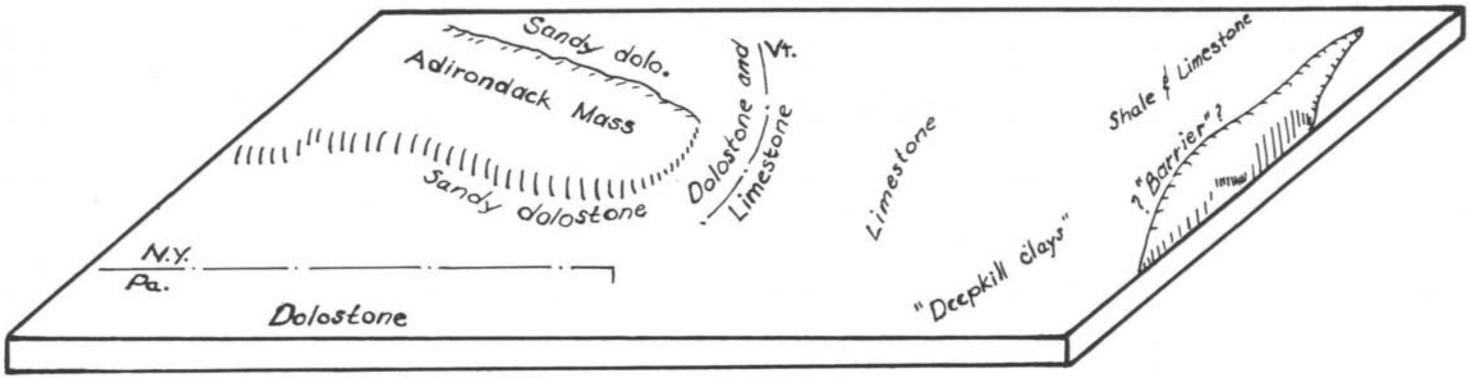
[1]Compiled from various authors and measurements by writer

or region. All the evidence at hand seems to indicate that the several formations are conformable and that no important breaks or withdrawals of the seas mark the change from one lithology to the other. Some events, such as the formation of the intraformational breccia at the base of the Cutting dolostone, were almost instantaneous in the sense of geologic time.

All evidence from within the Central Champlain Valley and from immediately adjacent areas seems to indicate the presence of a shallow sea during the Canadian and the uppermost Cambrian. The plethora of current-formed structures, including cross-laminations, stringing-out of silt and dolomite layers, and channels filled with fossil debris, points to the importance of currents in the seas of this time. Layers of intraformational pebble-conglomerates, silt-rimmed pebbles, and carbonate grains found in the rocks all support such a concept.

Current structures in the dolostones of the Whitehall, Cutting and Ticonderoga formations suggest strongly that the dolomite grains of these rocks are primary; the presence of dark-rimmed, subspherical aggregates of dolomite crystals also point to such a history for the dolostones. Harbaugh (1959) has recently described from limestones small-scale structures which indicate transportation of the calcite grains prior to their final deposition; similar structures are found in most of the dolostones of the Beekmantown group, especially in the finer grained ones. Calcite-rich and dolomite-rich laminae, fractions of a millimeter thick, alternate; the calcite and dolomite grains are believed to have formed essentially contemporaneously. Other evidence concerning the origin of the dolomite grains has been cited in the discussions of the several formations.

A brief history of the Beekmantown of the Central Champlain Valley and adjacent areas may be sketched from the information at hand. It opens with deposition of Ticonderoga-Clarendon Springs-type dolostone in a shallow sea (Text-figure 12) that was bordered on the west by a barrier in the region of the present-day Adirondack Mountains. The eastern margin of the sea is indeterminate; perhaps the area was covered by a shallow shelf sea, or perhaps a low barrier existed in the relative position of the Green Mountain axis, making the sea of the shallow inland type. The unconformity, dated as Lower or Middle Ordovician (Osberg, 1952), found in the sequence east of the Green Mountain axis may imply that this area was undergoing erosion during the deposition of the Beekmantown beds west of the axis. Rocks correlative with the Beekmantown seem absent east of the Green Mountain axis (Currier and Jahns, 1941;



Text-fig. 12. Possible paleogeography and distribution of sediments during Canadian time.

Osberg, 1952; Brace, 1953; Billings, 1956; Cady, 1956). The nature of the barrier, if it existed, is not clear.

Flower (1949) from studies in the Hudson Valley pictures two basins, one to the east which was filled with detrital material from a rising landmass lying east of it and a western basin in which accumulated limestones and dolostones. The carbonates are correlative with the Champlain Valley Upper Cambrian and Lower Ordovician carbonates. Oscillatory movements presumably exposed the carbonates occasionally and permitted brief erosion. With the exception of the many intraformational conglomerates which are believed to be submarine in origin, there is no recognized evidence for such oscillatory movements in the Central Champlain Valley.

Distribution of the Beekmantown and correlative sediments around the Adirondacks suggests that they were a low-lying landmass. From them probably came the quartz sand and silt of the Ticonderoga dolostone and formations higher in the sequence. The sea extended at one time north and northeastward south of the Canadian Shield to the area of the Mingan Islands (Belyea, 1952) and during lower and middle Canadian time reached around the north side of the Adirondacks.

While the evidence for such connections is not abundant, the Champlain Valley sea probably connected with the shallow epeiric sea which seems to have transgressed upon the southern margin of the Adirondacks at the beginning of the Ordovician (Fisher, 1954, p. 94), although the connection may not have been constantly maintained. South and east of the Central Champlain Valley the Deepkill shales were accumulating, apparently derived from an eastern source (Swartz, 1948, p. 1561).

Beginning with the deposition of the dolostones of the Ticonderoga formation, the Upper Cambrian and the Canadian deposits reflect conditions favorable for the accumulation of dolostones, for within the Central Champlain Valley and areas immediately adjacent to it dolostones form the bulk of the rocks until the advent of the Chazy group. Gradually the conditions on the shallow shelf changed, causing textural differences in the dolostones. The Whitehall-type dolostones replaced those of the Ticonderoga-type. Accompanying the change from the Ticonderoga to the Whitehall was the appearance of limestone as an important component of the sediments. The Ticonderoga equivalent east of the thrust belt, the Clarendon Springs, is largely dolostone, while the eastward correlative of the Whitehall is the Shelburne formation with its marble, limestone, and interbeds of dolostone.

The presence of the dolomite-rich sediments closer to a landmass and of the calcite-rich sediments farther away conforms to a pattern or general relationship observed elsewhere between dolostones and limestones (Pettijohn, 1957, p. 421). Dolostones are believed to be a near-shore facies and the limestones a deeper water facies deposited farther off-shore. Limestone, however, is interbedded with the dolostones of the Whitehall and its equivalents, and the two lithologies may grade laterally as well as vertically into one another. To the northeast of the Central Champlain Valley the limestone and slate sequence of the Highgate formation began to be deposited (Shaw, 1958), recording the interfingering and interbedding of the chemical sediments and clastic material thought to have come from the east.

During the deposition of the Whitehall minor amounts of quartz in the form of frosted, as well as clear, rounded quartz grains were brought into the shallow sea; depending upon the vagaries of the currents, they were concentrated locally into thin calcareous sandstone horizons or scattered throughout the dolostones. Wave action or local bottom disturbances broke semi-consolidated beds, forming blocks which were then cemented with similar dolomitic and calcareous sandy material. The presence of channels in the Whitehall dolostone on the west shore of the bay bifurcating Thompson Point, channels filled with an intraformational breccia, points to some rather strong current activity.

From the west a flood of medium- and fine-grained quartz entered the region of the Central Champlain Valley with the opening of Cutting-type deposition. The cross-bedding, the worm borings, the characteristic breccia at the base of the Cutting point to a very shallow-water environment, one that was near wave-base. None of the evidence seen within the Central Champlain Valley suggests that the breccia is related to a withdrawal of the sea and subsequent advance; rather the evidence points to the continued presence of the sea in the area through the time represented by the *Ophileta complanata* and *Lecanospira* zones. Perhaps the events that led to the influx of the quartz sand from the west are represented by the unconformity between the Tribes Hill and the Chuctanunda formations of the Mohawk Valley.

Sand seems to have been fed into the shallow seas at least twice during the deposition of the Cutting, the first at the beginning of Cutting deposition and the second during the deposition of the C-3 unit. At the later date the sand came in lesser quantity than earlier for dolostones are more prominent than the sandstones. Cady (1945, p. 542) shows that the dolostones and sandy horizons of the Cutting pass into limestones eastward and southward from the meridian of Shoreham. Once again, as in the Whitehall, the pattern of dolostones to the west and limestones to the east is found.

If the limestones associated laterally with the Whitehall and the Cutting formations can be said to reflect a deeper water environment than the dolostones of these formations which lie to the west, then perhaps one might imply from the limestone forming the lowest part of the Bascom formation east of the thrust belt that the trough deepened with the beginning of the middle Canadian or that the axis shifted to the west slightly. Since there are no exposures of beds equivalent to the lower Bascom within the Central Champlain Valley, a transition from limestone to dolostone in an east to west direction can not be proved.

The Cassin formation records deposition in a shallow-water environment within the Central Champlain Valley both to the east and west. The beds with raised ridges on the weathered surfaces record the influx of quartz sand into the trough. Again the sand came from the west, and its deposition seems to have been almost rhythmic. The sub-even spacing of some of the sandy, raised ridges in the Thorp Point member suggests that the sand was brought in almost periodically. On the other hand, some of the ridges branch, the upper layer connecting with a sandy layer formed later. The long lateral extent of most of the sandy layers suggests that the sand was dumped rather rapidly and over a large area. While one might be inclined to view the Thorp Point "ribbed" sandy limestones as being deposited in a rather quiet environment, the intimate association of intraformational breccias, channels filled with fossil fragments, cross-laminations, stringers of the sandy limestone and calcareous sandstone connecting one calcareous sandstone layer with another, and layers of coarse-grained fossil debris point to an environment in which currents were very active.

The dark, sublithographic limestones of the Emerson School member seem to indicate an environment of relative quiet water. The black, platy, silty laminations distributed through much of the limestone seem to have been laid down on slightly irregular surfaces of lime mud and to have been supplied to the trough more or less continuously. At the same time the laminae, while they are connected by vertical "risers," appear more or less equally spaced through the limestone beds; such a relationship again implies the possibility of some sort of periodic incursion of the silt.

A yet unanswered question is the difference between the environment favoring deposition of finely crystalline limestone and the environment favoring deposition of sublithographic limestones formed of aggregates of silt- and clay-size calcite grains. Perhaps the type or amount of detritus was a controlling factor; perhaps an alteration in current patterns or in the salinity of the water effected the change in sedimentation.

Belyea (1952), in a study of the Beekmantown of the St. Lawrence lowlands based on data from wells, recognizes in the Montreal area the transition from the Potsdam sandstones to the Beekmantown dolostones and limestones. She suggests that the seas in which the early Beekmantown sediments were deposited transgressed onto a stable shelf. From the data presented the transgression seems to have come from the south or southeast. The middle portion of the Beekmantown in this area is carbonate and is thought to indicate shallow-water conditions in a tectonically stable environment.

The upper Beekmantown is thought to have been deposited in deeper water than that in the middle portion of the section because of the presence of darker shales, siltstones, and argillaceous limestones and dolostones. Encroachment of the seas is thought to have come from the south during the time represented by the upper sediments.

The section thickens to the south and east from north and northwest of Montreal. The thickening is brought about by the addition of beds at the base and at the top of the section in a southward direction.

The presence of *Lecanospira* in some of the Beekmantown dolostones (Clark, 1952) from the Montreal area suggests that the Beauharnois formation is correlative with part of the lower Bascom and that the fluctuations noted by Belyea may be fluctuations restricted to the time of the *Lecanospira* zone, and possibly the *Eurystomites kellogi* zone. Similar expansion of the seaway can not be shown for areas adjacent to the Central Champlain Valley.

Everywhere that the author has seen the contact between the Bridport and the underlying limestone of the Cassin the Bridport is conformable on the Cassin. From a purely sedimentological point of view the change is abrupt. The bluish-weathering limestones of the Cassin formation are replaced by the dolostones of the Bridport. There is no gradation from one lithology to the other within the Central Champlain Valley.

If the dolostones be viewed as representing deposition in water more shallow than that in which the limestones were deposited, than the area west of the Champlain Thrust appears to have been more shallow than the area to the east in the longitude of Middlebury and Weybridge where the Beldens formation dominated by a limestone lithology outcrops. The greater thickness of the Beldens in the Middlebury area is attributed to the wedge of Weybridge clastics that poured into the upper Canadian seas (Cady, 1945) .The fact that the site of deposition could accommodate the clastics in what appears to have been relatively shallow water implies that the eastern area was sinking downward at this time. The fine silt found in many of the Bridport dolostones may have come from the east, but it is believed that the primary source lay to the west. Likewise the detrital material forming the shales of the formation is believed to have been derived from a low-lying landmass to the west.

The conditions favoring an alternation of limestone and dolostone during accumulation of the Bridport are unknown; not only did the bluish-weathering limestones of the Bridport form between layers of slightly thicker and massive dolostones, but within some of the massive dolostones there are thin layers of limestone deposited in vertical continuity with the overlying and underlying dolomitic material. There is simply a gradation upward from dolostone to limestone and back to dolostone; the only evidence of bedding in any of the layers is fine, current-caused, raised lines on weathered surfaces.

The upward increase in the quantity of silt found in the Bridport dolostones coupled with the appearance of interbedded fossil-fragmental limestones in a few places may imply that the land areas adjacent to the trough were becoming more unstable with the passage of time. Perhaps it was during this later period that the dolostones of the Bridport were flexed into the small folds that seem to characterize it in many places, folds that are not reflected in the superjacent or subjacent beds.

The alternation of shale and dolostones near the top of the formation at several places may support the picture of instability. One such occurrence is in the outcrops south of Summer Point; a similar relationship has been seen in the outcrops below the Day Point-Bridport contact in the Grosse Point area. Alternation of shale and dolostone in the Bridport along the coast line south of Coll Bay on the New York side of Lake Champlain has also been seen.

All evidence found within the Central Champlain Valley and in areas nearby seems to indicate that the Bridport is overlain conformably by the Day Point formation of the Chazy group. There seems to have been no withdrawal of the sea from the area, and the silty dolostones and dolomitic siltstones of the Day Point resemble very closely, if they are not identical to, like beds in the Bridport. Further consideration of the evidence is left to the discussion of the Day Point and the history recorded by the formations of the Chazy group.

Ordovician—Champlainian Series—Chazyan Stage

Chazy Group—General

Emmons (1842, p. 107, 315–317) used the term Chazy to describe the massive, bluish-weathering limestone beds characterized by outlines of *Maclurites* found near Chazy, New York. Subsequent work has expanded the term to include underlying and overlying beds which seem to be related to the *Maclurites*-bearing beds both lithologically and faunally (Hall, 1847, p. 14–36; Brainerd and Seely, 1888; Cushing, 1905, p. 368; Raymond, 1906; Cady, 1945, p. 548; Twenhofel and others, 1954; Oxley and Kay, 1959) and to raise the term from one of formational usage to one of series rank (Oxley and Kay, 1959).

Brainerd and Seely (1888) described the rocks of the type area at Chazy, New York, dividing them into three groups: A, B, and C. Later, Brainerd (1891) and Brainerd and Seely (1896) described the three subdivisions in several sections in the Champlain Valley. While they were concerned with the fossil content of the beds and recognized the typical faunal associations of each subdivision, their recognition of the three units was primarily on a lithologic basis. Cushing (1905, p. 365–369), in giving formal names to the units, recognized the differences in lithology and considered them lithologic entities. Raymond (1902) described the fauna from the Chazy beds of the Crown Point area and later (1906) the fauna from the Chazy of the Champlain Valley. He divided the Chazy on a faunal basis into three paleontologically defined units which correspond generally, but not perfectly, with the three lithologic units recognized by earlier workers.

The author has elected to use the stratigraphic classification of the Committee on Stratigraphy of the National Research Council (Twenhofel and others, 1954). He considers that the deposits earlier termed Chazy formation should be called the Chazy group; the time-rock term is the *Chazyan Stage*, and the correlative pure time term is the Chazyan Age.

The three formations that comprise the Chazy group and the Chazyan Stage are from oldest to youngest: Day Point formation, Crown Point limestone, and Valcour formation. Recognition of each of these formations depends to a large extent upon a number of features which vary rapidly, both vertically and laterally. While in a broad sense each formation is distinctive and recognizable, each contains lithologies which can be found in the others at one place or another. Hence lithologic change is one of the primary criteria on which the formations have been defined locally. Once a change has been recognized, then its importance must be evaluated on both a local and a regional scale. The fact that a change in lithology does occur seems more important than the exact details of the change. This statement is particularly true of the lithologic changes which are utilized in determining the contact between the Day Point and the Crown Point formations. On a regional scale the two formations can be clearly differentiated, but locally the differentiation is not always sharp, and local criteria must be used.

Day Point Formation (Cushing, 1905)

The term Day Point was applied by Cushing (1905, p. 368) to the lowermost of the three divisions of limestone and calcareous sandstones commonly grouped together under the term Chazy up to that time. Brainerd and Seely in 1896 (p. 305) described the type section of this formation from Valcour Island as their Division A. Their description is given below for comparison with the sections from the Central Champlain Valley area.

"Group A (Lower Chazy)

1. Gray or drab-colored sandstone, interstratified with thin (or sometimes thick) layers of slate, and with occasional thin layers of limestone at the base, containing *Camarella* (?) *costata* Bill. . . . . 56 feet
2. The slaty sandstone gradually passes into massive beds, made up of thin alternating layers of tough slate and of nodular limestone, containing undetermined species of *Orthis* and *Orthoceras* . . . . 82 feet
3. Dark bluish-gray, somewhat impure limestone, in beds of variable thickness; often packed with *Orthis costalis* Hall, which occurs with more or less frequency through the whole mass. Other fossils are: *Lingula huronensis* Bill., *Harpes antiquatus* Bill., *Harpes ottawaënsis* Bill. (?), *Illaenus arcturus* Hall, (*I. bayfieldii* Bill.), *Lituites*, sp. (?) . 110 feet
4. Gray, tolerably pure limestone in beds 8 to 20 inches thick, separated by earthy seams, the bedding being uneven. Many layers consist of crinoidal fragments, largely of *Palaeocystites tenuiradiatus* Hall. Near the middle of the mass, for a thickness of 10 feet, some of the fragments and small ovoid masses (*Bolboporites americanus* Bill.) are of a bright red color . . . . 90 feet"

More recently the formation has been described in the Champlain Valley by Erwin (1957) and by Oxley and Kay (1959).

Within the Central Champlain Valley the Day Point formation is consistently present between the overlying Crown Point limestone and the underlying Bridport dolostone. Its thickness varies along the strike and in an east-west direction, but there seems to be no local structural discordance between the Day Point and the underlying Bridport. Irregularities observed at the contact between the dolostone below and shale or limestone above are duplicated repeatedly within the Bridport, either where shale beds lie between dolostone beds, where dolostone lies on dolostone, or where limestone beds overlie dolostone beds. There is no question but that the Day Point deposition was uneven; the thickness data bear out this fact, but the rather regionally uniform thickness suggests the existence of local basins instead of an irregular topography caused by erosion—either submarine or subaerial—although the local basins may have been of an erosional origin instead of structural. The warping that may have been initiated during deposition of the Bridport could have caused formation of local basins which might then have been filled by a greater thickness of the Day Point sediments.

The author has found Day Point beds as far south as Murdock's Point, New York, in the Crown Point 7½ minute quadrangle. The formation is also exposed on the east side of Bulwagga Bay where Brainerd and Seely (1896, p. 314) attributed to the Day Point (Division A) the lower 48 feet of the section. Raymond (1902) described the beds at Crown Point and concluded that the lower beds of the section represent the Day Point. Subsequently he held (1906, p. 554) that the sandy and shaly beds at the base of the Crown Point section do not represent the same horizon as the Day Point beds farther to the north. However, the lithologic similarity between the lower 40 to 45 feet of the section on Bulwagga Bay and the beds mapped as Day Point in the Central Champlain Valley combined with their stratigraphic position seems to support their inclusion within the formation and the conclusion that they should not be placed with the Crown Point formation as Oxley and Kay (1959) and Raymond (1906) have done. Whether or not there is an age difference between the outcrops to the north and those at the southern end of the Champlain basin is another problem.

The presence between the Bridport and the overlying sediments in the southern part of the area of a noncalcareous shale similar to that found lying on the Bridport at the Addison-Chittenden County line exposures in West Ferrisburg, and at Grosse Point, Kingsland Bay, and Summer Point lend strength to the argument that the Day Point is represented south of the island exposures. The author places the Day Point-Crown Point contact at the top of Raymond's (1902) A-7 horizon or slightly higher, in the A-8 horizon. The placement of the contact at the top of the A-7 horizon gives a thickness of 40 feet for the Day Point on Bulwagga Bay, a figure in close agreement with that presented by Brainerd and Seely (1896).

The formation crops out along the shore of Lake Champlain from near the mouth of Kimball Brook in Charlotte southward to the south side of the headland southeast of Dean Island. It reappears on the south side of Hawkins Bay and can be traced in the bluffs southward to Grosse Point where it disappears beneath the lake. An extensive outcrop occurs in the bluffs south and southeast of Summer Point, and the outcrop belt continues westward and southwestward for about two-thirds of a mile until the formation again disappears beneath the lake. Exposed for only a short distance along the west face of the ridge about a mile southeast of Kellog Bay, the formation reappears approximately a mile south-southwest of Panton in the southward continuation of the ridge.

The County Line, Hawkins Bay, Summer Point, and Thorp Brook sections (Sections 13, 14, 15, 18) describe the formation at or near the shore. Measured sections at Intersection 146 southeast of Kellog Bay, and 3500 feet southeast of Spaulding Bay (Sections 16, 17) describe the upper part of the formation at the inland exposures. The formation, poorly exposed and represented entirely by limestones, is present at the base of the Chazy group outcrops about a mile northeast of Cedar Island in Charlotte.

Oxley and Kay (1959) in their discussion of the Chazy of the Champlain Valley have described the section at Intersection 146 (Section 16) and in the fields to the north. The author's interpretation of the area differs somewhat from theirs as comparison of the measured sections in the two reports will show. It is the author's contention that the Bridport is not exposed in the area and that the Day Point is considerably thicker than Oxley and Kay have indicated. The bryozoan-reef zone with its stromatolites is believed to be in the Day Point. However, similar stromatolite-bearing beds lie to the north of the gully near the crest of the ridge within what is considered to be typical Crown Point; these beds overlie the massive limestone with *Maclurites* and *Stromatocerium*. Farther to the north, approximately due west of the small hill on which the Valcour "reefy" zone outcrops, near the turn-off to Fort Cassin, stromatolite-bearing beds, apparent continuations of those to the south, outcrop near the base of the west-facing escarpment; they are within the Crown Point.

Immediately south of the gully and west of the best outcrops of the Day Point bryozoan-reef zone, stromatolite-bearing beds within the Day Point, but lower than those exposed at the gully, abut against the massive Orwell beds. The latter have been dropped down as a small sliver between the Day Point to the east and the beds west of the main Kingsland Bay fault.

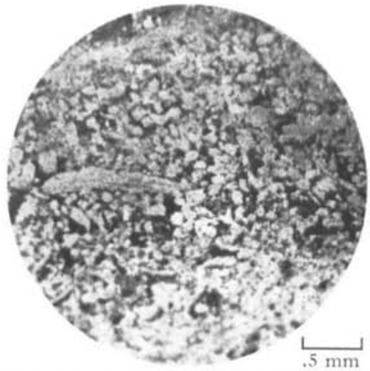
Presence of a small fault in the gully is inferred by slight warping of the Crown Point 20 to 30 yards south of the gully and by the change from the massive, *Maclurites*-bearing bed on the north side to the sandy and dolomitic limestones overlying the reefy zone on the south side of the gully. The tracing southward of one of the dolostones outcropping on the north side of the gully seems to indicate the presence of a small fault also, for it is offset. The stratigraphic throw is probably small, but any measurements made across it are in error.

The author has collected typical Chazy fossils from a horizon near the base of the cliff, but within the gully on the west side of the ridge; these are listed as locality 247 in Appendix II. The stratigraphic position of the locality is beneath the beds that Oxley and Kay have considered as Bridport. Fossils collected from the Day Point at localities 459, 460, and 461 on the north side of the gully and noted in Section 16 indicate only a Chazyan age.

South of the gully, as well as to the north as far as Porterboro School, minor flexures in the Crown Point make detailed assessment of the Crown Point and its variations difficult. Apparently the stromatolite-bearing horizons are not restricted to the Day Point but occur also in the Crown Point and in the Valcour, although they do not seem to be so prominent in the latter formation as in the lower ones.

The measured section north of the gully at Intersection 146 (Section 16) and detailed mapping of the ridge north and south of the intersection indicate that the following average thicknesses appertain in this vicinity: Day Point, ± 75 feet; Crown Point, ± 100 feet; Valcour, ± 25 feet.

In the easternmost parts of the Central Champlain Valley, the Day Point appears as a thin (20 to 50 feet) band between the Bridport dolostone and the Crown Point limestone. The single, most extensive outcrop of the formation in the easternmost part of the area lies about a mile southeast of Ferrisburg where it reflects the intense folding to which the rocks have been subjected. Scattered outcrops of limited size point up the wide areal distribution of the formation.



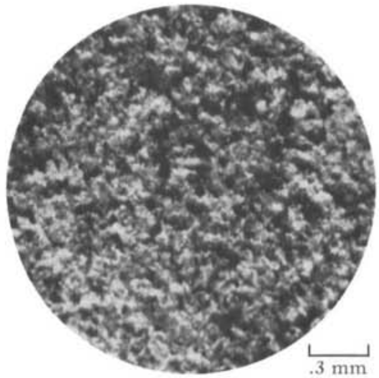


PLATE 9

Figure 1. Sublithographic limestone with "pellets" composed of .005- to .01-mm calcite grains cemented by slightly coarser calcite. Pellet-like areas are light-gray; lower, darker areas are cement. Note shell fragment. Etched surface, reflected light; Orwell, west of Intersection 146, Ferrisburg, southeast of Kellog Bay.

Figure 2. Etched surface of typical Day Point dolostone. Light-colored areas are raised dolomite grains; reflected light, 33X; base of Day Point outcrop approximately .75 mile southeast of Spaulding Bay.

The Day Point consists of a varying sequence of quartz sandstones, dolomitic quartz sandstones, very finely crystalline to sublithographic and silty dolostones, and limestones, both fine- to coarse-grained fossil-fragmental and sublithographic to very finely crystalline types whose calcite crystals appear to have formed initially by chemical precipitation. Subrounded and rounded quartz grains of a wide range of sizes occur

PLATE 9

Figure 3. Isoclinal, overturned fold in massive Crown Point limestone. Position of high-angle fault is indicated by the arrow; 3400 feet east of Ferrisburg village in gravel quarry.

scattered through many of the limestones. Because of the variations in the quartz content of the limestones, the presence or absence of quartz can not be utilized in defining the formation except locally and in conjunction with other criteria. Thin-bedded, brittle, noncalcareous shale is also important in many sections of the formation.

Some beds are persistent over considerable distances; other beds change laterally to different lithologies within relatively short distances. The variability of the formation both laterally and vertically contrasts with the more or less uniform nature of the overlying Crown Point limestone.Bedding varies from beds between 3 and 4 feet thick down to beds

4 to 6 inches thick. In the lower part of the formation beds average 1 foot thick while in the upper part beds 4 to 6 inches thick are most prevalent.

The dolomitic (Plate 9, Figure 2) and sandy beds might be said to typify the formation, although in aggregate they probably do not comprise more than a third to a half of the formation. The relative proportion of quartz and very finely crystalline dolomite grains in these rocks varies from 30 per cent quartz and 70 per cent dolomite to 30 per cent dolomite and 70 per cent quartz. Most likely the average value is near a 1:1 ratio of the two components. Where there is a significant quantity of calcite mixed with the dolomite grains, either chemically precipitated or in the form of fossil fragments, the relationship does not hold. Some of the rocks with a high dolomite content are silty dolomitic limestones.

The silty calcitic dolostones (Plate 9, Figure 2) and dolomitic, very fine-grained sandstones and siltstones weather in shades of yellowish-gray (5Y8/1 to 5Y7/2) and pale-orange (10YR8/2). The fresh surfaces are light-gray to very light-gray (N7 to N8), and often they present a fresh surface whose luster might be called sparkling or vitreous, although many exhibit a dull luster. The individual beds average between 1 and 2 feet thick.

No single characteristic typifies the limestone beds of the Day Point, and the recognition of the formation depends upon the interpretation of a number of features which vary in importance from place to place. Close examination of the weathering properties, fresh surfaces, and the general overall appearance of the rock enables one to separate the Day Point from similar limestones of the Crown Point. Where the Day Point contains black silty laminae in considerable quantity, the laminae are more widely spaced than those in the overlying beds of the Crown Point limestone. Comparison of the Day Point and Crown Point beds from a short distance shows the contacts between individual beds of the Day Point to be more crenulated than those of the Crown Point beds; in most cases the mass effect of the Day Point suggests the presence of smaller quantities of the black silty laminae than in the overlying Crown Point beds.

The contact between the Day Point and the Crown Point has been placed where the black, silty, reticulating laminae and partings increase notably and the limestones change slightly, but systematically, simultaneously. The change in limestone lithology is most frequently seen as a luster change on fresh surfaces. Day Point limestones seem to have a vitreous-like or vitreous to dull luster while Crown Point limestones exhibit a dull luster accompanied by the "salted" appearance of a fresh surface. Weathered surfaces of Day Point beds are less blue, and often the weathered vertical surfaces exhibit a white-speckled appearance that is not associated with the Crown Point beds.

Experience has demonstrated that the sublithographic limestones of the Day Point are more frequently thin-bedded and that they show a greater tendency as a whole toward weathering in a nodular fashion than do the overlying Crown Point limestones containing only small percentages of dolomitic and silty laminae. Crown Point limestones possessing a large percentage of silty laminae are much more nodular in appearance and thin-bedded; the thin-bedded nature of the Day Point limestones is not so closely related to silty partings and laminae.

The vitreous or sparkling luster of the Day Point limestones seems to reflect the general, rather uniform, distribution of dolomite crystals through the rocks, in addition to the occasional wisps and laminae. Moreover, the resistant, black silty laminae or silty films which stand out on the weathered surfaces of the typical Crown Point beds are of relatively minor importance in the limestones of the Day Point.

Many of the fossil-fragmental limestones of the Day Point, especially those near the top of the formation, possess pink-, reddish-, or flesh-colored spots on a fresh surface. The flesh-colored spots appear related to the presence of the pelmatozoan fragments in the limestones while the reddish and pink spots seem to represent concentrations of iron oxides. Similar-colored spots have been noted in the Day Point beds of Valcour Island and the adjacent mainland (Brainerd and Seely, 1896, p. 306–308). There spots are generally lacking in the Crown Point limestones, although in the lower part of the formation occasional reddish spots do occur, giving rise to faint red stains on weathered surfaces.

At several localities, in the Summer Point area, and along the lake shore between Grosse Point and Kingsland Bay, for example, yellowish-orange dolostone beds occur near the top of the formation. The immediately overlying limestones are probably Day Point, but changes in the limestones a few feet above the dolostone beds fix the position of the contact. Where the Bridport formation is exposed along with the Day Point, stratigraphic position is of considerable aid in mapping the Day Point.

Along the shore of Lake Champlain the Day Point consists of a sequence of fossil-fragmental limestones, varying amounts of arenaceous limestone, dolomitic limestone, and calcitic dolostone together with important quantities of cross-bedded quartz sandsone and black non-calcareous shale (Sections 13, 14, 15).

Terriginous material is more prominent in the lower part of the Day Point, decreasing upward to be replaced by both fossil-fragmental and sublithographic to very finely crystalline limestones. The clastic limestones are medium- and coarse-grained and are composed of rounded and subrounded fragments of bryozoan, brachiopod, trilobite, and pelmatozoan fragments. The matrix material, usually forming a minor part of the rock, is microcrystalline (± .01 mm) calcite.

Sublithographic limestones are composed of ± .01-mm calcite grains; many of these limestones are dolomitic, containing up to 25 per cent ± .06-mm dolomite rhombs more or less evenly distributed through the rock. Fossil fragments are present in varying amounts, but seldom are they more than an accessory component of the rocks.

Some of the very finely crystalline limestones contain subspherical to ellipsoidal masses up to .5 mm in diameter which are composed of microcrystalline calcite. The masses as a whole are slightly darker than the surrounding matrix, and many have a thin rim of still darker material separating the bulk of the mass from the matrix material. The suggestion is that these masses formed through the aggregation of silt-size particles of carbonate on the sea floor followed or accompanied by movement along the bottom. It is thought that they originated in a manner similar to that described by Illing (1954, p. 26–27, Plate 1:3) for the ovoids of the Bahaman calcareous sands.

The upper third to quarter of the formation in the western exposures is composed of clastic and sublithographic limestones which are silty, sandy, and dolomitic. These medium-gray limestones are thin-bedded (4 to 6 inches), nodular-weathering, and tough. They possess a sparkling or vitreous luster which gives a harsh appearance to a fresh break. On the other hand, some of the upper limestones both along the lake shore and in the exposures inland exhibit a dull luster on a freshly broken surface and give an impression of softness, much as the luster and texture of milk chocolate impart the impression of softness. These latter limestones are generally coarse-grained fossil-fragmental with a small percentage of ± .01-mm calcite cement. The more harsh-appearing limestones seem to be dolomitic, and while containing important percentages of fossil fragments, they often possess a higher percentage of microcrystalline calcite than do the more soft-appearing limestones. Both of these general appearances contrast with the "salted" appearance of the sublithographic-textured limestones of the Crown Point. Figure 3,

Plate 8 illustrates the upper limestones in the Summer Point section (Section 15).

Well-cemented quartz sandstones are important components of the Day Point along the lake shore. The sandstones are so well bonded in some instances that the term quartzite might better be used in describing them. Coarse- and medium-grained, the sandstones are composed of subrounded and rounded, subspherical, frosted quartz grains. Undulatory extinction is a common optical feature of most of the quartz grains, and secondary overgrowths have been found in a thin section of one of the sandstones from the east side of Bluff Point, as have sutured contacts between individual grains. A few of the sandstones contain rounded quartz pebbles as large as .25-inch. The cement is silica in the purer sandstones, but in others calcite or dolomite, or both, may be the bonding agent. The purer quartzose sandstones are white or bluish-gray.

All gradations between relatively pure quartz sandstones and calcareous and dolomitic sandstones, and sandy limestones and sandy dolostones exist. Occasional ripple-marked zones such as the one exposed near the cement dock at the swimming area of École Champlain on the west side of Bluff Point accompany some of the sandstones. Cross-bedding and cross-lamination are common features of the sandstones, being faintly discernible in some and prominent in others. Shale is commonly interbedded with the sandstone. Fucoids may be found in some of the dolomitic sandstones.

The coarse- and medium-grained relatively pure quartz sandstones comprise an important part of the lower Day Point on the east side of Bluff Point, along the south side of Hawkins Bay and in the area south of Summer Point. Seely (1910, p. 270) called some of the Day Point sandstones on Bluff Point, "Potsdam," a fact which emphasizes the general appearance of many of these sandstones at this locality and their resemblance to certain of the cleaner sands of the Potsdam. Elsewhere the sandstones are fine-grained to very fine-grained and generally calcareous or dolomitic.

Thin-bedded, generally noncalcareous dark-gray to olive-gray shale is an important component of the Day Point. The shale seems composed of clay-size particles of quartz, and much of it is silty. Most of the thicker shale beds are intensely jointed and fractured.

Along the shore exposures, from Kimball Brook southward, a thin shale bed lies on the dolostones of the Bridport and is succeeded by a quartz sandstone. The same relation appertains on the east side of

Bluff Point. The basal shale is seen in both the County Line and Summer Point sections. In the exposures on the west side of Kingsland Bay, the Bridport is succeeded first by a limestone bed 1 to 2 feet thick which is succeeded in turn by an 18-inch shale bed.

A similar shaly horizon has been observed between the "Providence Island dolomite" and the Day Point on Isle la Motte on the east and south sides of The Head, and its presence at Crown Point has been noted previously. The change from the Bridport to the Day Point in the section exposed along the bluffs south of Coll Bay north of Port Henry (Kemp and Ruedemann, 1910, p. 66) takes place as follows. Bridport dolostones alternate with dark-colored, noncalcareous shale near the top of the formation. Finally a shale bed is succeeded by a 3-foot orange-brown-weathering, light-gray, cross-bedded dolomitic sandstone which is replaced southward by a dolostone or sandy dolostone; the dolomitic sequence gives way upward to thin-bedded limestones that are elsewhere typical of the upper part of the Day Point. The conglomerate described from this area (Kemp and Ruedemann, 1910, p. 66) is apparently well above the base. The basal shale has also been found south of Ligonier Point west of Shelburne Point. Other shale beds lie within the Day Point at several horizons (Sections 13, 14, 15, 19; exposures on west side of Kingsland Bay).

The average shale bed is less than a foot thick, but several attain a thickness in excess of 3 feet. In the more easterly exposures shale is less prominent as individual beds. Rather, it is more commonly distributed as thin lenses and laminae between the sandy and silty carbonate beds, but beds of noncalcareous shale are to be found between some of the dolomitic and sandy beds.

In the Grosse Point area, coarse- and medium-grained, fossil-fragmental limestones predominate. Limestones of the lower part of the formation are thick-bedded, but above the middle of the sequence the limestones become thin-bedded (4 to 6 inches), and occasional thin shale beds are intercalated. The shale beds associated with the thicker bedded limestones are thicker than the beds of shale higher in the sequence.

East of Spaulding Bay, in the ridge approximately 4000 feet S. 35° E. of Mud Island, the Day Point is represented not only by fossil-fragmental limestones, but also by calcareous, fine-grained quartz sandstones whose calcareous matrix is composed largely of trilobite and brachiopod fragments with small amounts of microcrystalline calcite. Also present are very finely crystalline to sublithographic calcitic dolostones and dolomitic limestones. Average grain-size of the quartz decreases upward notably in this part of the Day Point, and the contact with the overlying Crown Point has been placed where the sand grains seemingly disappear or become a minor part of the thin-bedded, somewhat nodular limestones. South of the road leading east from the south edge of Spaulding Bay, in the vicinity of the Spaulding Bay measured section, the "soft" appearance of the Day Point limestone beds contrasts with the generally dull, bluish appearance of the overlying Crown Point limestones; furthermore, the fossil-fragmental Crown Point limestones are in beds 1 to 2 feet thick with indentations 4 to 6 inches deep between individual beds. The indentations are caused by the weathering out of silty laminae.

Only the upper portion of the Day Point is exposed in the ridges extending from the area approximately a mile east of Kellog Bay southward to the latitude of Spaulding Bay. In these exposures the Day Point is dominantly clastic, fossil-fragmental limestone and with a lesser amount of sublithographic limestone. Some of the limestones contain significant quantities of dolomitic material, and calcitic, silty dolostones are present in parts of the exposures (Sections 16, 17).

The sandstones which are so prominent along the lake shore to the north and west are absent in these more easterly exposures. The absence of sandstones in the Day Point exposures south of Porterboro School and the fact that the upper part of the Day Point along the shore is composed of limestones of a similar nature together with the stratigraphic position of the Day Point beds in the easterly exposures suggest that only the upper part of the formation is exposed here. Moreover, the structural relationships would seem to lend support to this argument.

The eastern exposures of the Day Point consist of silty and sandy calcitic dolostones and dolomitic silty and arenaceous limestones in beds 1 to 3 feet thick (Plate 8, Figure 2). Noncalcareous, olive-gray shale is also an important component, forming thin beds but occasionally being found as beds 1 foot thick. The texture of the dolomitic rocks is generally fine-grained or very finely crystalline to sublithographic while weathered surfaces of the beds are a characteristic yellowish-orange color (10YR6/6 approximately) to light-brown (5YR4/6), and in some instances the more intensely scored beds may be mistaken for the sand- and silt-rich beds of the Bridport. The Day Point, however, contrasts with similar beds in the Bridport by being less intensely scored and by possessing a light-gray color and a sparkling luster on a fresh surface. Fresh surfaces of the silt-rich Bridport beds exhibit a dull luster and a dark-gray to black coloration.

Occasional horizons of fossil-fragmental limestones, such as are exposed .8 mile southeast of Ferrisburg, are interbedded with the dolomitic beds of the Day Point. Some of the more arenaceous beds are cross-bedded, and minor quantities of quartz grains up to 1 mm in diameter are present in some of the silts and very fine-grained sandstones.

Evidence in the east for cessation of deposition either prior to the deposition of the Day Point or after its deposition is lacking. On the contrary, the evidence seems to indicate a period of continuous deposition through the time represented by the Bridport into Day Point time and finally into the time recorded by the Crown Point formation. The lower contact of the Day Point is best differentiated using an increase in the silt content of the dolostone beds, which is detected with the aid of the luster and texture of the weathered rocks, as the guide to the Day Point. Everywhere it has been observed, the lower contact seems gradational. Yet it can usually be pinpointed where the rocks are adequately exposed, for the dolostones of the Bridport are predominant below the contact and the dolomitic sandstones and siltstones predominate above it. Figure 2, Plate 8 illustrates the contact .8 mile southeast of Ferrisburg.

The upper contact of the Day Point in the easternmost exposures is gradational. The Day Point dolomitic lithology changes to the gray and bluish-gray sublithographic limestones of the Crown Point abruptly in most cases, yet there are thin zones near the top of the Day Point in which rocks of the Crown Point-type lithology are interbedded with the more dolomitic beds found in the Day Point below. In other instances the change is marked by a more or less shaly sequence; in still other outcrops relatively pure limestones form the top of the formation, lying above the dolomitic sequences of the Day Point. These limestones usually have a vitreous or sparkling luster and are thin bedded, being similar in general aspect to the uppermost beds of the Day Point along the lake shore. The contrast between the uppermost limestones of the Day Point in these occurrences and the lower beds of the Crown Point lies chiefly in the luster of the fresh surface. Day Point limestones are sparkling on the fresh break whereas Crown Point limestones exhibit a dull luster and a sublithographic-appearing texture. In addition, the Day Point limestones seem to be more thinly bedded than the overlying Crown Point beds. Two of the occurrences of limestones at the top of the Day Point are at the southwest corner of Waltham and about .7 mile west of the airway beacon atop the north end of Snake Mountain.

Usually no difficulty is encountered in separating the Day Point formation in the easternmost exposures from the Crown Point. The yellowish-orange-weathering dolomitic beds are readily identifiable even where the Day Point becomes extremely thin, such as near Marsh Hill northeast of Vergennes or in the southeastern part of the area, near the Champlain Thrust. However, there are horizons within the Crown Point which are sandy, silty, and dolomitic; in an area of complex folding these horizons can easily be mistaken for the Day Point.

The quartz sandstone-dolostone-clastic limestone lithology of the western exposures of the Day Point contrasts sharply with the Day Point of the easternmost exposures and with the Crown Point lithology; no zone of lateral gradation is exposed. It is believed that the upper limestones of the Day Point may in part be replaced eastward by limestones of Crown Point-type lithology which have been mapped as part of the Crown Point. The slight thinning of the formation in an eastward direction suggests this relation.

If the exposures east of Kellog Bay represent nearly the entire formation, then the sandstones of the formation pinch out in an eastward direction abruptly and are replaced by the clastic and sublithographic limestones. Furthermore, the classic limestones are replaced in an eastward direction by the dolomitic sandstones and siltstones and silty dolostones exposed in the eastern half of the area and in part by limestones of the Crown Point lithology.

Thickness

A number of thickness measurements have been made on the Day Point formation. Some of these are presented in the measured sections described in Appendix I. The County Line measured section southeast of Dean Island shows the formation to be approximately 150 feet thick. This figure agrees with the thickness given by Oxley and Kay (1959, fig. 2) for this locality.

On the ridge approximately .5 mile northwest of where the Rutland Railroad crosses the Addison-Chittenden County line in Ferrisburg, a sequence of arenaceous, dolomitic, fossil-fragmental limestones with lesser portions of dolomitic sandstone and dolomitic sandstone with moderate amounts of rounded and subrounded fossil fragments overlies the Bridport. Lateral variations are common in this section. The thickness of the sequence is 35 feet (Section 19); the top of the Day

Point is placed where significant quantities of black silty laminae in the limestones first appear in combination with a change in the overall appearance of a fresh surface of the limestones. A short distance to the north (Section 18) shale appears near the base of the 19-foot exposed section; at the top oölitic horizons are found in the massive limestones.

The Summer Point section shows the formation to be 75 feet thick; Oxley and Kay (1959, fig. 2) assign a value of 85 feet to the formation at this locality. The discrepancy probably lies in the interpretation of the upper contact of the formation. The top of the Day Point is placed where the nodular-weathering limestones with a predominant vitreous luster give way to limestones with a dull luster; although dull-lustered limestones do occur below the contact, they are not dominant components of the sequence. Moreover, the Crown Point seems to be more bluish and more nodular-weathering than the Day Point.

Southeast of Summer Point and east of the road leading to it, approximately 55 feet of the Day Point is exposed. The base is not exposed, but it is thought that it lies close to the foot of the west-facing escarpment; nodular-weathering limestones form a ± 15-foot interval between the top of the beds considered unquestionable Day Point and undoubted Crown Point. Because of their closer resemblance to the Crown Point beds than to the underlying Day Point rocks, they have been mapped with the Crown Point.

On the east side of Bluff Point where a small anticline and some minor faults bring the Bridport above water level, both the upper and lower contacts can be seen. It is estimated that at this spot the formation is between 45 and 50 feet thick. Oxley and Kay (1959) suggest that the value is in excess of 100 feet (fig. 2). West of the mouth of Little Otter Creek, near the bostonite dike, 35 to 40 feet of Day Point lie exposed in the north-facing bluffs. The base of the formation can not be seen, but the outcrop pattern extending westward toward Bluff Point suggests a thickness of between 40 and 45 feet. Along the west side of Kingsland Bay the formation is between 40 and 50 feet thick.

While the base of the formation is not exposed in the Panton area, its thickness is believed to be only slightly greater than the ± 40 feet measured almost due east of Spaulding Bay. Section 17 records only the upper 16 feet of the formation.

In the eastern part of the area Oxley and Kay (1959, fig. 2) assign a thickness of 94 feet to the Day Point near the southwest corner of Waltham, southwest of Buck Mountain. However, as the formation is interpreted in this report its thickness here is approximately 30 feet.

About 1.75 miles north of this locality thickness measurements made on the silty dolostones and dolomitic very fine-grained sandstones indicate that the formation is between 20 and 25 feet thick. Furthermore, the thickness of the dolomitic sandstones, sandy dolostones, and dolomitic limestones lying between the Bridport and typical Crown Point limestones .8 mile N. 30° E. of where Route 17 crosses Otter Creek at the north end of Snake Mountain, is between 40 and 45 feet. Measurements of other outcrops of the Day Point in this area indicate a general thickness of from 35 to 40 feet.

At the locality of Oxley and Kay's Ferrisburg section (1959, p. 852), Section 16 of this report, the author has failed to locate the Bridport reported by them. It is thought that their Bridport is actually a silty dolostone within the Day Point. Measurements made both north and south of the small gully west of the intersection indicate that between 65 and 75 feet of the Day Point is exposed here (Section 16). Small-scale cross-faulting complicates the interpretation of the Day Point at this locality.

In the Thompson Point area, approximately one-half mile north of Emerson School, the Day Point is apparently chiefly fragmental and sublithographic limestones with an aggregate thickness of between 50 and 70 feet. The actual thickness can not be determined as the base is not exposed and the contact with the Crown Point is gradational.

Correlation

In a general way the Day Point is probably susceptible of being divided into two subunits, possibly members. These would correspond roughly with the Head member and the combined Scott-Wait-Fleury members of Oxley and Kay (1959). During the course of the present work a lower sandy and shaly interval and an upper interval dominated by fossil-fragmental limestones were recognized in general, but no attempt was made to map them on a systematic basis. The paleontologic sampling done in conjunction with the mapping is inadequate to permit the recognition of the several "zones" found in the Day Point of the Lake Champlain islands (Brainerd and Seely, 1896; Erwin, 1957) and adjacent areas. Unfortunately Oxley and Kay did not tie their subdivisions of the Chazy in the islands in with the "zones" of earlier workers.

Oxley and Kay (1959, p. 825) found in the Day Point fossils which were once thought to be restricted to beds younger than the Day Point (Raymond, 1906; Bassler, 1915; Cooper, 1956). Among these are *Isotelus* *platymarginatus* Raymond, *Multicostella platys* (Billings), *Camarella varians* Billings, *Isotelus harrisi* Raymond, and *Atelelasma? multicostatum* (Hudson). Comparison of the faunal lists accompanying this report (Appendix II) with that given by Bassler (1915, p. 1448) will show other forms whose ranges have been extended, some through the whole Chazy sequence.

Raymond's faunal list from the beds of section A (1902) on the west side of the Crown Point peninsula points only to the fact that the beds are of Chazyan age. Raymond at first (1902) correlated these beds with the Day Point of Valcour Island, but subsequently (1906) he decided that they belonged in the Crown Point. Oxley and Kay (1959) followed this later interpretation.

The paleontologic evidence provides only an equivocal answer; in the present writer's opinion the dolomitic sandstones and silty dolostones at Crown Point and the overlying thin-bedded limestones are part of the Day Point formation. They are to be correlated as approximate time-equivalents with the Day Point sequence on Valcour Island, South Hero Island, and Isle la Motte. The beds to the south and to the north of this locality are thought to be equal in time with these beds also.

The general sequence of beds is remarkably constant from the latitude of Kimball Brook in Charlotte to Crown Point and south to Murdock's Point on the west side of Lake Champlain. Yet there are some rapid variations (compare the County Line section with the Kimball Brook section), and locally (Kimball Brook section and area 1 mile northeast of Cedar Island) fossil-fragmental and sublithographic limestones are almost the sole lithologic type. The exposures of the Hawkins Bay section (Section 14) contain less sand than do the exposures on Bluff Point to the west where horizons equivalent to the limestone and dolostone beds of Section 14 are quartz sandstone. Much of the lower part of the section resembles in a general way the section exposed on The Head at Isle la Motte. In particular, the presence of a shale just above the last Bridport dolostone seems to argue for a degree of contemporaneity when taken with other relations within the Champlain Valley. The upper part of the sequence on the islands with its reef zones is unlike anything seen in the Central Champlain Valley; the reefy zone at Intersection 146, east of Kellog Bay, is not as extensive as the reefy zones on the islands and is composed primarily of stromatolites. This is the only place that a "reefy" zone has been recognized in the Day Point of the Central Champlain Valley.

The thickness data from the several localities within the Champlain

TABLE 4

THICKNESS OF CHAZY GROUP

Approximate values compiled from various authors and from measurements made within the Central Champlain Valley area

Location	Thickness—feet Day Point	Crown Point	Valcour
Chazy, N. Y.	300	250	150 ±
Isle la Motte	200	150	200–300
Valcour Island	300–340	325 ±	200 ±
South Hero	230 ±	± 250–350	230 ±
County line—Long Point	40–150	225 ±	90 ±
Coll Bay, N. Y.	50 ±	not deter.	not deter.
Summer Point	75	200 ±	125
Panton—Arnold Bay	50 est.	200 ±	85–110
Crown Point peninsula, N. Y.	45	200	60
Braisted Creek, West Bridport	not exposed	200 est.	80 est.
Mt. Fuller slice	40 est.	100 est.	absent
Buck Mt. area	30–40	100–180	absent
West of Snake Mt.	45 ±	100 ±	absent
Middlebury	Middlebury limestone up to 600 feet; probably includes equivalents of all three formations		

Basin (see Text-figure 15; Table 4) show that the Day Point formation averages over 200 feet north of Valcour Island where it is some 338 feet (Brainerd and Seely, 1896). South of the latitude of Valcour Island the thickness drops to an average value of from 40 to 50 feet, being somewhat less to the east in the vicinity of the Champlain Thrust. Just south of Ligonier Point on Willsboro Point, New York, the Day Point is estimated to be between 30 and 40 feet thick. A like thickness is present south of Coll Bay. Local exceptions are south of Kimball Brook (Section 13) and Summer Point (Section 15).

The greater thickness of each of these sections is believed related to local depressions in the sea floor and/or to a slightly greater accumulation of fossil-fragmental debris during the formation of the Day Point. The reason for the greater accumulation of the Day Point at Valcour Island and in the localities to the north is not positively known. However, it is felt that the accumulations in the region are related more to conditions favoring rapid deposition of a great amount of sediment rather than to a long period of deposition followed by a southward encroachment of the sea. It is thought that the abundant fossil-fragmental limestones associated with the reef structures at the north end of the lake represent a flood of shell debris into the seas of the time; perhaps the area to the north was sinking downward to accommodate this abundance of detrital matter. In the south the seas are envisioned as being shallow and favoring the deposition of the dolomitic sands and silts. The limestones of the upper part of the Day Point are dolomitic, and while dominantly fossil-fragmental, they do not suggest to the author the history of rapid accumulation that the ones to the north do. By and large, the clean quartz sandstones prominent in the sequences to the north are not as common in the area of the Central Champlain Valley. Since the sandy beds thin to a feather edge to the east and the upper part of the Day Point is replaced in that direction in part by limestones of the Crown Point type, it is presumed that much of the sand and silt fed into the seas came from the west, that is, from the Adirondack area.

Crown Point Limestone (Cushing, 1905)

The widespread middle formation of the Chazy group, the Crown Point limestone, is readily distinguished from most of the other formations cropping out in the Central Champlain Valley and adjacent areas. It resembles closely the Middlebury formation (Cady, 1945) lying east of the thrust belt. The massive, bluish-gray and light bluish-gray-weathering beds with their black, thin, irregular, silty laminae or yellowish-orange-weathering, silty and dolomitic, raised ridges of irregular aspect commonly exhibit on weathered surfaces outlines of the gastropod *Maclurites magnus* Lesueur. While it was to this unit that Emmons (1842, p. 107, 315) first applied the name Chazy and to which the general appellation, "*Maclurites*-beds" has since been given, *Maclurites magnus* occurs in both of the other formations of the Chazy group (see faunal lists, Appendix II).

Girvanella is another fossil common in the Crown Point limestones. It appears on weathered surfaces as small (± .25 inch), concentrically laminated, oval-shaped areas. This fossil algae is particularly useful in identifying the formation where it is poorly exposed. Quartz grains often form the core or nucleus around which the plant grew. Seely (1886) described specimens of this fossil as a sponge, "*Strephocetus*."

Fossil-fragmental limestones of various grade sizes, finely crystalline to sublithographic limestones, and a few lithographic limestones make up the essential lithologic elements of the formation. The lithographic limestones are generally black on a fresh break, weathering with smoother surfaces than do the accompanying limestones of coarser grain-size.

Chert nodules and small lenses of blue-black chert occur occasionally. They seem to appear near the top of the formation and to be associated with sublithographic and lithographic limestones. In cliffed exposures the limestones present a very massive appearance, as if the bedding planes are 3 to 10 feet apart, but where weathering has attacked those limestones containing an abundance of black silty partings, the limestones appear thinly bedded; individual limestone layers separated by the partings average 2 to 3 inches thick.

Interbedded with the limestones are beds of dolomitic siltstone and silty dolostones composed of black, silty and dolomitic laminae with intercalated sublithographic and fossil-fragmental limestone layers. As a whole these beds generally weather in shades of yellowish-orange and black; the limestone components weather in shades of gray and appear as splotches and irregular-shaped areas on the darker surfaces. The siltstones represent local concentrations of the material forming the thin silty and dolomitic laminae of the limestone beds. Because of the close resemblance of these rocks to the beds of the Day Point of the eastern part of the area, it is frequently difficult to ascertain from isolated outcrops whether a silty and dolomitic horizon represents one from the Crown Point or whether it is part of the Day Point formation. In intensely sheared portions of the eastern part of the area, it is difficult to separate the silty and dolomitic Day Point from the Crown Point siltstone beds. The stratigraphic position with relation to the Bridport is an invaluable aid wherever the Bridport is exposed.

Massive, yellowish-orange- and yellowish-brown-weathering beds of very finely crystalline silty dolostone form another component of the formation, albeit a minor one. Only a few black silty partings are found in these beds; the silt is more or less uniformly distributed throughout the rock. Casual observation of these beds can lead to their misidentification as very fine-grained, somewhat dolomitic sandstones. Usually the detrital material forms less than 10 per cent of the whole rock.

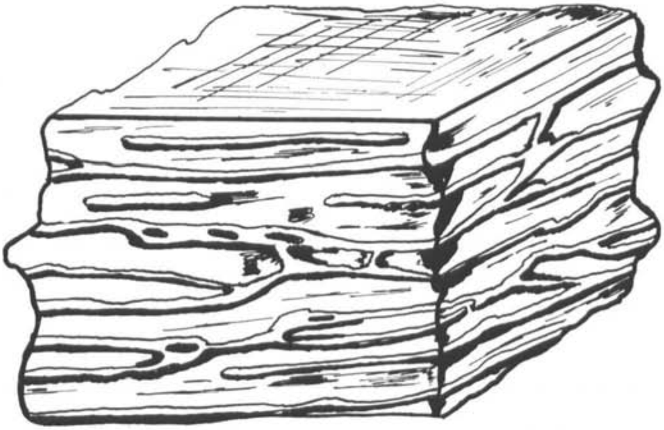
Inconspicuous, finely crystalline dolomitic limestones form another component of the formation. Dolomite rhombs are distributed more or less evenly through the limestones, and in some of the beds the dolomite is of sufficient abundance to warrant calling the rocks calcitic dolostones. The composition of these latter beds is suggested on the fresh break by a dusty aspect. In some of the dolomitic limestones the dolomite rhombs are concentrated in small spherical and ellipsoidal areas, in laminae with associated quartz silt, and as scattered grains in a groundmass of .01-mm calcite crystals which compose the bulk of the rock. Most of the limestones with a high dolomite content weather light-gray while the calcitic dolostones tend to weather pale yellowish-gray (5Y8/1 to 5Y9/1).

Fresh surfaces of typical Crown Point limestones are medium bluish-gray (5B5/1), dull-lustered, and appear to be sublithographic when first examined; the textural term aphanitic might be appropriately applied to them. However, etching with dilute acid brings out rounded or subrounded fossil fragments in many. Fossil fragments stand up on weathered surfaces of the coarse-grained fragmental limestones whose fresh break often exhibits a coarsely crystalline appearance if the individual shell fragments are not discernible.

The dull luster of the fresh surface of a typical Crown Point limestone is an important feature of these limestones since the luster contrasts with the more sparkling or vitreous luster of the average Day Point or Valcour bed. Many of the Crown Point limestones have the appearance of a dull, bluish-gray surface lightly sprinkled with very fine-grained salt which has partially dissolved or melted. This appearance contrasts with the more or less uniform appearance of the fresh break of the limestones in the underlying and overlying formations; of course, within both the Valcour and the Day Point there are limestone beds which closely resemble the typical Crown Point beds, and therefore the "salted" appearance may be found occasionally in limestones of the other formations.

The different aspects of the fresh surfaces are extremely useful in recognizing the contact of the Crown Point with the beds underlying and overlying it. In particular the differences in fresh surfaces are of great value where the limestones of the several formations closely resemble each other on weathered surfaces and in the general bedding characteristics. In the case of the Day Point-Crown Point contact the change from the thin-bedded limestones with a sparkling luster and a sometimes "harsh" appearance to the dull-lustered, "salted"-appearing bluish limestones of the Crown Point marks the position of the contact. The change from the Crown Point-type of fresh surface to the very fine-grained, generally even-textured, vitreous-lustered and slightly dusty-appearing limestones and dolostones of the Valcour sets off the upper boundary of the Crown Point.

The differences described above are general ones to which there are exceptions. Some of the Crown Point limestones possess an even-textured appearance like that associated with the "typical" Valcour dolomitic limestones and calcitic dolostones, and they weather in a similar light-gray or pale yellowish-gray color. However, quantitatively these beds are less important in the Crown Point than in the Valcour, and their close



Text-fig. 13. Generalized diagram showing branching and anastomosing, brownish-weathering, silty, raised, dolomitic laminae of typical Crown Point limestone.

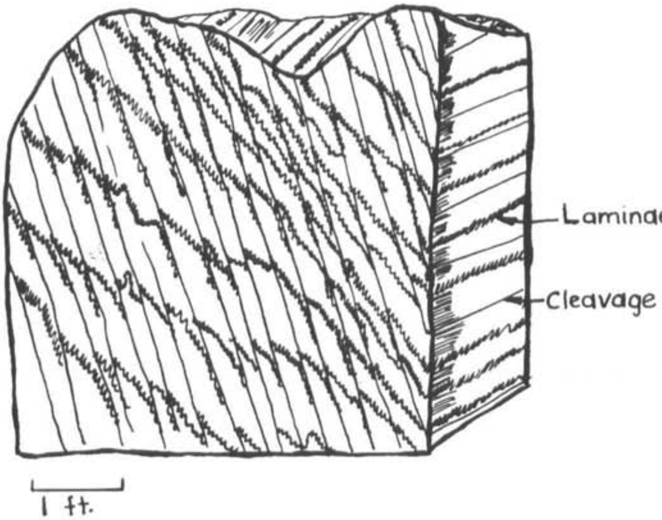
association with limestones of the more typical Crown Point luster serves to place them correctly in the stratigraphic sequence.

The black-weathering, silty and dolomitic laminae and the yellowish-orange, yellowish-gray-weathering laminae give to the weathered surface of the limestones a chained appearance. The yellowish-orange material tends to occur as small discontinuous irregular masses in many of the limestones rather than as well-defined, more or less continuous laminae. Text-figure 13 suggests the appearance of these masses. Generally the black laminae are less than a millimeter thick, but locally they may increase to bands as much as 2 to 4 inches thick.

On the average, the laminae and the irregular masses probably constitute only about 5 percent of the rock, but locally they become more important, comprising as much as 15 or 20 percent. Exceptionally they may constitute up to 50 percent of a limestone bed 3 or 4 feet thick.

The individual laminae branch and anastomose, expand and contract, in a very irregular fashion; many form loops which are filled with the bluish-gray matter of the limestone beds. Yet the laminae define the bedding planes of the limestones and thus may be utilized in areas of extensive shearing to separate the bedding and fracture cleavage where shearing may have obliterated all other evidence of stratification.

In the highly sheared limestones the fracture cleavage resembles closely spaced bedding planes and is easily mistaken for bedding; how-



Text-fig. 14. Generalized diagram illustrating cleavage-bedding relationships in Crown Point limestone. Note offsetting of buff- and brownish-weathering laminae along cleavage planes. Generalized from field notes and sketches. See Plate 9, Figure 3 also.

ever, close examination of the exposures will demonstrate that the true bedding is defined by the silty and dolomitic laminations and that it lies at an angle to the apparent bedding or cleavage. Text-figure 14 is a field sketch illustrating these relations. Where the limestones have been extensively sheared, black, thin, platy material lies along the cleavage, adding further to the ease of confusion between bedding and cleavage. Even in areas that have not been intensely sheared, as along the lake, the beds with the black, silty partings in some abundance exhibit fracture cleavage, and in these beds extra care must be exercised that cleavage is not mistaken for bedding.

Brainerd and Seely (1896, p. 306) recognized a fourfold division of the Crown Point on Valcour Island and in their initial work on the Chazy (1888) they recognized a fivefold division of these beds in the type area at Chazy, New York. Similarly, Erwin (1957) was able to differentiate a fourfold sequence on Isle la Motte, but could not systematically map the four divisions on South Hero. Oxley and Kay (1959, p. 830–833) recognized only normal marine and reef facies within the formation and made no attempt at subdividing it otherwise. It appears that away from the reef structures of the Crown Point there are no variations of the limestones that are systematic or widespread enough to be amenable to mapping. Aside from the general trends noted on the following pages the author has recognized no well-defined stratigraphic variations within the formation.

Though no attempt has been made to map in detail the variations in concentration of the black silty partings and the yellowish-orange, dolomitic laminations and irregular masses, it has been noted that black silty partings and laminae which give rise to the nodular, thin-bedded appearance of the limestones on weathered surfaces are more prominent in the lower part of the formation. As a rule the layers of limestones in the lower part of the formation, separated by silty partings, are somewhat thinner than the beds at the top of the underlying Day Point.

Upward in the Crown Point section the dolomitic, black, silty partings become less important. In parts of the formation they are replaced by yellowish-orange-weathering, silty, dolomitic laminae and irregular masses which do not stand out as sharply on the weathered surfaces as do the black laminae and which do not cause the limestone beds to weather with the thin-bedded aspect of those lower in the section. The beds become thicker with the decrease in the silt laminae. Elsewhere there is simply a decrease of the dolomitic and silty components of the formation or a uniform spreading of the dolomite through the limestones. Such occurrences give the Crown Point limestones a very finely crystalline, sparkling appearance similar to that of the Valcour. The soil over the less silty beds lacks the small, platy, black fragments so common over the limestones of the lower part of the formation.

Where the silty laminae decrease in importance, reflecting a general decrease in the silt content, an accompanying increase of bedding thickness is apparent. Concomitantly the bedding becomes more massive. Sublithographic limestones form a larger proportion of the formation in intervals where the laminae are less prominent. An example of the change may be observed in the exposures southeast of Dean Island.

Where the dolomite increases in the small masses, an attendant change in their appearance on weathered surfaces takes place. They appear more as splotches and wisps of buff-colored material than as well-defined partings or laminae.

Some parts of the lower portion of the formation also lack the black, silty laminae and contain in their place the buff-weathering, irregular masses and laminae. These beds lack the well-developed nodularity associated with the base of the formation elsewhere.

On the headland west of Kingsland Bay in Ferrisburg, the silty partings are replaced in part by fine-grained quartz sand, and the limestones are more dolomitic than those elsewhere in the lower part of the formation. Across Kingsland Bay, on Bluff Point and in the vicinity of École Champlain, the lower limestones contain the typical black, silty partings.

In a general way, the black, silty partings are less important in the limestones of the Crown Point along the eastern margin of the Central Champlain Valley while the dolomitic material is more important than to the west.

Systematic variation in the distribution of the fossil-fragmental and sublithographic limestones is absent. Coarse-grained fossil-fragmental limestones may be overlain by sublithographic limestones and underlain by fine-grained fossil-fragmental limestones, or any of the other variants found within the formation. Likewise, a sublithographic or lithographic limestone may grade vertically as well as laterally into a coarse-grained fossil-fragmental limestone, or *vice versa*. Pockets of very coarse-grained fossil fragments, literally coquinoid, are found associated with local concentrations of ***Stromatocerium***, straight nautiloid forms, an abundance of *Girvanella*, and *Maclurites* in sublithographic and fine-grained fossil-fragmental limestones. The oval-shaped masses of *Girvanella* form not only pockets in the limestones but also more extensive bands or layers, and sometimes thin lenses.

In the fossil-fragmental limestones and in the sublithographic limestones with significant proportions of fossil fragments, the dolomite crystals occur in irregular masses and laminae which usually have quartz silt distributed through them. The quartz dominates in some masses while in others the dolomite rhombs are more abundant. It has been noted in conjunction with the study of etched specimens of this type of limestone that the quartz silt is almost invariably restricted to the dolomitic masses and laminae and that only relatively small quantities of it are ever scattered through the limestones in the form of isolated grains. Similar associations of quartz silt and dolomite grains have been observed in limestones of the Cassin formation.

Texturewise the fossil-fragmental limestones are diverse, ranging from coarse- to fine-grained. The percentage of fossil fragments varies widely, microcrystalline calcite forming the matrix. Fragments comprising the fine-grained limestones are better rounded than are those of the coarser varieties; in the latter the grains are rounded only on the corners while in the finer grained types the fragments are more commonly subrounded to well rounded.

The bulk of the sublithographic limestones are composed of calcite grains between .005 and .01 mm. Some of these limestones have small percentages of fossil fragments, but for the most part they are rather uniform in composition with the only additional material being scattered clusters and laminae of dolomite rhombs and quartz silt.

Quartz sandstones appear in the formation as thick, massive, cross-bedded lenses composed of medium- to coarse-grained, subrounded to rounded, frosted quartz grains which have been cemented by .05- to .1-mm calcite crystals; small quantities of dolomite are mixed with the calcite in some of the sandstones. Laterally the sandstones grade into arenaceous limestones; vertically the individual sandy horizons are of limited extent. Less extensive laterally than the sandstones of the Day Point, the Crown Point sandstones record accumulation of quartz sand in pockets. No special relationship seems to exist between the type of limestones associated either laterally or vertically with the sandstones other than their being more sandy than some of the other limestones in the formation. Fossil-fragmental limestones are perhaps more common than the sublithographic varieties; some dolomitic limestones and calcitic dolostones are also associated with the sandstones.

The two most prominent occurrences of the sandstones are on the west side of the headland west of Kingsland Bay and along the ridge extending south-southwestward from Kingsland Bay to Rock Landing on Otter Creek. Stratigraphically the sandstone west of Kingsland Bay lies in the lower part of the Crown Point section; possibly it is near the middle of the section. The sandstones and sandy limestones of the ridge southeast of Kellog Bay are in the middle and upper part of the formation and outcrop intermittently from the head of Kingsland Bay to Rock Landing. Sections 16 and 22 describe the outcrops of the ridge at two localities.

Approximately 1300 feet north of Intersection 146 southeast of Kellog Bay, a massive, cross-bedded, coarse-grained sandstone appears in the Crown Point; both to the north and south of this locality the limestones are notably sandy. The cross-bedded sandstone is composed of .5- to .75-mm clear subangular and subrounded quartz grains cemented by a carbonate cement composed of both dolomite and calcite. Oxley and Kay (1959, p. 830), suggesting that it represents an environment intermediate between the reef structures and the "normal marine facies", have related this sandstone lens to the reefy structures of the area. The limestones in the immediate vicinity of the sandstone bed west of Kingsland Bay are fossil-fragmental for the most part. The bedding at this locality varies from 5 to 10 feet.

Quartz grains are locally abundant elsewhere in the Crown Point.

While they do not build up into definite sandstone beds, locally they may comprise almost 50 percent of a bed. Usually occurring as thin stringers several grains thick and only a foot or so long, the grains provide evidence of the current activity that took place as the sediment accumulated; little other evidence is readily apparent.

Evidence for current activity within the Crown Point seas consists of the rounding of fossil fragments, rounded pebbles of lithographic limestone, water-worn *Girvanella* specimens, and the distribution of the quartz grains. No current structures have been observed in the limestones except those outlined by the quartz grains and those occurring in the sandstones. The distribution of the black, silty partings also suggest the presence of gentle currents. *In toto* the evidence points to rather quiet seas. Presence of small ovoid accumulatuons of .01-mm calcite grains in some of the sublithographic and lithographic limestones suggests the presence of oscillatory currents.

Thickness.

The most northerly exposure of the Crown Point lies in Charlotte, east of Wings Point, whence the formation extends southward to the southern edge of the area in a series of discontinuous outcrop belts controlled by the faulting of the region. It also appears along the eastern part of the area in the several fault slices adjacent to the Champlain Thrust.

The best localities for thickness determinations are in the western outcrop belt where the formation is simply tilted. Even though there are only a few places where both the top and the bottom of the formation are exposed, reasonably accurate estimates of the thickness of the formation can be made in other localities.

Approximately 1 mile northeast of Cedar Island and slightly south of the line of Section 23 the outcrop width indicates a thickness of between 175 and 200 feet. Section 19, approximately .4 mile east of Dean Island shows a thickness of 180 feet in an incomplete section; a thickness of 225 feet has been measured across the main part of the hill 100 yards south of Section 18. This latter value, while representing an incomplete section, is believed to be close to the total thickness of the formation. Oxley and and Kay (1959, fig. 2b) suggest a thickness of approximately 150 feet for this area.

South of Hawkins Bay the formation appears to be between 150 and 175 feet thick. Section 16 shows a minimum Crown Point thickness of 95 feet, a value which is considerably greater than the thickness of 56 feet recorded by Oxley and Kay (1959, fig. 2b; Section 24, p. 852). There may be another 10 to 25 feet at this locality. The discrepancy in values comes about because of a different interpretation of the section in this area on the part of the author as is brought out subsequently. At Porterboro School to the north the formation appears to be approximately 75 feet thick, and south of the intersection, near Porter Cemetery, it thins down to approximately 50 feet. From Summer Point southward the formation averages approximately 200 feet in thickness.

In the eastern part of the area sections suitable for thickness determinations are rare.[2] The 300 feet assigned to the formation by Oxley and Kay (1959, p. 833) in the eastern area may or may not be correct. Faulting and tight folding in the area southeast of North Ferrisburg station complicate any thickness determination. Any value derived from the area probably represents a guess since many of the beds are repeated, and it is virtually impossible to distinguish one from another. Plate 1 and Plate 9, Figure 3 illustrate the structural relationships. Minor faults within Crown Point elsewhere limit accurate thickness determinations.

The author places the thickness of the Crown Point at 180 to 185 feet at the southwest corner of Waltham. This value contrasts with the value of 226 feet assigned to the formation at this locality by Oxley and Kay (1959, fig. 2b). A thickness of 170 is exposed between the lowest fault at the northwest corner of Buck Mountain (elevation 400 feet) and the overlying Orwell. The nature of the limestones here suggests that the fault lies in the lower part of the Crown Point; thus it is thought that a value of less than 200 feet may be assigned to the Crown Point in this area. On the other hand, only about 100 feet of Crown Point limestones are exposed on the west slope approximately a mile south of the Vergennes city line along the first road east of Otter Creek and about 300 yards north of the road to the east. Less than 100 feet, and probably less than 75 feet of Crown Point limestones, are exposed in the isoclinally folded area west of Mt. Fuller.

At the foot of Snake Mountain, near its northwest corner, the formation is approximately 200 feet thick. The thickness of the formation in the isoclinal fold on St. George Hill (approximately a mile south of the south ern margin of the Port Henry quadrangle, in the Bridport 7½ minute

[2] Oxley and Kay (1959, p. 833) report a thickness of "more than 300 feet 3 miles northeast of North Ferrisburg station." The northeast direction probably represents a misprint since such a location would place the Crown Point on top of Mt. Philo where the Monkton outcrops. Hence the belief that the direction should probably read "southeast" as the Crown Point does outcrop approximately 3 miles southeast of North Ferrisburg station.

quadrangle) is approximately 200 feet; northward and southward from this locality the thickness seems to be slightly less.

South of the area, on Crown Point peninsula in New York, Brainerd and Seely (1896) record a thickness of 200 feet for the beds containing *Maclurites magnus*. Raymond's (1902) measurements do not give a complete section of the Crown Point here; they include complete sections of the Day Point and the Valcour, but the sequence from the three measured sections is broken in the Crown Point. Raymond's (1902) Section B along the shore seems to be in the Crown Point from interval B-1 through B-9, a thickness of approximately 90 feet. If B-10 through B-12 are also Crown Point, then another 12 feet may be added to the value. The base of the section lies at the fault east of the lighthouse. Section C, also incomplete, has 138 to 150 feet of Crown Point in its lower part, depending whether the contact between the Crown Point and the Valcour is placed at the top of the C-10 interval or within the cover of C-11. Interval C-12 appears to be Valcour.

On the basis of outcrop width and average attitude a thickness of 175 to 200 feet is suggested for the Crown Point. In contrast, Oxley and Kay (1959), following Raymond (1906), assign all of the Chazy rocks at Crown Point to the Crown Point limestone and give a thickness of 306 feet to the formation (fig. 2b).

The evidence cited, together with relations not described in detail, suggest that the average thickness of the Crown Point in the Central Champlain Valley lies between 175 and 200 feet. No known evidence exists to support a much greater thickness, and in many places the formation is thinner.

Aside from possible thinning in the area of a reefy environment (Oxley and Kay, 1959, p. 833) there seems to be no obvious relationship between the variations of thickness and lithology or environment. Lateral variations of the order of magnitude found might be considered a normal phenomenon in an environment such as that in which the Crown Point apparently was deposited.

Fauna of the Crown Point

In general the collections made during the field work do not permit stratigraphic analysis of the Crown Point limestones. However, it has been noted that environmental control of the distribution of the animals is recorded in the rocks. *Maclurites magnus* Lesueur and its opercula are widely distributed through the formation, though they are not restricted to it. Specimens of this fossil are most commonly found in sublithographic, less silty, massive limestones. In the Grosse Point-Bluff Point area and east of Long Point occasional irregular masses of *Stromatocerium* can be seen; locally they become abundant, but they do not form "reefs." Orthoceraconic nautiloids are common in some places, and a few cyrtoceraconic forms were found in the massive limestones at the south corner of Kingsland Bay. Also a large (± 1 foot) nautilicone (*Plectoceras* ?) was found between North Harbor and Mile Point.

Brachiopod, bryozoan, and pelmatozoan fragments are abundant throughout the formation as coquina-like layers and as scattered elements of the sublithographic limestones. The manner in which they protrude on weathered surfaces is a characteristic of the Crown Point. The outcrop belt south of Kingsland Bay contains many fossiliferous localities; in a few the limestones suggest small biostromes.

Large colonies of cerioid corals have been found in several places in the Crown Point and Valcour limestones. On preliminary examination these corals might be mistaken for *Foerstephyllum* (=*Favistella* of some authors and *Columnaria* of the early workers, in part), for they closely resemble the coral colonies of this form. However, study of sections of the colonies show them probably to be the form *Nyctopora* (Bassler, 1950). Bassler (1950, p. 262) reports a species of this genus from the Middlebury limestone a mile northwest of Middlebury.[1]

Specimens have been collected from two localities and a large coral head of the same type occurs at a third. Fossil locality 233 (Appendix II) located approximately 850 to 900 feet west of Triangulation Point 131, east-southeast of Grosse Point is one of the locations. Here the form occurs with numerous specimens of *Stromatocerium*. Scattered small heads of *Stromatocerium* are common in the Crown Point limestone of this area, but there is no strong evidence for a "reefy" environment. A number of specimens of the coral can be found here. Another large cerioid coral colony occurs in the Crown Point on the small knob approximately .25 mile south of the mouth of Little Otter Creek. On a weathered surface it resembles in appearance the forms from the locality to the west, and therefore it is assumed that it is the same genus.

The third locality at which *Nyctopora*? has been found is in Braisted Creek, approximately 5400 feet N. 30° E. of West Bridport in the Ticonderoga 15 minute quadrangle (Crown Point 7½ minute quadrangle). The coral forms a mass 18 inches in diameter. Other forms tentatively identi-

[1] Study since the preparation of this manuscript shows that these forms are *Foerstephyllum*. See Welby, 1961, Journal of Paleontology, v. 35, p. 391–394.

fied at this locality are *Stromatocerium*, *Streptelasma?*, ramose bryozoa, *Rostricellula, Isotelus, Maclurites,* and a number of small gastropods. The bed lies beneath undoubted Orwell, and its relationship to adjacent rocks places it within the Valcour formation, perhaps near the base.

All of the specimens collected closely resemble *Foerstephyllum*, but the septa appear to be shorter and to be in a cycle or cycles of 8. The beds from which all the specimens were collected or in which they were seen are undoubted Chazyan. In the case of the specimen south of the mouth of Little Otter Creek typical *Maclurites magnus*-bearing limestones of the Crown Point lie over and beneath it. The specimen from locality 233 might be in the Valcour, but certainly it does not come from any formation younger than this.

Identification of the form as *Foerstephyllum* would lead one to think that either *Foerstephyllum* is not restricted to post-Chazyan rocks or that parts of the Crown Point are younger than now thought. The occurrence of *Streptelasma* or *Streptelasma*-like corals with the colonies might suggest a correlation with beds of the overlying Black River and Trenton groups.[1]

Valcour Formation (Cushing, 1905)

General

The Valcour formation, conformable over the Crown Point, is a variable unit within a general limestone lithology. Parts of the formation resemble the Day Point; other parts resemble the underlying Crown Point, and still others are distinctive and readily recognizable. Within the sequence of beds grouped together as the Valcour formation are beds that can be differentiated from the overlying Orwell sublithiographic and lithographic limestones only with difficulty. Yet, despite the variability of the lithology and the resemblances to other formations, the Valcour is a distinctive unit possessing characteristics of its own.

The formation is restricted to the western part of the Central Champlain Valley, although it is believed present on the west bank of Little Otter Creek approximately .4 mile south of the Ferrisburg railroad trestle. This exposure is isolated from the rest of the Valcour, and actually it may belong to the Crown Point. However, the stratigraphic position of the outcrop and the general dolomitic aspects of the limestone suggest strongly that the outcrop represents the Valcour. If the outcrop is correctly placed srtatigraphically, then its presence infers the existence of a small isolated basin separated from the main area of Valcour deposition.

[1] See footnote on p. 137.

The formation has not been recognized in Charlotte northeast of Cedar Island nor east of Wings Point. In this northern area Crown-Point-type limestones grade directly into the massive, sublithographic limestones of the Orwell. The thickness data shows that the formation thins northward and presumably disappears between Long Point and the latitude of Thompson Point. Absence of the formation at the northern end of the Chazy outcrop belt and in the eastern part of the area is attributed to lateral graduations into Crown Point-type lithology rather than to any general hiatus in the depositional history of these areas or to removal by erosion. All evidence seems to point to continuous sedimentation.

Thickness.

The thickness data indicate that the formation is a wedge-shaped body which thins to the east and north, eventually disappearing completely. Southward from Panton and westward from its meridian the Valcour thickens. On the tip of Long Point, in Ferrisburg, the formation has a thickness of approximately 85 to 95 feet, and east of Long Point, halfway to the North Ferrisburg railway station, the formation is probably no thicker and very likely is somewhat thinner.

On the small knob .75 mile east of Porter Bay (Section 22,) the Valcour is 25 to 30 feet thick; the mixing of dolostone and sublithographic limestone suggests that the uppermost beds on the east side of the knob are less than 5 feet below the contact. At Porterboro School, approximately a half mile to the south, the thickness is of the order of 20 to 30 feet. On the small knob south of the Fort Cassin turn-off, southeast of Kellog Bay, an incomplete 20- to 25-foot section lies above the Crown Point; the top of the formation is covered here. This value contrasts with the 37 feet reported by Oxley and Kay (1959, Ferrisburg section) for this locality. In the exposures just north of Porter Cemetery, south of Intersection 146, the Valcour is from 15 to 20 feet thick while some 70 to 80 feet of the formation are exposed south of the cemetery. A section measured across the ridge about halfway between Panton village and Webster School shows the presence of approximately 64 feet of Valcour (Section 20.) Slightly north of the position of the line of Section 20 the formation is 53 ± 5 feet thick.

The measured section east of Spaulding Bay (Section 17) includes approximately 85 feet of Valcour with an additional 25 to 30 feet at the top lying beneath the cover to the west of the road from Panton. Approximately a quarter mile north of Arnold Bay, 75 to 80 feet of the Valcour dolomitic limestones are exposed above the fault. Near the mouth of Hospital Creek, north of Chimney Point the outcrop width suggests a thickness of 100 to 110 feet.

Brainerd and Seely (1891) assign a total of 57 feet to the unit at Crown Point, recognizing a lower dolomitic horizon and an upper limestone horizon in which the beds weather with slightly raised ridges. This latter feature is a characteristic of the formation in other localities. The upper 35 feet of Raymond's (1902) Section B is probably Valcour (intervals B-10 to B-16 inclusive). Interpretation of Section C (Raymond, 1902) suggests a thickness of approximately 75 feet (C-11 through C-17; C-17 should probably be given a value of 8 feet instead of the 20-foot value assigned it by Raymond). Outcrop width points to a thickness of this order. A thickness of 150 to 175 feet is assigned to the formation in the outcrop belt from North Harbor to Button Bay in Ferrisburg. On the small hillock .7 mile S. 30° E. of Summer Point the measured thickness of the formation is 125 feet. Text-figure 15 shows some of the variations within the formation.

Lithology

As a unit the Valcour includes a great array of calcareous sediments, but massive beds, 1 to 2 feet thick, of very finely crystalline to sublithographic dolomitic limestones and calcitic dolostones are the rock types that seem to be most common. Less common are sublithographic limestones as well as medium and coarsely crystalline limestones. Dolomitic siltstones and silty dolostones occur interbedded with the other dolomitic beds. In addition fossil-fragmental limestones are locally common; many of these contain significant quantities of dolomite either as discrete, individual rhombs scattered through the limestone or as irregular masses of dolomite mixed with the shell debris. Within sequences of more or less uniform, very finely crystalline dolostone and dolomitic limestone the laterally limited layers of shell debris seldom exceed 4 to 6 inches in thickness. Regional differences stand out when rocks of the Valcour are compared with those of the Crown Point, but locally resemblances exist which make differentiation of the two formations difficult. The most striking difference between the rocks of the two formations is the presence of the dolomitic and silty partings and laminae of the Crown Point limestones and their general absence in the Valcour beds; furthermore, the nodularity and thin-bedded appearance of the Crown Point is lacking in most of the Valcour.

On an exposed surface the Valcour beds tend to weather to a darker bluish-gray or gray than do the beds of the Crown Point, or they weather to a yellowish-gray or dun color which contrasts with the bluish tints of the weathered surfaces of the Crown Point limestones. Fine raised lines on the weathered surfaces of some of the Valcour dolomitic beds hint at current activity.

Fresh surfaces of the Valcour limestones and dolostones give a rather uniform, sparkling luster which contrasts with the dull "salted" appearance of the more bluish fresh break of a typical Crown Point limestone. Moreover, fresh surfaces of the Crown Point limestones reflect light unevenly, causing an irregular distribution of luster characteristics.

The luster combined with the fine texture of the rocks frequently suggests that the rocks contain significant proportions of silt or secondary silica; however in most, silt is absent, or present in very limited quantity, and secondary silica is rarely found except in occasional veinlets. Blue-black chert is locally common in the black, lithographic limestones and in some of the sublithographic limestones.

The grayish-orange- and yellowish-gray-weathering dolomitic beds of the Valcour are resembled in the Crown Point only by the occasional dolomitic and silty beds. Some of the calcitic dolostones present a fresh surface that has a "dusty" appearance. Examination of etched surfaces indicates that the "dust" is composed of silt-size dolomite rhombs which rarely exceed .1 mm and which average .06 mm.

Weathered bedding surfaces of many of the dolomitic limestones and calcitic dolostones exhibit low yellowish-gray masses that are approximately 1 inch long, perhaps .25 inch across and .12 inch high. These ridges or masses represent local concentrations of dolomite and seem to characterize much of the finely crystalline to sublithographic rocks of the Valcour. Their presence combined with the even-granular texture of the weathered surface and the sparkling luster serves to identify the Valcour; however, some of the uppermost beds of the Crown Point resemble these beds. Therefore, attention must also be given to other criteria when separating the two formations. When the dolomite is concentrated in thin zones or laminae, its greater resistance to weathering causes ridges on weathered surfaces. This weathering characteristic is best developed in the exposures at Crown Point.

Like the Crown Point below, the Valcour contains quartz sandstone in places; at other localities and stratigraphic horizons the limestones bear significant quantities of rounded, frosted quartz grains and subrounded clear quartz. The arenaceous beds are distributed from Long Point to Crown Point. About halfway between Panton village and Webster School to the north, quartz becomes especially prominent in the limestones and remains as an important constituent of the rocks of the formation southward to the limits of the Valcour outcrop belt in Panton.

Quartz pebbles 2 to 4 mm in diameter occur in some of the coarser sandstones, as. for example, in the outcrops between Kingsland and Porter Bays. About 500 feet north of the Hospital Creek bridge on Route 17, north of Chimney Point, purple quartzite pebbles up to several millimeters in diameter are mixed with the quartz grains of the sandy limestones and calcareous sandstones.

While no definite pattern of distribution of the sands within the formation has been recognized, it is noted at the same time that the arenaceous beds seem more common in the lower and middle parts of the formation than in the upper third which grades into the Orwell through dark-colored, conchoidal-fracturing, sublithographic limestone, finely crystalline dolomitic limestone, and calcitic dolostone.

The sandy horizons are best exposed southwest of Kingsland Bay and in Panton from the Panton-Ferrisburg town line south to the limit of the exposures of the formation in Panton. In the vicinity of Kingsland Bay the contact between the Crown Point and the Valcour is placed where the limestones first contain quartz in abundance together with a concomitant change in the luster of the limestones. Locally in this area, coarse-grained sandstones develop in the formation at or near the contact. Brainerd and Seely (1891) recognized the presence of a sandstone at what they considered the top of the Chazy group here.

The more finely crystalline carbonate sediments range from limestone to dolostone. Calcite grains .01 mm in diameter are accompanied by varying proportions of dolomite, silt and sand, fossil fragments, and .1- to .3-mm subspherical and ellipsoidal masses composed of .01- to .02-mm calcite grains. Subspherical masses of calcite may be surrounded by a matrix of .2- to .3-mm calcite crystals or by a matrix of .01-mm grains, or the matrix may contain significant proportions of each. Average grain-size of the dolostones is slightly under .06 mm. A few are coarser; many are finer grained. Generally the dolostones possess significant quantities of calcite closely intermixed with the dolomite rhombs and of approximately the same size. Larger crystals of calcite may be scattered through the rock.

Many quartz grains in the limestones appear to have thin ($\pm$.02 mm) rims of calcite or dolomite with admixed quartz silt. Some of the dolomite masses scattered through the limestones are ellipsoidal or circular in cross-section and exhibit dark, silty rims. These relationships imply that the quartz and dolomite masses have been rolled along the bottom prior to final deposition. Similar silty and carbonate rims may be seen on fossil fragments or subspherical masses of calcite.

Many of the very light-gray to whitish, coarsely crystalline and coarse-grained fossil-fragmental limestones of the Valcour contain small pebbles of smooth-weathering, sublithographic limestone up to several millimeters in diameter. Other light-colored limestones are arenaceous with as much as 20 per cent coarse-and medium-grained, clear, subrounded quartz.

Channels filled with shell debris, intraformational breccias, and cross-bedding in both the sandstones and the limestones, attest to the activity of currents within the seas, as do the ellipsoidal and subspherical .1- to .2-mm masses of ± .01-mm calcite. The distribution pattern of some of the silty and dolomitic wisps and small masses within the limestones also testifies for current activity. Yet parts of the sea bottom appear to have been relatively quiet, for sublithographic and lithographic limestones occur, composed of mosaics of ± .01-mm calcite crystals, presumably precipitated in a quiet environment.

In conjunction with this study the author examined microscopically 77 specimens from the Valcour. Of these 18 were calcitic dolostones, 17 dolomitic limestones, 21 fossil-fragmental and coarsely crystalline limestones, 16 sublithographic limestones, 3 dolostones and 2 quartz sandstones. While many of these specimens were collected for specific purposes, it is thought that the relative values indicate the approximate total composition of the formation in the proper proportions; dolomitic limestones and calcitic dolostones may be somewhat more abundant than indicated by the figures.

In the Panton area the Valcour is notably sandy and contains large proportions of fossil-fragmental limestones. The exposures north of Panton village display black, conchoidal-fracturing, sublithographic limestone which is difficult to differentiate from the overlying Orwell, although the lower part of the Valcour is typically light-colored and coarse-to medium-grained (Section 20). In this area the Crown Point-Valcour contact is placed where the limestones change in color from bluish to light-gray or almost white coincident with the appearance of significant quantities of quartz in the limestones. In the absence of quartz the appearance of a sparkling luster which suggests the presence of moderate amounts of dolomite in the rock is utilized in recognition of the contact. The top of the formation is placed below the black limestones with a slight nodular appearance caused by the scoring which seems characteristic of the Orwell. Dolomitized fossil fragments typical of the Orwell begin to make their appearance at about the same stratigraphic horizon. Since the change from one formation to the other is gradational, the contact is placed only with difficulty.

South of Panton village the sandstones and sandy limestones are more prominent than in the exposures north of the cross-roads; however, calcitic dolostones and arenaceous, finely to coarsely crystalline dolomitic limestones outcrop on the ridges approximately a half mile northwest of the cross-roads. These beds strike into sublithographic and lithographic limestones to the north. Cross-bedding is evident in many of the limestones, with or without the presence of quartz, and intraformational breccias of various sizes are not uncommon.

The sandstone beds are lenticular in shape; pockets of calcareous quartz sandstone are common. Interbedded with the coarser grained limestones are dolomitic sublithographic and very finely crystalline limestones. These latter limestones are composed in large portion of subspherical and ellipsoidal aggregates of .01-mm calcite.

Behind the house approximately a half mile south of the cross-roads at Panton, a prominent cross-bedded horizon within a light-gray-weathering sublithographic limestone may be seen. While there is a small amount of medium-grained subangular quartz present in the limestone, the cross-bedding is defined by a succession of whitish spots 1 mm in size. The spots are composed of .04-mm dolomite crystals. Examination of a thin section of this rock discloses that the whitish areas possess an exceedingly thin dark rim. This fact suggests strongly that they were transported prior to coming to rest; their definition of north-dipping cross-beds lends support to this idea also.

The northernmost exposures of the Valcour seem to be chiefly very finely crystalline to sublithographic calcitic dolostones and dolomitic limestones. Most of these rocks are slightly silty, and all are characterized by their dark-bluish cast on a fresh break and by their sparkling luster. The more dolomitic beds weather in shades of yellowish-gray. Interbedded are coarsely and medium crystalline limestones; fossil-fragmental limestones are relatively rare in this part of the formation, although locally some of the limestones contain moderate amounts of fossil debris, and some fossils appear on the weathered bedding surfaces of the limestones. The shell material of the gastropods and some of the cephalopods has been dolomitized; brachiopod, pelmatozoan, and cephalopod fragments are present. Instead of occurring as extensive beds, shell fragments are more commonly concentrated in pockets and local areas within the fine-grained limestones. The associated sublithographic limestones are composed of subspherical and ellipsoidal masses of .01-mm calcite as well as mosaics of calcite grains of this size. In proximity to many of the pockets of fossil fragments are pockets of quartz sandstone or very arenaceous limestone.

The exposures of the formation in the outcrop belt beginning approximately a mile southeast of Grosse Point and extending southward to Otter Creek are chiefly dolomitic limestones and calcitic dolostones. Coarsely crystalline limestones and coarse-grained fossil-fragmental limestones form important elements of the formation here too.

At two localities the formation is characterized by intimate mixtures of light bluish-gray-weathering sublithographic limestones, coarse-grained fossil-fragmental limestones of various shades of gray, and yellowish-gray to yellowish-brown-weathering sublithographic calcitic dolostones, some of which contain significant portions of fossil fragments. The dolostones are distributed irregularly through the limestones, and they may or may not form well-defined beds. Sometimes the dolostones form irregular pods within the sublithographic limestones.

The northernmost locality lies at the north end of the outcrop belt, approximately a mile southeast of Grosse Point. It is described in some detail in Section 22. The southern locality is located on the small knoll .75 mile southeast of Kellog Bay (Section 21). This latter locality has been described by Oxley and Kay (1959), and they refer to it as a "reef zone" (p. 836). Large, straight cephalopods (up to 10 inches along) are to be found at both localities, being more common, perhaps, at the southern one. Brachiopods, pelmatozoans, and bryozoans are other faunal elements at both localities. Fossils identified from the Valcour of Section 22 are listed under locality 362A. Fossils identified from the Valcour at the locality of Section 21 are given under localities 363 and 463. Fossils from the lower part of the Valcour approximately a half mile to the north are listed under localities 250 and 464.

The Valcour formation in the area between Summer Point and Button Bay consists of sublithographic limestones and calcitic dolostones; locally quartz sand grains are important in the rocks, building up into occasional lenses of coarse-grained quartz sandstone. Fossil-fragmental limestones are also important locally in this part of the formation.

The contact between the Valcour and the Orwell is exposed in only a few places. The most revealing of these are located on the west shore of Long Point and about 600 feet south-southeast of Porterboro School, east of Kellog Bay. In each of these localities pods and blobs of sublithographic, yellowish-gray and yellowish-brown, calcitic dolostones and

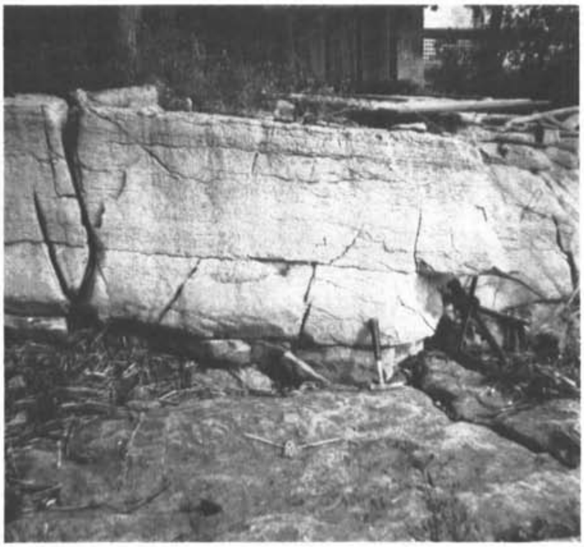


PLATE 10

Figure 1. Limestone and dolostone mixing near top of Valcour; west side Long Point, Ferrisburg. Darker splotches are dolostone.

Figure 2. Valcour-Orwell contact, west shore Long Point. Hammer rests on top of splotchy Valcour which is overlain by very light-gray-weathering, massive Orwell, locally containing "*Phytopsis*".

PLATE 10

Figure 3. Orwell biostrome on Button Island, showing coral and *Stromatocerium* heads.

dolomitic limestones up to 3 feet in diameter can be seen mixed with the light bluish-gray-weathering, conchoidal-fracturing, lithographic and sublithographic limestones of the Orwell. Blobs and pods of Orwell lithology occur isolated within the dolomitic material of the Valcour; similarly, above the last well-defined bed of dolostone yellowish-brown-weathering blobs of dolostone and limestone are suspended in a matrix of light bluish-gray-weathering limestone. At Long Point the lowest Orwell bed has a sharp contact with the underlying zone of mixing. Figure 1, Plate 10 is a photograph of the zone of mixing on Long Point, and Figure 2 shows the contact between the Valcour and the *Phytopsis*-bearing Orwell limestone.

The best explanation for the phenomenon seems to be one that views the two lithologies as chemical precipitants. It is believed that the Orwell material began to precipitate while the seas were still charged with the dolomite-rich sediment of the Valcour-type and that the dolomite-rich material remained in the environment for a short period after the Orwell-type of limestone became the primary precipitant of the sea. Perhaps there was some physical mixing to distribute the materials.

Another possible explanation emphasizes more the physical mixing of the two materials while they were still soft and plastic. However the boundaries between the blobs and the matrix are not sharp, a fact which suggests that the two components blend into one another and that there has not been any significant stirring of the materials. The top of the formation is most conveniently placed at the base of the well-defined *Phytopsis*-bearing bed of the Orwell.

The mixing of the bluish-gray limestones and the dolostones at both the locality a mile southeast of Grosse Point and the outcrop on the knoll approximately .75 mile southeast of Kellog Bay are suggestive of the transition zone at the top of the Valcour.

In the outcrop belt extending north and south of Panton the change from the Valcour to the Orwell is gradational, but the appearance of mixing is not present. The limestones at the top of the Valcour resemble closely the black limestones of the Orwell. However, variations in the weathering characteristics and the presence of the scoring and layers of dolomitized fossil fragments in the Orwell serve to set it apart from the Valcour. North of Arnold Bay the relations are similar.

Fauna and Correlations

The faunal list for the Valcour when studied with those for the Day Point and the Crown Point formations (Appendix II) provides no clues on correlation of the Valcour, indicating only that forms once thought (Bassler, 1915, p. 1448–1449) restricted in their ranges have longer time spans. *Maclurites magnus* Lesueur is common in the light-colored Valcour fossil-fragmental limestones and in some of the arenaceous beds, particularly in the outcrops north and south of Panton village. The form is also common in limestones outcropping near Basin Harbor School and northwest of Button Bay. The faunal evidence presented here, that given by Raymond (1902; 1906), and the summary of Bassler (1915, p. 1448-1449), together with the evidence assembled by Oxley and Kay (1959) would seem to indicate that the Valcour deposits exposed in the Central Champlain Valley of Vermont and at Crown Point were formed essentially contemporaneously with those in the northern part of the Lake Champlain region.

The occurrence of a specimen closely resembling *Christiania subquadrata* (Hall) at fossil locality 250, southeast of Kellog Bay, lends support to the contentions of Rodgers (in Twenhofel and others, 1954) and Kay (1958, p. 84) that *Christiania* ranges lower than had been previously thought (Twenhofel and others, 1954). The locality is in the lower half of the Valcour exposure stratigraphically. Approximately 150 yards to the north, at locality 464, *Rostricellula plena* (Hall) has been found in a position slightly lower stratigraphically. Oxley and Kay (1959) report finding *Rostricellula* south of École Champlain (p. 834), presumably at the knob on which the Valcour is exposed in Section 22.

Chazy History and Correlations

The break between the Canadian and Champlainian is slight, if existent, in the Central Champlain Valley, and a similar relationship is believed to apply to the deposits of the northern part of the Lake Champlain region. The structural relations fail to indicate any significant break, and if a hiatus exists, the contact between the Bridport and the Chazy sequences is paraconformable. Previously (Raymond, 1906; Oxley and Kay, 1959) the Day Point has been thought absent from points south of Summer Point in Ferrisburg, but as shown elsewhere the Day Point outcrops south of Crown Point. The fauna recorded from the exposures at Summer Point (localities 303, 324, 479A) provide only flimsy evidence for the age of the rocks. The assemblages imply the equivalence of the Summer Point sequence to the type Day Point rather than to the beds higher in the section. The "argillaceous calcisiltite" reported by Kay (1958, p. 81) to outcrop at the north end of the Sudbury Nappe suggests the presence of beds equivalent to the Day Point even farther south and east.

The "disconformity" at the top of the Bridport seems non-existent within the immediate Lake Champlain area. The author submits that the Ordovician seas covered continuously much of what is now the Central Champlain Valley from the Canadian into the Champlainian. Local warping may have changed the configuration of the bottom and affected the distribution of the sediments, but no general withdrawal of the sea followed by erosion seems indicated.

The Middlebury limestone of the area east of the Champlain Thrust represents the entire Chazy sequence of the Central Champlain Valley. To the northwest lies the St. Martin limestone of the St. Lawrence lowland which is correlated with the lower part of the Valcour (Wilson, 1946; Kay, 1958). While the Pamelia formation of the Thousand Islands region is presently placed with the Black River group (Kay, 1937; Twenhofel and others, 1954; Cooper, 1956, p. 18), earlier it had been correlated with an interval between the Crown Point and Valcour (Cushing and others, 1910, p. 78–79; Cushing, 1911, p. 139; Ulrich, 1911, p. 27; Wilmarth, 1938). Figure 10 of Kay's paper on the Highgate

Springs sequence (1958) suggests that the Pamelia might be in part correlative with the Valcour. The fact that the lower sands are gradational with the Almyer in the Ottawa Valley (Cooper, 1956, p. 18) suggests a similar conclusion.

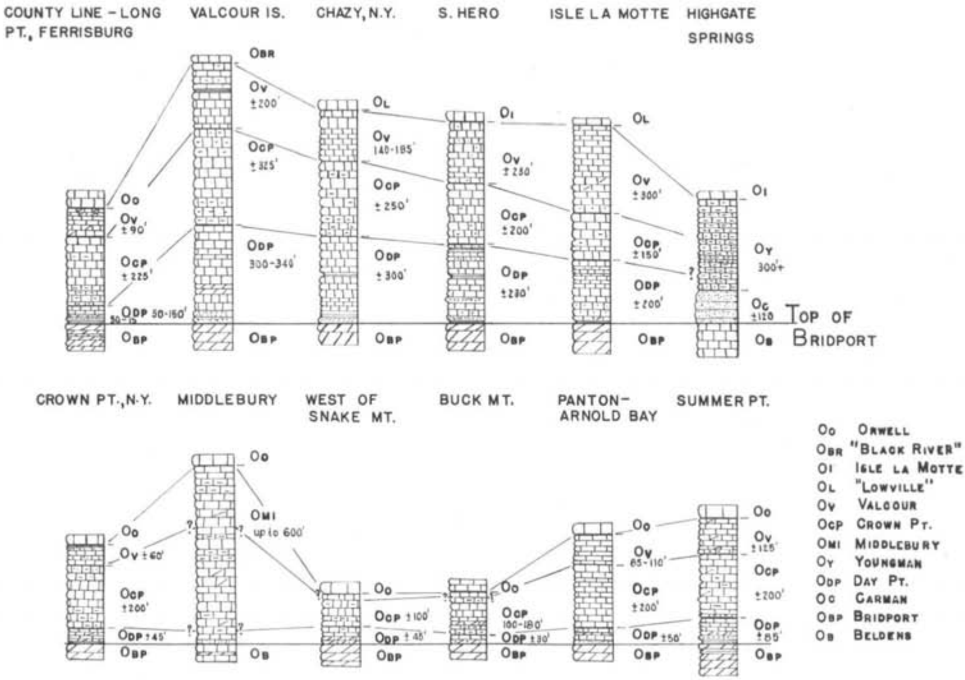
Kay (1958) correlates the Carman quartzite and Youngman formation of the Highgate Springs sequence with the Chazy of the adjacent Lake Champlain area. The Carman is correlated with the lower half of the Day Point, and the Youngman is taken to represent the rest of the Chazy (Oxley and Kay, 1959, fig. 4).

Comparison of the thickness data for the Central Champlain Valley and the northern part of the lake (Text-figure 15; Table 4) emphasizes the greater accumulation of sediments in the island region. The relations imply the presence of a more rapidly downsinking area in the north, as if a "hinge-line" existed in the latitude of Burlington. Part of the greater thickness may be related to the abundance of shell debris spread from the organic structures. The data also show a thinning of the Chazy from west to east to the meridian of the Champlain Thrust belt. The thickness of the Middlebury limestone to the east of the Central Champlain Valley is up to 600 feet (Cady, 1945, p. 554) on the eastern limb of the Middlebury Synclinorium.

Implications drawn from the available information point to the possible existence of a submarine barrier or a less rapidly downsinking, linear feature in the longitude of the eastern margin of the Central Champlain Valley. To the east lay possibly a slightly deeper trough or a slightly more rapidly downsinking area. In the deeper water accumulated the Middlebury limestone while the Day Point through Valcour sequences were accumulating to the west. It is believed that all the accumulations occurred in the neritic depth zone.

The Central Champlain Valley and immediately adjacent areas may be pictured as an area of a shallow shelf sea with the Adirondacks as a low-lying landmass on the west. From the landmass came the quartz sand found in the formations of the group and probably that forming the Carman quartzite in the Highgate Springs area (Kay, 1958). Perhaps the area was a narrow, shallow, inland sea.

An abundance of fossil fragments accumulated in the shallow seas as did lime muds, lime oozes, and quartz sands. Notable is the association of dolomite with much of the very fine sand and silt in the form of silty and sandy dolostones or dolomitic sandstones. The Day Point instead of representing a sandy horizon associated with an advancing sea apparently represents a wedge of detrital material spread eastward at the



Text-fig. 15. Correlation of Chazy group. Stratigraphic datum is the top of the Bridport-Beldens, top of the Canadian; from various authors and actual measurements.

opening of Chazyan time. Initial distribution was over a wide area. The limestones of the upper part of the Day Point are taken to record a lessening of the input of detritus into the system. The hypothesized "barrier" or "hinge area" along the eastern margin of the Central Champlain Valley may have acted as an impediment to the eastward transportation of the detrital grains.

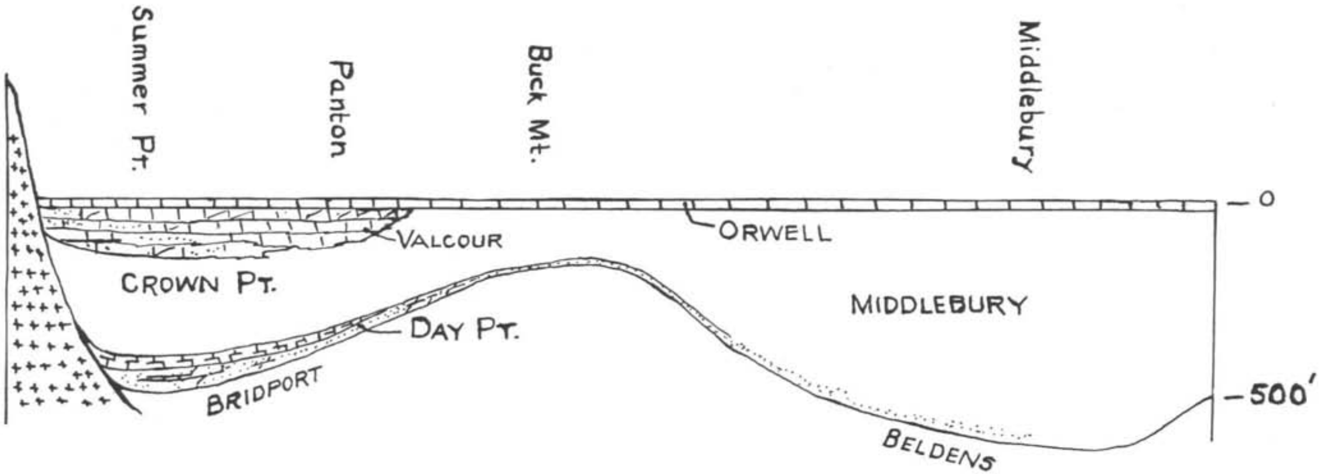
Quartz sandy horizons at the base of the Middlebury formation imply that some of the detritus was spread rather widely. After the early influx of sandy sediments in the area east of the Central Champlain Valley, the sediments became largely lime muds and oozes. To the west layers of fossil fragments which were to become the upper limestones of the Day Point accumulated. To the north the Day Point reefs appeared as low eminences on the sea bottom. Similar structures continued to grow throughout Chazyan time. In the Highgate Springs area the detrital material dominated the environment so completely that essentially only quartz sands were deposited.

Day Point environments were succeeded gradually by environments favoring the deposition of widespread layers of shell fragments and lime muds which were to become the Crown Point limestones. The Crown Point environments probably encroached from the east, representing an expansion of the Crown Point-Middlebury type of deposit. Some of the calcite grains aggregated into small masses and were rolled about the bottom by currents. Sand was supplied from the west, but in decreased amounts, and locally lenses of quartz sands were deposited. Some of these seem closely associated with "reefy" zones; others represent local accumulations that were not ostensibly affected by organic structures.

The Crown Point detritus was primarily very fine silt which today forms the laminae found in the Crown Point limestones. Locally very fine sand and silt was mixed with the precipitating carbonate in a magnesium-rich environment. The resulting product forms at the present time the silty and sandy dolostones of the Crown Point.

The widespread distribution of beds of Crown Point-type lithology throughout the Champlain Valley and in adjacent areas suggests that the Adirondack landmass was temporarily lower than in the immediate past. Also the sea may have expanded, overlapping adjacent areas.

A second influx of sand and silt is reflected in the Valcour formation; also a return to conditions favoring moderately widespread dolomite formation is implied by the dolomitic limestones and calcitic dolostones of the Valcour. Local, renewed vigor on the part of the currents is suggested by the features of the sediments; some of these features could imply a shoaling of the water. Reef-making continued to the north in the latitude of the Lake Champlain islands, but to the south, in the Central Champlain Valley, the reef environments seem to have been limited. Like the Day Point below, the Valcour wedges out to the east where it is replaced laterally by limestones of the Crown Point-Middlebury type. Valcour lithology seemingly disappears at about the position of the supposed northerly trending "barrier" or "hinge-line" mentioned above. A preponderance of very finely crystalline and sublithographic dolomitic limestones in the Valcour with little or no fine silt in the form of black, platy partings suggests that the clastic material may have decreased in quantity. Yet locally currents were active bringing in moderate quantities of coarse quartz sand and depositing them in cross-bedded layers with dolomite grains and fossil fragments. The fines were probably winnowed out and carried eastward.



Text-fig. 16. Restored section, Adirondacks to Green Mountains, illustrating probable facies relationships of the Chazy group. Stratigraphic datum is the base of the Orwell limestone.

Gradually conditions altered so that the area in which the Valcour was deposited became less favorable for the deposition of dolomitic materials, and in local areas, at least, the components of the sublithographic and lithographic limestones closely resembling the succeeding Orwell were laid down. In other areas the dolomite-rich sediments were mixed with material containing less dolomite so that a transition from the Valcour to the Orwell began. One can picture a gradual quieting of the currents and a decrease in the amount of detrital material that was fed into the area. Finally the conditions favoring the accumulation of the components of the sublithographic and lithographic limestones of the succeeding Orwell took over, and Chazyan history came to an end. The restored section at the beginning of Orwell deposition is given in Text-figure 16.

Champlainian Series
Lower Mohawkian (Black River) Stage

ORWELL LIMESTONE (Cady, 1945) (*Revision*)
General

Cady in his description of the geology of West-Central Vermont (1945) proposed the name Orwell for limestones lying between the Middlebury limestone and the Glens Falls limestone (p. 556). He correlated these limestones with the Rockland formation. Recognizing the presence of "Lowville" limestones beneath the Orwell in some places, Cady lumped them with the Orwell on his map. Thus in effect he placed all of the beds between the Middlebury and Glens Falls limestones in the Orwell. The rocks over the Valcour and beneath the Glens Falls formations in the Central Champlain Valley fit the description of the Lowville-Orwell sequence of West-Central Vermont. The term Orwell is expanded to include all of the limestones between the Chazy formations and the Glens Falls.

Kay (1937, p. 260, fig. 9) thought he could differentiate in the Crown Point section several limestones between the Chazy group and the lower beds of the Glens Falls limestone. Immediately below the Glens Falls limestone he placed the Isle la Motte limestone, indicating that it was above the "Amsterdam" and "Chaumont" limestones. More recently, however, he has indicated that the Isle la Motte limestone should be correlated with the Chaumont (Kay, 1958, p. 86–87).

It has been the author's observation that there is a two fold division of the limestones in the Central Champlain Valley and that the same subdivision is appropriate at Crown Point. A lower, thin (± 5 feet), very light-gray-weathering, smooth-fracturing, "*Phytopsis*"-bearing limestone of good lithographic texture is overlain by a series of massive, slightly darker weathering, scored and sometimes rubbly weathering limestones. These are dark grayish-black to black on a fresh surface and fit closely the appearance of the Isle la Motte limestone of Isle la Motte and South Hero. The lower limestone is the "Lowville" of most authors (Cushing, 1905; Kay, 1937; 1958; Cady, 1945; Erwin, 1957; Oxley and Kay, 1959), although Kemp and Ruedemann (1910, p. 72) indicate that more than just the "dove-colored" limestone should be correlated with the Lowville of the Black and Mohawk River valleys. They note the apparent absence of the lower limestone in the Westport region.

Beds correlative with the sequence between the Valcour and Glens Falls limestones are not exposed in the New York part of the Willsboro quadrangle (Buddington and Whitcomb, 1941). Cushing (1905, p. 371–373) outlined the general distribution of the "Lowville" and "Black River" limestones and showed the presence of the latter in the vicinity of Chazy, New York (Plate 12). He pointed to the twofold subdivision of the post-Chazyan rocks and pre-Glens Falls rocks, but he failed to recognize the presence of the Lowville in the Champlain Valley.

In the Central Champlain Valley the Orwell outcrops sporadically and in association with the Valcour and Crown Point formations. Its northernmost outcrop is at Wings Point where the upper part is exposed just above water level; the southermost outcrop is northeast of West Bridport. The only extensive outcrop belt lies on the ridge extending north and south of Panton. Several other outcrop belts lie beneath the Champlain Thrust where the formation is involved in the structural complications attendant upon this rupture. Near Mt. Fuller, southeast of North Ferrisburg, the massive Orwell beds are isoclinally folded in a slice beneath the Champlain Thrust.

Thickness

The formation averages between 40 and 50 feet thick. In at least two localities it is almost twice this figure; in other places it is much less. At Porter Cemetery the light-weathering, "*Phytopsis*"-bearing limestones and overlying darker gray limestones are 75 feet thick. The fossil layers and bands are present throughout the sequence of beds, and a large cerioid coral colony resembling *Foerstephyllum halli* is also present about midway in the section. The lower, light-colored limestone is between 10 and 15 feet thick. Slightly north of the fault .25 mile north of Arnold Bay, the formation is between 95 and 100 feet thick. Here a 3- to 4-foot lower bed composed of very light-gray-weathering, smooth fracturing limestone characteristic of the lower part of the Orwell underlies the more common darker limestones.

In a small quarry of the Weeks School, northeast of the administration building, an interval of 11 feet of Orwell lies exposed between the underlying Crown Point and the overlying Glens Falls limestones. Slightly north of here, approximately 2000 feet N. 60° E. from the northwest corner of Vergennes, the formation is 24 feet thick.

Between 1.25 and 1.5 miles south of Vergennes along the first road east of Otter Creek, the Orwell is approximately 30 feet thick. The thickness of the formation in the outcrop belt north and south of Panton village averages about 45 feet, and southeast of Summer Point the formation is of a similar thickness. At Crown Point, the interval is between 60 and 70 feet (White, 1899; Raymond, 1902; Kay, 1937).

Lithology

Limestones of the Orwell are black and medium light-gray, massive, moderately thick-bedded (1 to 3 feet) and possess a characteristic conchoidal and subconchoidal fracture. Textures range from sublithographic to lithographic with thin layers of fossil debris. Darker colored, sublithographic rocks break with a subconchoidal fracture whereas the lighter colored, more uniform limestones exhibit an excellent chert-like conchoidal fracture.

Smooth-appearing, light-gray or light ashen-gray to light bluish-gray (5B7/1 to 5B8/1), "dove-colored" weathered surfaces are important distinguishing attributes of the beds. The very light color of the weathered surfaces generally contrasts with the darker weathered surfaces of the massive limestones of the underlying Crown Point and Valcour formations. Some of the Orwell limestones weather in medium-gray shades, but their dark-gray to black coloration contrasts with the more bluish coloration of similar-appearing limestones in the lower formations.

Most Orwell limestones are "scored" by a subrectangular pattern of joints or gashes which cause the beds to weather block-like and with deep solution cavities. Many outcrops thus have a rough-hewn appearance. Where the blocks lie in a jumbled mass on dip slopes, one is reminded of the ruins of an ancient amphitheater. The scoring and jointing are useful in differentiating the formation from similar limestones of the Valcour.

White calcite veinlets, usually less than 2 feet long, are common in the limestones of the Orwell. Their presence is an aid to recognition of the formation where other evidences are lacking or inconclusive.

The two lithologies of the formation can be separated locally, but seem to be so intimately related that lumping them as one mapping unit seems appropriate. Moreover, the lower one is too thin to show on a small-scale map. The so-called "Lowville", or lower unit, is very smooth-weathering lithographic limestone which weathers a very light bluish-gray and is a medium light-gray (N5 to N6) or light chocolate brown. A remarkably smooth conchoidal fracture characterizes the limestones of this lithofacies. It is within these limestones that the vertical calcite-filled tubes, commonly referred to as "*Phytopsis*," are found. In many places this lithology is not clearly recognizable and may or may not be present; in others it contrasts sharply with the overlying darker limestones of the upper part of the Orwell.

Limestones of the lower unit have been recognized at Porter Cemetery in the western part of Ferrisburg, east of Porterboro School, north of Arnold Bay, on Long Point, and at the north end of Buck Mountain. The unit may be present in the ridge north of Panton, but it has not been positively identified here, nor has it been definitely recognized at the base of the Orwell outcrop approximately a half mile west of Spear School, in Charlotte. While the lower limestone outcrops above the zone of mixing in the Valcour on Long Point, it has not been recognized in outcrops to the east across the bay.

In the small depression a few yards north of Porter Cemetery, southeast of Kellog Bay, the lower, light-colored limestones outcrop between the Valcour and the darker limestones of the upper part of the Orwell. Yet on the east slope of the ridge, east of the cemetery, the light-colored limestones are absent, and the subconchoidal-fracturing dolomitic beds of the Valcour grade stratigraphically upward into the typical black, subconchoidal-fracturing limestones of the Orwell. The exact position of the contact is difficult to place because of the near-identity of the limestones of the two formations. Appearance in the limestones of the bands and layers of fossil fragments typifying the Orwell is taken to mark the lowermost Orwell beds.

Distributed through some of the lighter colored limestones are .1-inch black, silty laminae whose slightly irregular distribution in the massive limestones give a "sutured" or styolitic appearance to some of the vertical weathered surfaces.

Limestones of the upper sequence are black or dark-gray on the fresh surface, weathering in some cases to light-gray and in others to medium light-gray (N6). These limestones are usually less smooth-weathering than the underlying beds. In many instances the weathered surfaces present a slightly hummocky or subnodular appearance. General appearances suggest that earlier precipitating calcium coagulated locally into small masses, a few inches in diameter, that were subsequently cemented by the later precipitating carbonate. The second-stage calcite has proved less resistant to weathering than have the coagulated masses. Depressions on weathered surfaces mark the position of the later carbonate. In at least one place, at Porter Cemetery, the darker limestones appear to be draped over the slightly irregular surface of the top of the lower unit.

Many of the darker limestones are composed of ± .2-mm ovoid bodies composed of .01-mm calcite and cemented by calcite of like size. Thin rims darker than the center area bound a number of the bodies; others lack the well-marked rims and are recognized by their coloration which is slightly lighter than the matrix of the rock (Plate 9, Figure 1). Fossil fragments may or may not be present in these limestones. Whereever there are local concentrations of fossils, the darker limestones seem to predominate.

Dolomitized and recrystallized fossil fragments are distributed through the rocks of the formation in bands and thin layers. Though most are thinner, bands locally attain a thickness of 1 to 2 feet. These bands are, perhaps, the most characteristic feature of the formation, for they enable one to separate the Orwell from the similar massive limestones that are occasionally found in the Crown Point and Valcour formations. Like bands and layers are absent in the older formations.

Brachiopod valves and shell fragments comprise the chief elements of these layers, but small gastropods, both planispiral and towered, trilobite fragments, and some bryozoan fragments are present in addition. Most of the brachiopod shells lie convex upward, but other orientations are common also. Pelmatozoan columnals are abundant wherever fossils occur in the formation. On many weathered surfaces coarse-grained fossil fragments are weathered out of the limestone.

Another attribute of the Orwell is the distribution of blue-black chert in nodules, irregular masses, and lens-like layers which seldom attain a thickness greater than 1 to 2 inches. Presence of thin beds of chert identifies the formation in some places where its identification by other means is questionable.

The contact between the Orwell and the Valcour has been described from Long Point and the area east of Porterboro School. Another instructive contact is to be seen west of Buck Mountain on the eastern limb of a small anticline located approximately 1.2 miles S. 40° W. of the top of Buck Mountain. Here the Crown Point grades upward into the overlying, *Stromatocerium*-bearing, massive, light bluish-gray-weathering, white-veined, lithographic limestones of the Orwell. Typical layers of brachiopod fragments may be seen in the Orwell, and the Crown Point beds have both black platy laminae and dolomitic silty irregular masses distributed through them. The contact itself is gradational; there is no sharp break between the Crown Point and the Orwell. Crossing the outcrop from the Crown Point beds to the Orwell beds, one can observe a decrease in the silty, brown-weathering dolomitic streaks and masses and a concomitant increase in light-gray-weathering, massive, dark-gray lithographic limestone. The Crown Point limestone beds have a bluish tint contrasting with the dark-gray hue of the Orwell-type of bed. Dolomitic, silty streaks continue for a short distance up into the Orwell, but eventually they disappear completely.

At this locality evidence for current activity accompanying the transition from the Crown Point to the Orwell appears on weathered surfaces of limestones near the base of the Orwell. Very fine lines suggesting distribution of discrete grains of calcite in a current-controlled environment are broken and tilted; all occur in a 6-inch interval within the zone of gradation. No evidence exists for disruption of deposition, except on a very local, ephemeral basis, before or after the formation of the lines. Rather the deposition must have been essentially continuous. There is no evidence for the "Lowville"-type of bed at the base of the sequence; yet to the northeast, at the northwest corner of Buck Mountain, this horizon is present. Other features of the outcrop evidence the activity of currents in this area at the time of Orwell deposition. Some of the brachiopod fragments and *Stromatocerium* masses seem to lie in small channels which are about 2 to 3 inches deep and which are oriented so that they extend down the face of the dipping beds.

On the coast S. 18° E. of Button Island a zone of intraformational conglomerate lies at and near the contact of the Orwell with the Valcour. The conglomerate records current activity accompanying the physical and chemical changes which effected the alteration from very fine-grained and sublithographic magnesium-rich deposits to relatively pure lime mud accumulations.

On the basis of the evidence at hand the conclusion is reached that the transition from the Valcour, and the Crown Point in the eastern part of the Central Champlain Valley, was gradational and that no great emergence, or even slight regional emergence took place. Absence of the lower very light-gray-weathering "Lowville" horizon from several localities bespeaks the lack of its deposition.

While the "Lowville"-type of lithology is widespread, it is also apparently discontinuous. Whether its absence represents a hiatus in those areas where it is missing or whether conditions favored other types of lime mud is at the present unclear. It is suggested from the outcrops seen that pockets, or at least local areas, existed where the upper, or Isle la Motte-type of lime mud and shell fragments were being deposited while the "Lowville"-type of mud was being deposited over most of the area. Of particular interest in interpreting the two rock types included in the Orwell is the fact that the characteristic layers of fossils, especially the brachiopod layers, are present in both lithofacies of the formation.

The widespread change from the lower lithofacies to the upper speaks for a general change from the conditions favoring deposition of impalpable lime mud to conditions favoring the deposition of slightly coarser material, more abundant fossil fragments and minute, subspherical aggregations of calcite grains. The draping of the upper lithofacies over the lower lithofacies near Porter Cemetery is suggestive of the relative abruptness of the change in some places.

Inspection of the thickness values for the Orwell and their distribution in the Central Champlain Valley discloses that the formation thins to the east. It is from 65 to 95 feet thick in the westernmost outcrops, decreasing to the order of 40 to 50 feet a short distance to the east, and decreasing even further to the order of 20 or 30 feet in the longitude of the eastern margin of the area. Its thickness east of the Champlain Thrust is not known.

Fossils

The formation is rather uniform except for local areas where it contains more fossils and perhaps approaches a "reefy" condition. North of Panton fossils are abundant in the formation; not only are layers and bands of brachiopod and gastropod fragments abundant, but *Stromatocerium*, including *S. rugosum* Hall, and *S.* cf. *S. lamottense* Seely, *Maclurites logani* (Salter), and cerioid corals resembling *Foerstephyllum* are common. The concentration of the *Stromatocerium* specimens seems to be near the base of the formation.

The most notable and interesting occurrence of fossils within the Orwell lies on small Button Island in Button Bay, Ferrisburg (Plate 10, Figure 3). Here a bed 18 inches thick and composed chiefly of *Stromato-*

cerium and *Foerstephyllum* record concentration of the colonial organisms. Individual colonies attain diameters up to 15 inches. Other forms found are *Streptelasma* (*Lambeophyllum?*), a few brachiopods, and pelmatozoan fragments. Seely (1910, p. 275) briefly describes the occurrence and notes the presence of "*Columnaria alveolata*." The form he reports is probably *Foerstephyllum halli* (Nicholson). Locality 422 lists forms identified from a small collection made on Button Island. Nowhere else in the Central Champlain Valley have colonial corals and *Stromatocerium* been found so abundantly in the Orwell. The occurrence is a typical biostrome.

Beneath the biostrome of Button Island are massive, moderately thick-bedded Orwell limestones containing brachiopod, gastropod, and pelmatozoan fragments. Chert is common as thin layers between limestone beds and as nodules. Near the base of the western margin of the island a 4-inch, very fine-grained siltstone bed lies between massive limestones.

Maclurites logani (Salter) which is common in the formation east of the Champlain Thrust (Cady, 1945) is less common in the limestones west of the thrust belt; in fact, the form occurs abundantly only in the outcrops north of Panton. *Foerstephyllum* and the rugose corals *Lambeophyllum* and *Streptelasma* seem more common in the formation than does *Maclurites*, although these two forms also have a spotty distribution. *Stromatocerium rugosum* Hall as well as larger members of the genus are found occasionally in areas other than those mentioned above. On Long Point and in the outcrop areas south of the base of the point, the limestones contain a number of orthoceracones in addition to typical colonial corals and some stromatoceria.

Age and Correlation.

Kay (1937, p. 261) cites evidence from Raymond (1902, p. 24, 38, Plate 19) which he interprets as showing that the upper 16-foot interval, called Isle la Motte limestone in 1937, contains *Triplesia cuspidata* (Hall). On the basis of this and associated forms he correlates the interval with the Rockland of the Ottawa Valley. Examination of the Crown Point section and comparison of it with the Panton and other sections in Vermont leads the author to believe that the Orwell may represent not only the Black River Stage but also the lowermost part of the Trentonian Stage. The uppermost part may correlate with the Rockland formation if the correlation at Crown Point is valid. The faunal evidence is inadequate for conclusive proof. A possibility that the Larrabee extends below a position correlative with the Kirkfield (Twenhofel and others, 1954) can not be overlooked. Facies faunas may be obscuring the relationships.

Champlainian Series
Upper Mohawkian (Trentonian) Stage

Glens Falls Limestone (Ruedemann, 1912)

Representing an abrupt change in lithology from the massive relatively pure, conchoidal-fracturing limestones of the Orwell, the Glens Falls limestone outcrops over an extensive area within the Central Champlain Valley. Even though the change to impure limestones and shale is abrupt in all sections where it is exposed, the contact is conformable so far as can be determined. Work from adjacent areas does not suggest the presence of any important interruptions in deposition at this horizon except near the north end of the Taconic Range (Kay, 1937, 1958; Cady, 1945, p. 560; Erwin, 1957), and Chenoweth (1952, p. 559) reports conformable relations between the Rockland and the overlying Kirkfield at the northwest corner of the Adirondacks.

The rocks of the formation are black or dark bluish-black on a fresh surface, and a bluish-gray coloration (5B4/1 approximately) characterizes the weathered surfaces. Color of the weathered surfaces of the limestones, combined with their other features, sets the beds apart from similar-appearing calcareous shales and impure limestones found in the younger formations. Shades of olive-gray appear on weathered surfaces of rocks rich in detrital material, both shales and massive limestones.

Many beds are composed almost entirely of coarse-grained fossil fragments, being coquinoid limestones. Other less fossiliferous beds are separated by thin layers of coquinoid limestone. Occasional, very fine-grained sandstone beds appear in the formation as do noncalcareous shales similar to those of the overlying formations.

Perhaps one of the most characteristic features of the formation is the presence of minute pits and ridges on weathered surfaces of many thin-bedded limestones. The pits and ridges represent differential weathering of finely pulverized shell fragments which comprise these limestones, and they are an invaluable aid in identification of the formation where it has been sheared intensely or where it possesses a high shale content.

Limestones containing a high proportion of detrital material and having few fossils, either as more or less whole specimens or as fragments, tend to break with a smooth fracture; highly fossiliferous limestones fracture irregularly. The smooth fracture of the impure limestones can not be accurately termed conchoidal or subconchoidal, and in this respect they contrast with the sublithographic and lithographic limestones of the older formations which do exhibit a conchoidal or subconchoidal fracture. Differences in the content and distribution of the detrital material of the limestones is believed the cause for differences in the fracture habits.

The rocks of the formation are thin-bedded; limestone beds average from 4- to 6-inches, though often attaining a thickness of a foot or more. Individual beds are separated by black calcareous shale layers which vary from mere partings to beds a few inches thick, and silt partings and thin beds are present also. Individual beds may extend for some distance laterally, or they may grade into calcareous shale which in turn is replaced laterally by limestone. Yet, despite these variations, the impression is given that as deposition progressed periods of predominant calcite precipitation alternated with times when the accumulation of detrital material was dominant. Interspersed were times when the biota supplied most of the clastics for the rocks.

Nodular-weathering habits and slight pinching and swelling of individual beds are associated with the thin-bedded sequences of the limestones. In other instances the contacts between individual beds in the thin-bedded sequences appear crenulated. Where the average thickness of the limestone beds approaches 1 foot, the nodularity is absent. Figure 1, Plate II is a photograph of typical Glens Falls.

A correlation between lithology and fossil content exists. The thin-bedded, nodular-weathering limestones commonly are very fossiliferous, but the beds approaching a foot in thickness, smooth-fracturing, and composed of moderate amounts of detrital material mixed with the sublithographic calcite contain only limited quantities of fossil fragments, and these are generally scattered through the limestone randomly. Fossils also occur abundantly in the shale interbeds in some sequences.

Examination of the insoluble residues left after the etching of a number of the limestones and interbedded calcareous shales shows them to be very finely divided quartz rather than argillaceous material. The residues are gritty, reflecting the presence of the quartz. Silt-size fragments ($\pm$.06 mm) of quartz, both clear and angular as well as frosted and subrounded are present in minute quantities; however the bulk of the residues appear to be quartz under a magnification of 80X with a binocular microscope, and this conclusion is substantiated when the residues are mounted in immersion oils. The average grain-size of the residues seems to be of the order of .001 to .002 mm. Finely divided, carbonaceous ma-

PLATE 11

Figure 1. Glens Falls limestone, shore S. 20° E. of Button Island.

terial gives to the limestones their black coloration as well as their fetid odor when struck. Some of the black material may be argillaceous, but the total amount is small in any case, and the quartz forms the bulk of the detrital material supplied.

Except in layers and beds where fossil fragments comprise them, the limestones are composed of .005- to .01-mm calcite intimately mixed with the uniformly distributed detrital component. Even where fossil fragments and fossils are major constituents of the limestones, the spaces between the fossil fragments are filled with the calcite of lithographic dimensions and varying amounts of associated detrital material.

There seems to be no layering of the detrital material; instead it is distributed more or less evenly throughout the limestones. Nor are there wisps of the quartz-rich material such as are found in the Chazy limestones. On the other hand, thin, .01-mm lines which are lower than the surrounding material may be seen on etched, polished surfaces of the limestones. These lines represent thin laminae composed of calcite grains which were deposited as a unit within an area of limestone in which an anisotropic distribution of detrital material and calcite is the general rule.

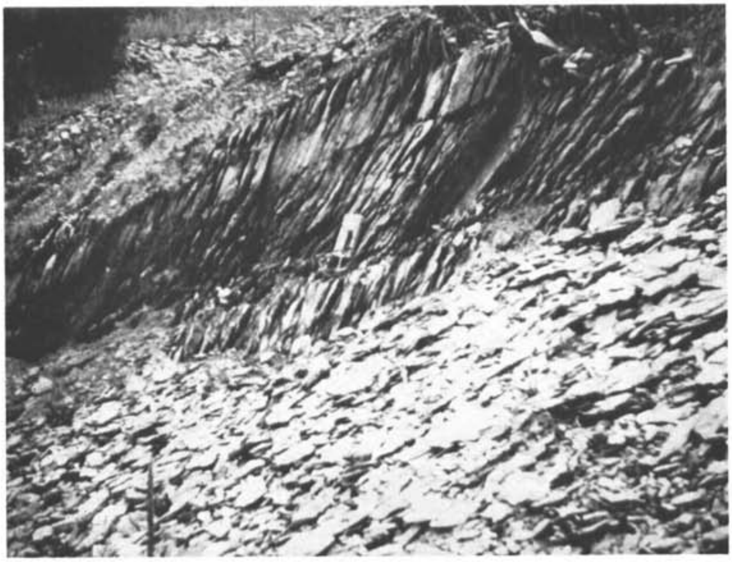


PLATE 11

Figure 2. Glens Falls transition shale; low knoll approximately 2100 feet N. 45° W. of Marsh Hill, Ferrisburg. Note cleavage dipping steeply to east; bedding dips gently eastward. Observer looking south.

The limestones lack the small spheroidal or ovoid masses of calcite which are common in many if the sublithographic limestones of the pre-Glens Falls formations.

As has been observed in the other limestones of the Central Champlain Valley, the quartz-rich detrital material of the Glens Falls limestones is an olive-gray color on etched surfaces. Additionally the scattered dolomite rhombs found within the limestones are concentrated almost exclusively within the areas of detrital material, a relationship between the quartz and dolomite which has been observed in pre-Glens Falls carbonates also.

While the dolomite rhombs average somewhere near .06 mm in the limestones and in calcitic dolostones of the older formations, the dolomite rhombs found in the Glens Falls limestones average between .01 and .03 mm. They are a relatively minor component of the limestones.

The clay-size quartz and its accompanying quartz silt forms as much as 25 to 30 per cent of the limestones; the intercalated shaly horizons probably average somewhere near 50 to 60 per cent detrital material with the balance being dominantly the sublithographic calcite grains except where fossil fragments are abundant. The shale beds at the top of the Glens Falls, representing the transition into the overlying Stony Point, probably average about 75 per cent detrital material and 25 per cent silt-size to clay-size calcite, although the necessary number of insoluble residues to support this statement have not been prepared. Dolomite rhombs are present in the shales at the top of the formation, but as in the limestones they represent only a very small percentage of the rock, perhaps at most 1 to 2 per cent.

Pyrite is present in most limestone and shale samples from the Glens Falls; it is present more consistently in the Glens Falls than in the lower limestones, although in these it is locally abundant.

Unrecognizable as separate entities in the highly deformed belts, two members have been recognized in the formation by earlier workers (Ruedemann, 1912, p. 22; Kay, 1937, p. 262). Kay (1942, p. 1611) raised the Shoreham member to formational rank. Along the lake shore where the beds are simply tilted, the two members may be differentiated, although they have not been distinguished separately on the map. Where exposed and positively identified, the lower member, the Larrabee (Kay, 1937, p. 262), is more thinly bedded and more shaly than the overlying Shoreham member. In addition the thickness of the Larrabee is much less than the thickness of the Shoreham.

Kay (1937, p. 263) assigns a thickness of 35 feet to the Larrabee on Crown Point peninsula. South of Crane Point, in an outcrop belt apparently continuous with the outcrop on Crown Point, the Larrabee is estimated to be of comparable thickness, although the exposures are very poor here.

The only other place that the Larrabee has been positively identified in the area is about a half mile north of Arnold Bay, where the town line between Panton and Ferrisburg intersects the coast line. This is the area of Ruedemann's Panton section (1921a, 1921b); the author has measured 30 feet of thin-bedded limestones and shales which seem to represent the Larrabee at this point. A large portion of the Larrabee limestones here are coarsely coquinoid, and in this aspect they differ from the Shoreham limestones which are mostly sublithographic and dense, although the Shoreham sequence contains many abundantly fossiliferous layers and beds and a number of fossil-fragmental limestones.

At Wings Point, in Charlotte, the Larrabee seems to be missing, but it may lie beneath the cover on the east side of the cove, although if it is present, it probably is not over 10 to 15 feet thick. The first Glens Falls beds exposed above the Orwell at Wings Point contain *Prasopora* and

Cryptolithus tesselatus, and south of Wings Point the limestones immediately over the Orwell appear to be Shoreham, although the presence of *Encrinurus cybeleformis* Raymond in beds west of the Essex Ferry landing (locality 427) suggests that a few feet of Larrabee may be represented. A like relationship seems to be present on the grounds of Weeks School where *Cryptolithus*-bearing limestones of the Shoreham member lie above the Orwell separated from it by a 6-inch layer of shell debris. Aside from these exposures, cover and deformation of the rocks make the recognition of the Larrabee, if it is present, extremely difficult.

Upward the formation grades into the overlying Stony Point shale through a transition zone in which shale gradually replaces the limestones. Individual impure limestone beds become noticeably thicker and better defined as individual beds, averaging about a foot in thickness and losing their nodular-weathering habits. Accompanying shale beds of the transition zone are slightly thicker than those of the lower part of the Glens Falls. There is evidence in some areas to suggest that from the middle of the formation upward the limestones become thicker and more sharply set off from the interbedded shales and that the thin-bedded, highly fossiliferous, nodular-weathering beds are features of the lower part of the formation. If this trend does exist, either locally or regionally, then the transition beds at the top of the formation would seem to record its culmination.

Along the shore of Lake Champlain the transition from the Glens Falls into the Stony Point is well displayed at Panton in the section described by Ruedemann (1921a, p. 93–95). The author places the Stony Point-Glens Falls contact where the limestone beds finally disappear and the beds of shale approximately 1 foot thick may be first discerned. Shales of the Glens Falls near the top of the transition zone weather with an olive tint superimposed on the common dark bluish-gray coloration whereas weathered Stony Point shales tend to be more bluish tinted.

The transition sequence may also be observed north of Owls Head Bay, although it is in part covered here. Interbedded with the impure limestones of the transition zone are olive tinted, dark bluish-black-weathering shales containing *Cryptolithus*, *Flexicalymene*, *Reuschella*, and *Lingula* fragments. The transition is also exposed on the coast northwest of West Bridport.

Inland an upper shaly sequence in which the limestones are less prominent than lower in the section is recognizable at several places. Among these is a discontinuous, partially covered belt extending northward from where Route 22A crosses the Bridport-Addison town line to the north end of Snake Mountain. Shale resembling the transition shales has been recognized approximately a mile N. 67° E. of North Ferrisburg, adjacent to the Champlain Thrust. The presence of the transition interval about 1.25 miles east of Mt. Philo is suggested. Shaly sequences are found near the top of the formation approximately a mile south of Ferrisburg and a few hundred feet east of the railroad; another outcrop of the upper shaly interval is on the hill approximately .35 mile west-northwest of Marsh Hill, northeast of Vergennes (Plate 11, Figure 2). In all of these cases fragments of typical Glens Falls limestone are closely associated with the shales, although the limestones are not clearly interbedded with them.

The shale beds observed in the eastern exposures represent the uppermost part of the transition zone. The lower part of the transition zone is usually unrecognizable because in the exposures available shearing as well as cover obscure the preciseness of the alternation of the shale and the limestone beds. However, along the shore the limestone beds disappear upward eventually and are replaced completely by shale which contains fragments of *Cryptolithus tesselatus* Green, *Flexicalymene senaria* (Conrad), and occasional brachipods which are found abundantly in the limestones and shales of the lower part of the formation. Presence of *Cryptolithus tesselatus* and *Flexicalymeme senaria* fragments in the shales of the inland exposures aids in their separation from the Stony Point. *Flexicalymene* is most commonly seen as disjointed thoracic segments scattered through the shale.

With careful mapping and attention to minute detail, one may separate the upper shaly part of the Glens Falls from the younger Stony Point and from the underlying sequence with its limestone beds. Because the distinction can not always be made systematically throughout the outcrop area of the shaly unit—whether because of lack of outcrop or obscuring by deformation—it is treated herein as a transition zone at the top of Glens Falls formation.

The shales of the uppermost interval of the Glens Falls weather to a more bluish color than the overlying Stony Point shales or to an olive-tinted bluish color. This color difference taken together with the presence of scattered fragments of fossils found abundantly in the lower part of the formation generally sets the two shales apart. Beds of the interval also exhibit a slightly different texture on the weathered surface—perhaps it might be described as being slightly rougher to the touch—reflecting an apparently higher silt content than is found in the Stony Point shales. These several differences are more important in exposures inland than in exposures along the lake or where the two shales must be mapped using fragments and blocks in the soil. Small black specks representing trilobite and brachiopod fragments appear on weathered surfaces of the transition shale; the Stony Point shales lack these small particles as well as the larger readily identifiable fragments.

At West Bridport the transition zone is between 50 and 75 feet thick; in the area north of Owls Head Bay the thickness is estimated to be 300 to 325 feet. Since cover obscures the contacts, it is possible that the zone is somewhat less, and a rupture zone near the base suggests that some of the section may be duplicated. At Panton the author assigns a thickness of ±75 feet to the interval; Ruedemann (1921a, p. 93) estimated a thickness of between 50 and 100 feet for the transition zone here. Because of the structural complications accompanying the exposures of the transition sequence in the eastern part of the area, the thickness can not be determined; however, estimates seem to indicate thicknesses comparable to those found along the lake shore. West of Snake Mountain the shaly sequence is somewhat thicker, being between 200 and 250 feet thick.

Wherever there is any doubt as to the correct identification of the Glens Falls formation, the problem may usually be resolved by diligent search, for fragments of *Cryptolithus tesselatus* Green may be found in even the most deformed of beds as may fragments of *Prasopora*. Except for the transition shale at the top of the formation, *Cryptolithus tesselatus* is apparently absent in all other formations exposed in the area. Usually, on the other hand, the thin-bedded nature, the coloration of weathered surfaces, and the rough surfaces of the weathered pieces together with the presence of abundant fossil fragments serve to identify the formation, even where it is extremely shaly.

Except for the little-deformed beds exposed along the lake shore, the Glens Falls is highly cleaved, and in the areas of intense shearing the cleavage may be easily be mistaken for bedding. Limestone "beds" and "lentils" several inches thick are separated by black, argillaceous partings which resemble closely the thin layers of shale separating the beds of the formation and average .1 inch thick. However, close examination of the beds often discloses some thin lines of stratification cutting across the cleavage; bands of fossil fragments may also be used to identify the bedding.

There are no completely suitable places for accurate thickness determinations within the Central Champlain Valley area; the thickness of the formation on Crane Point is 315 feet (author's measurements and Raymond, 1902), but this is an incomplete section, and to it must be added the exposures northward to the Owls Head Bay area. From the attitudes along the shore and the configuration of the shore between the north edge of Crane Point and the upper boundary of the formation north of Owls Head Bay, it is estimated that another 900 to 950 feet are present, giving a total thickness of approximately 1250 feet for the Glens Falls in this area, including ±35 feet of Larabee and 300 to 325 feet of transition shales. A minimum thickness of 450 feet for the Shoreham member is indicated for the Crane Point area. Repetition of the section between Crane Point and Owls Head Bay by faulting can not be dismissed; however, no positive, incontrovertible evidence for faulting has been found even though two doubtful faults are indicated on the map (Plate 1). Slight variations in attitude may indicate the presence of ruptures on the south side of Owls Head Bay, but similar changes elsewhere record simple warps in the limestones. Serviceable marker horizons for determination of faulting have not been recognized.

The outcrop of the formation north of Arnold Bay is the only locality where the Glens Falls is completely exposed from the underlying Orwell to the overlying Stony Point; west of Snake Mountain the entire formation is more or less exposed, but the position of the uppermost contact can only be inferred because of the cover. At Arnold Bay the total thickness of the Glens Falls, including 30 feet of Larrabee and the ±75 feet of the upper transition zone, is 480 feet; the formation is estimated to be 500 feet thick west of Snake Mountain including the 200 to 250 feet of the upper, shaly sequence which has been tentatively correlated with the transition zone exposed at the lake shore.

Formation thickness in the Cedar Beach-Wings Point area of Charlotte is estimated at 350 to 400 feet, but since the top of the formation is not exposed, this figure represents a minimal value. Nothing in the outcrops at Wings Point suggests near proximity of the upper beds to the transition zone or to the contact of the Glens Falls with the Stony Point. East of Long Point, in Ferrisburg, the formation is estimated to be 250 to 300 feet thick beneath the cover, though this value may be affected by unrecognized faulting. The outcrops on the low ridge approximately 1700 feet west of North Ferrisburg Station are believed to be Stony Point shale rather than Glens Falls.

Age and Correlation

The Glens Falls and its equivalents are widespread, being known from the Mohawk Valley, west and northwest of the Adirondacks, and in the St. Lawrence Valley as well as in the northern part of the Champlain Valley (Kay, 1937, 1942, Cady, 1945; Chenoweth, 1952; Erwin, 1957). The contact with the lower beds of the Trenton group seems conformable everywhere suggesting simply a change of environment. At Crown Point the formation lies on beds that have been correlated with the Rockland formation of Ontario (Kay, 1937). Whether the Isle La Motte limestone of the northern part of Lake Champalin includes Rockland or not is unclear.

At the base of the Glens Falls are beds (the Larrabee member) which are correlated with the Kirkfield formation northwest of the Adirondacks, both because of similar stratigraphic position and similar faunal elements. The top of the formation is defined by the appearance of the Stony Point shales. Deposition of this formation may have begun at different times in different places, but from all evidence concerning the Central Champlain Valley the change probably was essentially synchronous throughout the Champlain Valley area.

The transition interval placed at the top of the Glens Falls correlates with the Cumberland Head formation of northern Lake Champlain (Cushing, 1905, p. 305; Kay, 1937, p. 274; Erwin, 1957, p. 32). Ruedemann (1921b, p. 110) correlates the transition sequence with the lower part of the Canajoharie shale. This interval has been called the Minaville member by Kay (1937, p. 268, 274). The fauna is that of the *Mesograptus mohawkensis* (Ruedemann) and *Diplograptus amplexicaulis* (Hall) zones (Ruedemann, 1921b, p. 126). The interval correlates with the Denmark member of the Sherman Falls formation of western New York (Kay, 1937, p. 274). The top of the Glens Falls in the Central Champlain Valley is placed in the middle of the Sherman Falls formation.

A few graptolites have been found in the transition beds north of Owls Head Bay (locality 344); other fossil localities from the transition beds are (Appendix II) 191, 253, 280, 316, 342, and 343. In addition graptolites have been observed in shales of the Glens Falls almost due west of Buck Mountain.

The thickness data from the Glens Falls show that the formation is much thicker in the Central Champlain Valley than elsewhere. Cady (1945, p. 558) gives a thickness of 115 feet for the formation in East Shoreham. Kay (1958, p. 87) reports that the Glens Falls is approximately 100 feet thick in the Highgate Springs sequence; Erwin (1957, p. 30) records 115 feet on Isle la Motte and from the incomplete section near McBride Bay on South Hero records 102 feet. Kay (1937) records 57 feet of the Glens Falls at the type locality. Cady notes the absence of the formation between the Orwell and the Hortonville in southwestern Orwell township (1945, p. 558).

The thickness data show that the formation thins away from the Central Champlain Valley. The relationship suggests that the area was more rapidly downsinking during the middle part of the Mohawkian than were adjacent areas. The eastward thinning fits with the thickness patterns of the Chazyan and Lower Mohawkian.

The Glens Falls represents an apparent deepening of the Champlain Valley area during the medial Mohawkian. During the upper part of the time recorded by the formation the seas seem to have connected across the Adirondack area with marine areas lying west of the present Adirondack region (Chenoweth, 1952, p. 559). Somewhere to the east a low-lying landmass probably existed. It was from this area that the fine quartz distributed through the formation was probably brought. The transition interval at the top of the formation probably reflects the beginning of an uplift in the area to the east, and possibly southeast, which brought about the influx of detritus which formed the shales of the interval and later the shales of the Stony Point and Iberville formations. Hawley (1957, p. 84) concludes that the landmass probably was nearer the southern end of the Champlain Valley than the northern end. The evidence from the Central Champlain Valley would tend to bear out this idea. The disconformities associated with the rise of the landmass (Fowler, 1950, p. 37) are peripheral to the Central Champlain Valley. The apparent absence of pre-Mohawkian beds on the east flank of the Green Mountains may be more related to erosion at this time than to nondeposition as suggested earlier.

Stony Point Shale (Ruedemann, 1921b)

Widespread through the field area, yet forming good outcrops only along the shore of Lake Champlain, the Stony Point shale represents a change from the dominant carbonate deposition of the lower horizons to a dominance of fine-grained detrital materials. The formation outcrops best along the lake shore, and it is exposed from the base of Shelburne Point southward to about a half mile north of Wings Point. In this area the beds are highly contorted and broken by fracture cleavage. Juniper Island and the Four Brothers are black calcareous shale of the Stony Point with lesser amounts of argillaceous and dolomitic limestone. Buddington and Whitcomb (1941) mapped the Four Brothers as Glens Falls, but the islands are composed of black calcareous shale more like the Stony Point than the Glens Falls. Rock Dunder is largely black calcareous shale, but there are intercalated dolomitic, silty beds with thin dolomitic, silty laminations characteristic of the Iberville as well as olive-gray-weathering argillaceous limestone beds. The overall appearance of the outcrop suggests the Stony Point-Iberville transition zone which is mapped with the Iberville.

The other shore exposures are in Panton and Addison where the formation outcrops almost continuously from Button Bay south to Owls Head Bay. The contortion and shearing that are so common in the beds between Shelburne Point and Wings Point are absent in these more southerly exposures. Attitudes of the formation are uniform for long stretches. The formation also outcrops along the shore from about .5 miles south of the Addison-Bridport town line to N. 50° W. of West Bridport where it grades downward into the Glens Falls.

Away from the lake shore where the formation is not well exposed, it may be mapped using the calcareous shale fragments found in the soil and brought to the surface by burrowing animals. This type of evidence is usually supported by scattered outcrops. The calcareous composition of the formation contrasts with the noncalcareous nature of the Iberville, and the presence of fossiliferous limestone fragments as well as the slight differences of the associated shales usually sets off the areas of shaly Glens Falls.

Inland the formation lies beneath the central part of the field area, adjacent to the Champlain Thrust along the front of Snake Mountain, and south of Mt. Philo where it is well exposed in the bed of Lewis Creek. The outcrops in the central part of the valley are limited, but all the evidence indicates that these outcrops are separated from the outcrops along the shore by one or more faults. Furthermore they are not continuous with the outcrops at the northern end of the area.

Thickness

It is impossible to give an accurate estimate of formation thickness, for nowhere is a complete, relatively undeformed section exposed. However, an approximation of the minimal thickness may be made from the shore exposures in the southern part of the area. The thickness estimated from the exposures between Owls Head Bay and Potash Bay is 700 feet; the section is interrupted by faulting and folding at the southern margin of Potash Bay. A thickness of 700 to 800 feet is found between Potash Bay and the south side of Spaulding Bay, assuming the absence of faulting. Folding and faulting complicate the picture from Spaulding Bay north to the fault north of Arnold Bay, although Ruedemann (1921b, p. 111) assigned a thickness of 500 feet to the shales adjacent to Arnold Bay.

North of Arnold Bay the shale is between 700 and 900 feet thick in exposures which are stratigraphically equivalent to those north of Owls Head Bay. If only half of the thickness between Potash Bay and Spaulding Bay is a repetition of part of the other two sequences, then the formation is ±1200 feet thick, and it may be as much as 1500 to 2000 feet thick. Ruedemann (1921b, p. 111) suggests that the thickness is over 1000 feet, noting faunal evidence which indicates that the shales adjacent to Arnold Bay are younger than the uppermost beds on the shore of Button Bay. In the area east and south of Crown Point the outcrop width and average dip suggest that the incomplete section is approximately 1000 feet thick.

Approximately 600 to 800 feet of the Stony Point is exposed beneath the thrust belt on Snake Mountain; perhaps as much as 1000 feet lies between the Glens Falls and the Iberville here. It is thought that the thickness of the Stony Point between Wings Point and Shelburne Point is approximately 1000 to 1500 feet, perhaps slightly thicker. Folding and shearing make thickness determinations here little more than guesswork.

Hawley (1957, p. 58) assigns a thickness of 1000 to 1500 feet to the Stony Point at the north end of Lake Champlain. Evidence at hand intimates that the Stony Point thickness in the Central Champlain Valley is within this range and that it may possibly be more.

Lithology

Black, fissile, splintery-fracturing, carbonaceous, calcareous shale is the most important lithologic type found in the formation. These rocks are black and dark bluish-black in color, often presenting a fibrous appearance on weathered surfaces of well-cleaved beds. Films of leached lime encrust many weathered surfaces. The shales are thin-bedded, thinly laminated, and fissile. Characteristically they are thinly ruptured by fracture cleavage where they have been subjected to even a minimum amount of deformation. The close spacing of the cleavage contrasts with the wider spaced fractures of the limestone beds. Thin, minute laminations of the argillaceous and silty components give to the beds their fissility. Rare laminations of medium-grained quartz are also present.

The shales are highly calcareous, probably averaging nearly 50 per cent calcareous material. However, the insoluble residues prepared from 8 shale samples collected at widely separated localities average 42 per cent by weight insoluble material, ranging from a low of 29 per cent to a high of 72 per cent. In only two of the samples was the residue more than 50 per cent.

The residues are argillaceous material, less than .001 mm, which shows an average refractive index of between 1.56 and 1.57. The values of the refractive indices imply that the argillaceous material is kaolinitic (Rogers and Kerr, 1942, p. 354). Quartz grains averaging .001 mm are also present in the insoluble residues; some are larger, up to .01 mm. Because of the extreme fineness of the grains comprising these residues, it is difficult to give an accurate estimate of the relative percentages of quartz and clay, but it is believed that in some of the residues examined the quartz may constitute almost 50 per cent of the sample. Carbonaceous matter in thin sections and in insoluble residues is brownish and opaque.

Where the cleavage has not obliterated it, the bedding varies from 3 to 6 inches, with some beds attaining a thickness of as much as a foot. Thin, lighter weathering dolomite- and calcite-rich laminae, as well as slightly silty laminae, show the bedding of the highly cleaved shales and may be observed on the less ruptured shales as well. In many of the shales the major zones of slippage along the cleavage develop .5 to 3 inches apart, causing the cleavage to appear as bedding; only the laminations and lines on the weathered surfaces indicate otherwise.

Pyrite nodules and small lenses are common throughout the formation. In the highly cleaved shales the lenses or lines of nodules may be utilized in identification of the bedding, for they lie along the bedding planes.

The second important lithologic type found in the Stony Point, forming intervals of considerable thickness, is medium-gray-to medium bluish-gray-weathering, black lithographic- and sublithographic-textured limestone. Where the limestone beds are present they usually form 30 per cent or more of a given interval; rarely are they present as isolated beds in a shale sequence. Weathered and water-worn surfaces of the limestones along the lake shore are smooth, a feature which contrasts with the rough-weathering or splintery surfaces of most of the Stony Point shales. In sequences that are broken by intense fracture cleavage, exposed surfaces of the limestones may present a hackly fracture or surface on a plane at right angles to the cleavage; more often the plane at right angles to the cleavage is smooth-weathering.

Planes of the fracture cleavage are a fraction of a millimeter apart in the limestones, but most of the slippage in the limestones has taken place on surfaces spaced 3 to 6 inches apart. These planes, or very thin zones of rupture, appear as thin, black, carbonaceous and argillaceous zones between thicker limestone intervals. It is sometimes difficult to separate the true bedding from this pseudo-bedding (Plate 12, Figure 1). Bedding

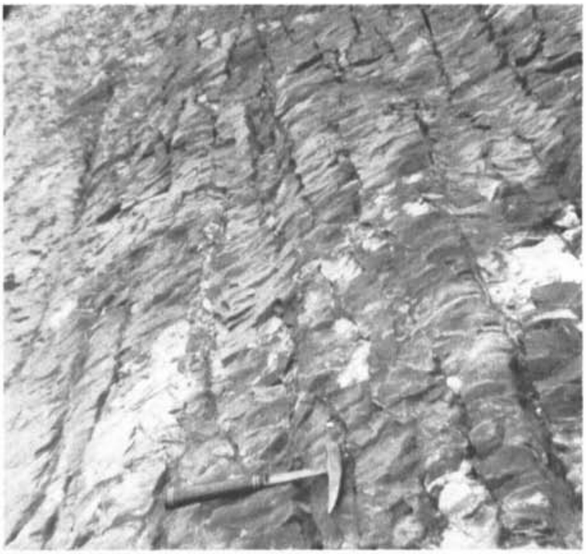


PLATE 12

Figure 1. Stony Point shale showing slip cleavage-bedding relationship. Hammer head parallels cleavage. Handle is approximately parallel to bedding; looking northward on shore, 3500 feet north of Wings Point, Charlotte.

is expressed on the weathered surfaces as laminations of various shades of gray, the shade depending upon the relative amounts of calcite and argillaceous matter in the lamination.

The limestones are composed of calcite ranging in size from .002 mm to .01 mm. Thus they fall within the lithographic-sublithographic size-range. Mixed with the calcite is argillaceous material, and occasionally a small amount of very fine quartz silt. Very finely divided carbonaceous matter intimately mixed with the argillaceous material gives to the limestones their black coloration.

Individual beds of the limestone range in thickness from 3 to 6 inches on the average, but thicker and thinner beds are locally present. Separating the beds are layers of black calcareous shale up to several inches thick.

The beds lack the crenulation or nodular-weathering aspects of the limestones composing the Glens Falls. Also the fresh break of most of the Stony Point limestones is more subconchoidal than the fracture of the Glens Falls limestone, even those that are smooth-fracturing. In addition the black or dark-gray surfaces of the Stony Point limestones reflect

PLATE 12

Figure 2. Iberville shale (dark) and dolomitic siltstone (light); small quarry at southwest corner of Pease Mt., 2000 feet southwest of top.

light with a degree of brightness that contrasts with the dull luster of the Glens Falls limestones.

Olive-gray (5Y4/1 to 5Y4/2) limestones with a moderate silt content occur as occasional interbeds in shale sequences. They seem to be rarely present in sequences of medium-gray-weathering limestones; most of these limestones are only a few inches thick, but occasionally one may be 1 to 2 feet thick. The silt content of these rocks is high, approximating 20 to 40 percent of the rock in some instances, and some of the beds may actually be calcareous siltstones. The olive-gray coloration, as in the Glens Falls limestones, is associated with the detrital material. Limestones of this type form a significant portion of the lower part of the Stony Point above the Glens Falls transition interval at Button Bay.

Rare, thin beds of black, calcitic dolostone or dolomitic limestone occur in the Stony Point; these beds are tough and are found with the shale sequences.

While no attempt has been made at delineating in detail the lithologic variations of the formation, several gross variations can be pointed out. The formation is dominantly shale along the Panton and Bridport shore where the shales are accompanied by occasional olive-gray silty lime-

PLATE 12

Figure 3. Iberville shale northeast corner tip of Shelburne Point, showing characteristic calcite veinlets of noncalcareous shale and occasional thin dolomitic limestones. Beds dip to the south.

stones and calcitic dolostones. Inland, black argillaceous limestones are interbedded with the shales but do not seem so common as in the Shelburne outcrop area. The olive-gray-weathering limestones seem the more important limestone type in the southern exposures.

In the Shelburne Point area, where the formation more closely resembles the Stony Point of northern Lake Champlain (Hawley, 1957) randomly interbedded shale and limestone characterize the formation from its contact with the Iberville south of Queneska Island to the east side of Quaker Smith Point. South from Quaker Smith Point to the south side of the southwesterly turn in the coast, west of the mouth of the Holmes River, the formation is shale with smaller amounts of interbedded medium-gray-weathering limestone. Finally, the exposures from the mouth of the Holmes River south to the last outcrop of the formation approximately a half mile north of Wings Point are more limestone than shale, but the amount of shale in the exposures increases near the southern end of the outcrops.

Because of the folding and rupturing of the formation in this area it is impossible to make an accurate estimate of the thicknesses of these several bands, but the first two would seem to be slightly thicker than the lowest and to be about equal. From the general pattern of the folding it is concluded that the bands are progressively older from north to south.

A number of faults bring limestone sequences against shale sequences, but the absence of marker horizons precludes determination of the throw.

White calcite veins and irregular masses fill rupture zones in the shales and limestones. The presence of an abundance of white calcite knots in the soil along with calcareous shale is another bit of evidence used in distinguishing Stony Point outcrop areas from Glens Falls areas.

Within the Stony Point are intervals of noncalcareous black shale with associated thin, dolomitic, silty laminae and interbedded dolostones. The noncalcareous shales in these sequences are frequently crossed by white calcite veinlets which follow one joint set in the shale. Sometimes a rectangular pattern is found. The white veinlets seem characteristic of the noncalcareous shales, for no similar distribution of white calcite veinlets is found in the calcareous shales and limestones.

Found as isolated outcrops, the noncalcareous beds would be mapped as Iberville; however, the intervals are surrounded by the typical black calcareous shale of the Stony Point, and in addition calcareous shales are intercalated with the noncalcareous ones. One such horizon occurs on the point forming the north side of Meach Cove, and it is present southward on the mainland east of Meach Island whence it can be traced southward intermittently for half a mile.

Inland a short distance from Meach Island and extending northward to Orchard Point is an outcrop belt of noncalcareous shale. Outcrops are not numerous, but the belt may be mapped on the basis of the fragments in the soil. Since structural evidence indicates the presence of small synclines whose axial lines follow the trend of the noncalcareous shale, the belt is interpreted as belonging to the Iberville. Interbedded noncalcareous shale, calcareous shale, and sublithographic, orange-brown-weathering, silty dolomitic limestones outcrop on the low ridges southeast of Mt. Philo.

Fauna

Triarthus beckii Green was found in the Stony Point at only one locality (**309**), in the northernmost exposures of the Stony Point north of Arnold Bay where the form is moderately abundant. The graptolite collections are small and do not afford a good faunal basis for subdividing the formation. However, graptolites seem to be abundant enough in some places to make a stratigraphic study of the Stony Point from Owls Head Bay northward worthwhile. The *Climacograptus* and *Rafinesquina* from locality 261 suggest that the lower Stony Point outcrops at the Vergennes waterfall; the suggestion is borne out by the occurrence of a very small outcrop of the Glens Falls a quarter of a mile east of Otter Creek. Foyles (1926a) lists *Diplograptus amplexicaulis* (Hall) from the shales at Vergennes as well as graptolites from a few other localtiies.

Age and Correlation

The Stony Point is correlated with the upper part of the Canajoharie shale of the Mohawk Valley (Ruedemann, 1921b, p. 112; Kay, 1937, p. 275; Hawley, 1957, p. 58). Cady (1945, p. 558) correlates the Hortonville slate of the Middlebury Synclinorium with the Canajoharie and the Stony Point shales. He reports a thin transition zone at the base of the Hortonville where it lies on the Glens Falls, and correlates this zone with the transition zone (Cumberland Head formation) between the Glens Falls and the Stony Point to the west of the thrust belt. He indicates that it may also include equivalents of the Stony Point. Where the author has seen it in the vicinity of Middlebury, the Hortonville resembles in many respects the noncalcareous shales of the Stony Point and the black, noncalcareous shales of the overlying Iberville.

IBERVILLE FORMATION (Clark, 1934)

Description of the Iberville formation in the Vermont portion of the northern Champlain Valley has been provided by Hawley (1957); the name is derived from exposures in Iberville County, southern Quebec (Clark, 1934, p. 5). The two lithologic variants found by Clark and McGerrigle (cited in Hawley, 1957) in Quebec and found by Hawley in the northern Vermont exposures are easily differentiated in the Central Champlain Valley; in point of fact, they extend south of the area described in this report, the author having found both the calcareous shale, Stony Point, and the noncalcareous, Iberville, lithologies in the latitude of Shoreham.

Hawley's descriptions of the Iberville exposed in the islands of Vermont and the eastern shore of Lake Champlain south to Appletree Point, northwest of Burlington, fit the rocks mapped as Iberville in the Central Champlain Valley. Because of the closeness of most Iberville exposures to the thrust belt of Logan's Line, the rocks of this formation are highly distorted and deformed, making detailed, meaningful stratigraphic descriptions impracticable. On the other hand, general recognition of the two Iberville subdivisions which have been differentiated by Hawley

(1957) is possible: the lower Iberville or Stony Point-Iberville transition zone, and the upper Iberville characterized by its usual lack of calcareous shales and limestones and by the presence of seemingly rhythmic sedimentation of black shale and dolomitic siltstone, with attendant sedimentary structures. The change from one to the other is gradational, with an upward decrease in calcareous shale and a concomitant increase in noncalcareous shale.

The only shore exposures of the formation are on Shelburne Point, southwest of Burlington. This outcrop area is continuous southward beneath the cover to the latitude of Pease Mountain in Charlotte; the noncalcareous shale can be mapped by means of soil fragments, exposures in animal burrows, and occasional outcrops of varying size. The formation disappears—probably in part because of structural relations and in part because of the Pleistocene cover—at Pease Mountain and reappears briefly in Lewis Creek at the U. S. Route 7 bridge in an outcrop which is apparently structurally separated from the Pease Mountain outcrop by faulting and which belongs to the lower part of the Iberville. Noncalcareous shales outcrop on the south side of Mt. Philo, and while they may represent a noncalcareous lithofacies in the Stony Point, it is believed that they are more likely Iberville.

The transition zone outcrops along the west shore of Shelburne Point from the fault contact with the Stony Point, where up to 35 percent of the section consists of calcareous shale, northward to the end of the point. Queneska Island and Rock Dunder lie within this belt. Lower Iberville noncalcareous shale with associated calcareous shales and olive-gray-weathering limestone beds crops out along the eastern shore of Shelburne Point also. Calcareous shales intercalated with noncalcareous shales appear in the small bay immediately east of the northernmost point of land and crop out intermittently along the eastern shore of the point south to the hill capped by the Monkton at the southwest corner of Shelburne Bay where the Stony Point-Iberville contact apparently lies beneath the overthrust plate. The thin zone of calcareous beds found along the thrust as far south as the road from Shelburne Falls to Meach Cove is interpreted as belonging to the Iberville transition zone. South of the Shelburne Falls-Meach Cove road Stony Point shales outcrop beneath the thrust with the transition zone lying to the west. On Pease Mountain interbedded calcareous shale and noncalcareous shale and calcareous shale with dolostone beds imply the presence of the transition zone immediately beneath the westward-thrust Bridport beds (section CC′).

Evidence indicating the presence of the Iberville beneath the central part of the valley is wanting, and the implication garnered from available water well data is that the central part of the valley is underlain by the Stony Point and Glens Falls formations south of the latitude of Hawkins Bay. Whether the Iberville lies under the Pleistocene deposits west of Route 7 and south of a line from Barber Hill to Pease Mountain is problematical. A well drilled about 400 feet north of the North Ferrisburg intersection on Route 7, approximately a mile north of Lewis Creek, seems to have encountered only Stony Point shales beneath a cover of approximately 165 feet. Wells along the road about a mile west of the Lewis Creek bridge on Route 7 apparently encountered only Stony Point, although cuttings from only one of these were seen; these were blue-black calcareous shale. Cuttings from a well drilled in the summer of 1957 at the White Milk Company plant approximatley 1800 feet east of North Ferrisburg Station consist of calcareous shale and argillaceous limestone, mostly shale, from a depth of 179 feet to the total depth of 500 feet. Cover at this point is 125 feet, and the cuttings from the interval beneath the cover to the 179-foot depth seen alongside the well were like those from greater depths. Thus if the Iberville is present west of Route 7 in the latitude of Lewis Creek, it must not extend as far as the next road west.

Evidence from wells south of Lewis Creek suggests that the formation is absent or of very restricted distribution in the area west of Route 7 and south to about the latitude of the middle of the west face of Shellhouse Mountain. From the available evidence and related inferences it is thought that the Iberville disappears at the cross-fault at the north end of Shellhouse Mountain. In part it is overridden by the rock mass shoved from the east.

The Iberville reappears at the north end of Snake Mountain and extends southward to beyond the limits of the Central Champlain Valley. Shales with dolomitic siltstones are well displayed in ridges south of Vermont Route 125, .5 to 1 mile east of Bridport and on the higher hills adjacent to the thrust belt on the east. In the latitude of Bridport the contact between the Iberville and the Stony Point lies along Route 22A for a mile north of Bridport and an undetermined distance to the south. Upper Iberville outcrops to the east of the road, and Stony Point outcrops to the west; the transition zone apparently lies slightly to the west of the road or along it.

In this southern area the intense shearing and deformation of the formation so common in the Shelburne Point exposures is absent, or not so well developed. The zones of calcitization frequently found in the northern exposures are absent here. However, the formation has been wrinkled into a number of low, plunging folds, some overturned to the west.

The formation consists largely of black to dark-gray (N1 to N3), thin-bedded, thin-cleaving, carbonaceous, noncalcareous shale. Other important lithologic types are yellowish-orange (10YR6/6)-weathering, black and dark-gray sublithographic dolostones up to 1 foot thick, and some as much as 3 feet, dolomitic siltstones ranging from thin laminae to beds as thick as 1 foot, and olive-gray (5Y6/1)-weathering, 6- to 8-inch thick, sublithographic black and grayish-black silty limestones and calcareous siltstones. This latter type of rock occurs in moderate abundance just north of the contact between the Iberville and the Stony Point south-southeast of Queneska Island. The moderate yellowish-orange (10YR5/4)-weathering, irregularly distributed dolostones are more incidentals in the formation than important units. They form no thick sequences.

Black and grayish-black (N1 to N2) argillaceous, splintery-fracturing and fibrous-appearing calcareous shale is an important component of the transition zone, but is generally absent in the upper part of the formation. No lenses of calcareous shale or of interbedded calcareous and noncalcareous shale have been recognized in the upper Iberville. Also in the transition zone are medium-gray, smooth-weathering, bluish-black, argillaceous limestones like those of the Stony Point. As in the case of the Stony Point limestones, where the limestones are highly contorted and sheared, veins, knots, and masses of white calcite are distributed through them but are most commonly concentrated in the minor faults.

The dominant noncalcareous shales of the formation are quartzitic, composed of very fine particles of quartz, and moderate amounts of argillaceous material stained with carbonaceous matter. Sericite (Hawley 1957, p. 67) is also present, and Clark (Clark and Strachan, 1955, p. 688) describes the shales as micaceous. The typical Iberville shale also reflects light evenly and as a result appears much like slate; the shales might also be described as platy. Because of their quartz content, the Iberville shales are harder than the calcareous shales of the Stony Point and transition sequence.

Many of the black, platy shales of the formation are extensively jointed, the joints being filled with white veinlets of calcite. In some instances the veinlets follow one set of joints; in others the joints of all sets are filled with the white material.

Dolomitic siltstones occur as very fine laminae, pencil-line thin in many instances, and as thicker beds; the average thickness is between .5 and 1 inch. The yellowish-orange coloration is effected by weathering of the dolomite grains. Most of the dolomitic siltstone beds exhibit cross-lamination, scour-and-fill structures and other evidence of current activity. Rhythmic bedding in the shales and the siltstones is much as described by Hawley (1957) for the more northern outcrops of the Iberville. Figure 2, Plate 12 shows a typical outcrop south of Pease Mountain while Figure 3 illustrates a typical outcrop at the tip of Shelburne Point.

Thickness

Areas suitable for direct measurement of Iberville thickness are lacking. Outcrop width along the west face of Snake Mountain suggests that a thickness of between 250 and 500 feet is exposed beneath the upfaulted Stony Point. Structural relations on Shelburne Point (see cross-section AA′) imply the presence of ±500 feet of the lower Iberville and to the south (cross-section BB′) approximately 500 feet of Iberville is thought to be preserved. The total of these values corresponds with the minimal thickness of 1000 feet that Hawley (1957, p. 64–65) suggests is in the northern Lake Champlain Valley. He indicates (p. 58) that the formation may be as high as 2000 feet thick.

Age and Correlation

Only fragmentary graptolites have been found in the Iberville of the Central Champlain Valley, in Bridport. Hence the correlation must rely on stratigraphic position over the Stony Point shale. The Iberville represents upper Mohawkian deposition in the Central Champlain Valley. Its upper limit is not well established, but Hawley (1957, p. 58) suggests that it may range into a position equivalent with the Gloucester formation of central and southwestern Ontario. The formation correlates with the Utica shales of the Mohawk Valley (Twenhofel and others, 1954; Clark and Strachan, 1955). Part of the Hortonville slate of the Middlebury Synclinorium may correlate with it also, although Cady (1945, p. 559) assigns a thickness of only 400 feet to the formation, noting that there once may have been 4000 to 5000 feet of shale present.

Upper Mohawkian History

The interbedded shale and limestone of the Glens Falls transition zone and its correlative, the Cumberland Head formation to the north, point to the gradual influx of very fine detritus. Presumably this material came from the east, although no direct evidence for this conclusion is found in the Central Champlain Valley. The implied relations between the Hortonville of the Middlebury Synclinorium and the Snake Hill shales to the south (Cady, 1945) seem to suggest an eastern or southeastern origin. The fine-grained nature of the deposits implies that the landmass which had supplied the detrital quartz for the silty horizons of the Glens Falls had been worn even lower or that the types of rocks exposed had changed so that rocks which weathered to clay were supplying the bulk of the detrital material. These changes could also be wrought simply by the uplifting of a different landmass or by a shift in the current pattern so that a new area was supplying the material. Perhaps the clay reflects winnowing activity in an adjacent area.

The Champlain Valley area seems to have been a trough-like feature during much of the time that the Stony Point and the Iberville were being deposited. The Adirondacks, while probably not above water level, were active as a barrier. Thinning of the shales toward Montreal implies the presence of a positive area. The limestones west of the Adirondacks show the presence of clear, shallow seas, seas that apparently were connected with the Champlain Valley area across the Adirondacks. Thinning of the Stony Point toward the east, away from the Central Champlain Valley is a possibility, although the evidence is rather flimsy. If the Hortonville in the Middlebury Synclinorium represents only the Glens Falls transition zone and the lower part of the Stony Point, then some quartzitic, noncalcareous deposits were accumulating to the east, perhaps geographically closer to the landmass which was contributing the sediments. According to Hawley (1957, p. 84) the structures in the Iberville indicate a broad slope or a bottom near the base of a broad slope. On the basis of the orientation of the current structures, he suggests that the bottom topography sloped upward to the northeast or east in the northern Lake Champlain region.

It is thought, but by no means proved, that the Iberville deposition represents the expansion of deposition of very fine quartz into the trough from an area in the east and that during Stony Point deposition some Iberville-like deposition, or at least Hortonville-like, was occurring in the area now represented by the axial region of the Middlebury Synclinorium. It is suggested that it is possible to picture the Champlain Valley area as a trough-like feature, or a more-actively downsinking area, which was bounded to the east and west by shallower seas. The unconformity between the Hortonville and pre-Hortonville beds to the south of the area (Cady, 1945, p. 558–559; Fowler, 1950, p. 35–36) emphasizes that in an area not too far south of the present southern limits of the Champlain

Valley the crust was acting in a positive manner. Within the Central Champlain Valley, at least, the downsinking-tendencies seem to have persisted uninterruptedly. The Iberville is thought to have been spread westward in response to a slight uplift; perhaps the formation overlapped the Stony Point locally. The quartz of the Iberville may represent the residue from weathering of the rocks which earlier had supplied the clay minerals for the Stony Point shales.

Pleistocene Deposits

Much of the Central Champlain Valley is covered by clay, sand, and gravel deposited in the arm of the sea that invaded the area following the retreat of the last ice sheet, and in the later, ancestral Lake Champlain. On the higher slopes can be seen deposits and terraces of the pre-marine Lake Vermont (Chapman, 1942). No specific study was made of these deposits. On the map they have been lumped as cover and shown in yellow. The marine blue clays with abundant shale fragments can be seen at the base of the Pleistocene deposits in the southern part of the area. The road cut south of the U. S. Route 7 bridge across Lewis Creek in Ferrisburg also exposes them. Well-formed terraces at Button Bay and south of Hill Point are the exposed bottom of the shallow sea.

Terraces left by the waters of Lake Vermont may be seen in a number of places; they are particularly evident on the south side of Mt. Philo, on the lower slopes of Snake Mountain (Chapman, 1942, p. 49–83), on the south side of Jones Hill, and south of Pease Mountain.

Glacial striations and grooves are abundant; they are best preserved where the Pleistocene deposits have been recently removed from massive limestones. Glacial grooves are exceptionally well developed at the head of Kingsland Bay, near the entrance to École Champlain, and on the Crown Point limestones east of Long Point.

IGNEOUS ROCKS

Numerous igneous bodies have invaded the sedimentary rocks of the Central Champlain Valley. The present work has added to the list of dikes compiled by Kemp and Marsters (1893), some from shore exposures and others from inland outcrops. Many intrusions too small to show on the map accompanying this report were found.

Two general types are present, being differentiated on the geologic map (Plate 1). The first and more common type is bostonite. These rocks are light-colored, fine-grained to cryptocrystalline. Dark-pink and reddish varieties are common, but the most common type is cream-colored or whitish. Some of the bostonites are porphyritic. Differing local histories are shown by several of the alkali-rich intrusions.

The second general type consists of lamprophyres. These rocks are dark, fine-grained, and occasionally porphyritic and vesicular. The most common rock-type in the second group is camptonite, but in the northern part of the Shelburne Point area monchiquites form the dark intrusions. Some of the dark dikes approach diabase in appearance.

The area of most intensive igneous activity is Shelburne Point. Other local areas of concentration are on Pease Mountain and in the Thompson Point area. Barber Hill in Charlotte is a mass of medium- and coarse-grained bostonite which can be easily mistaken for a pink granite. The southernmost intrusion found is a lamprophyre, probably a camptonite, exposed in a patch of the Stony Point shale in the east bank of the West Branch of Dead Creek, south of the road, almost due east of Crane Point.

Many of the bostonites are actually bostonite breccias, containing blocks of earlier formed bostonites, as is the case of the Orchard Point intrusion, or fragments, up to 1 or 2 feet long, of the rock through which the intrusive material has passed. In some cases the inclusions form over 90 percent of the rock and the igneous material only about 10 percent, serving as little more than cement.

The breccia located on the east side of Shelburne Point, S. 25° W. of Redrock Point, is composed of pink-lavender porphyritic bostonite with blocks of shale, several kinds of gneiss, white quartzite, red quartzite, and black limestone. Shale fragments from the invaded Iberville and Stony Point are the most abundant rock type. Hawley (1956) has effectively described this occurrence. Another breccia on the north side of the Monkton-capped hill at the southwest corner of Shelburne Bay is 90 percent 1- to 6-inch, corroded fragments, including quartzite, various dolostones, and shale.

On the west side of Shelburne Point, on the south side of Pheasant Hill between the two 20-foot bostonite dikes, there is a series of smaller bostonite dikes containing fragments of pre-Stony Point rocks up to 3 or 4 inches in size. At the southwest corner of Pheasant Hill a darker dike containing limestone, reddish shale, reddish and white quartzite, black shale, white or light-colored shale, and black limestone cuts a 1-foot bostonite dike containing a similar assortment of fragments and in addition calcitic dolostone and buff shale fragments. The intersection of the two dikes is at or below late summer lake level. The dark-colored dike is highly calcareous and very fine-grained. Study of a thin section reveals that it is probably largely kaolinized or highly altered feldspar; in outward appearance the material resembles the shales into which it was intruded, and the inference is that the molten material absorbed much carbonate from the calcareous shales through which it passed. Nearby dikes contain fragments of calcite-veined Stony Point shale and black limestone. The large bostonite dike at the northwest corner of Pheasant Hill shows evidence of two intrusions of bostonite, including chilled borders on the later intrusion.

Barber Hill in Charlotte is composed of relatively coarse-grained bostonite easily mistaken for a fine-grained to medium-grained granite. Interstitial quartz up to 10 per cent and ± 5 per cent biotite are present locally. The individual feldspar crystals average between 2 and 3 mm. Kemp and Marsters (1893, p. 53) mentioned the occurrence briefly. The coarse-grained body is cut by fine-to very fine-grained dikes of bostonite and porphyritic bostonite similar to the dikes exposed along the lake shore. Some thin veins of milk-white quartz are also present; similar white quartz is associated with the bostonite dike located approximately 3600 feet N. 70° E. of Cedar Island. Much evidence of internal shearing in the Barber Hill body exists in the joint pattern. Near the crest of the hill at its northwest corner a camptonite dike cuts the bostonite.

The Iberville shale in contact with the main part of the Barber Hill mass has been baked and locally hornfelsed. Studies of the contact zones of some of the other intrusions show very limited temperature effects on the country rock. At best the baking is only an inch or so thick, and the intrusions have chilled borders. Apparently the Barber Hill intrusion was much warmer than the other intrusions, or its greater size led to more metamorphism.

The corroded, rounded fragments in the sill at the north end of Garden Island are chiefly dolostones and sandy dolostones derived from the Whitehall and Ticonderoga formations.

The black lamprophyres form thinner intrusions than do the bostonites. Most are very fine-grained to microcrystalline, but many have fine-grained phenocrysts of hornblende or augite. Rarely biotite forms phenocrysts. Kemp and Marsters (1893, p. 58) indicated that the lamprophyres on the tip of Shelburne Point are monchiquites, and thus essentially feldspar-free. The author has not verified this determination microscopically. The dike on Juniper Island is most likely a monchiquite, although it contains large phenocrysts of sodic plagioclase as well as amygdaloids of zeolites. The intrusion .8 mile east of Saxton Point appears to be a monchiquite also.

In the west face of Saxton Point a thin (4 to 6 inch) carbonatite sill and dike has intruded the Stony Point. The rock is composed of fine-grained (±.2 mm) calcite crystals and traces of angular quartz and feldspar. Near the south end of the west face the sill portion of the intrusion is cut by the lamprophyre which Kemp and Marsters called a hornblende monchiquite (1893, p. 59, field no. 567).

Most of the intrusions are discordant and thus dikes. However, a few sills such as those at Summer Point and Garden Island do occur. There are also a number of "apparent sills." These intrusions are discordant in the sense that they have cut across the folded bedding; yet they are concordant to the structure of the region in that they have been intruded parallel to the fracture cleavage. The most conspicuous of these intrusions is at Orchard Point (Nash's Point of Kemp and Marsters, 1893). Others are found 900 feet south of Orchard Point, where a lamprophyre has been intruded parallel to the cleavage, 3600 feet north of Pheasant Hill, approximately 1 mile east of Saxton Point, and approximately 1.5 miles east of Quaker Smith Point. The breccia on the east side of Shelburne Point and S. 25° E. of Redrock Point appears to parallel the cleavage. Whether the intrusions have followed a regional joint pattern or not can not be proved at this time. However, where the author has noted the joints, adjacent dikes have different attitudes.

Evidence concerning the relative ages of the bostonites and lamprophyres has been discovered in only three places. At Orchard Point the bostonite "sill" has cut through a monchiquite which is exposed both above and below the bostonite. This is the "basic dike" beneath the intrusion numbered 107 by Kemp and Marsters (1893, p. 52). On the next small point north of Orchard Point a vertical, northwesterly striking bostonite dike cuts a westerly striking lamprophyre dike resembling a monchiquite or fourchite. The third locality is in the Barber Hill intrusive where a camptonite dike intrudes the bostonite. No relation between the camptonite and the bostonite dikes cutting the coarser bostonite was seen. While the suggestion has been made that the bostonites followed the lamprophyres in time, it appears more likely that the two rock types were intruded during the same general period of igneous activity. In one locality the former may be the earlier while at another the latter may have been intruded first.

Obviously the igneous activity succeeded the formation of the cleavage; the utilization of the cleavage by the intrusions points this fact out. Some of the intrusions are closely associated in space with intense zones of calcitization in the shales of the Iberville and Stony Point formations.

However, the calcitization is thought to be related to the deformation of the shales rather than to the intrusions. Several of the dikes have inclusions of Stony Point limestone with characteristic white calcite veins. It appears then that the calcitization of the shales took place prior to the intrusive activity. Also in several places the intrusives cut the Champlain Thrust and allied high-angle faults.

The question of whether the dikes preceded or followed the cross-faulting can not be answered unequivocally. Hawley (1957, p. 84) believed that the North Ferrisburg fault cuts the bostonite dike at the bridge in North Ferrisburg. The dike is offset in Lewis Creek, but the small fault seems more related to the intrusion of the dike than to the major fault through the locality. This dike is the porphyritic monzonitic bostonite of Alling (1928). The only place where a possible answer may lie is on Shelburne Point about .5 mile north of Pheasant Hill. At this locality the fault between the Stony Point and the Iberville may be cut by the large bostonite mass. No certain conclusion can be made from the relationship as the exposures are extremely poor. On the other side of the argument is the fact that insofar as is known none of the intrusions have followed zones of weakness caused by any of the faults, either high-angle or thrust. The only ones structurally controlled are those paralleling the fracture cleavage.

Cady (1945, p. 580–581) suggests an Upper Ordovician age for the basic dikes. The Monteregian intrusives of the Montreal, Quebec, area resemble in some ways the intrusives in the Champlain Valley. According to Clark these intrusions may be as young as Cretaceous or early Tertiary (Clark, 1952, p. 109–110). Billings (1956, p. 86) points to camptonites and bostonites associated with the White Mountain series of New Hampshire which he dates (p. 106–107) as Mississippian (?).

Evidence from adjacent areas seems to imply that the Central Champlain Valley intrusions are post-Devonian. A closer dating can not be made at the present time.

STRUCTURAL GEOLOGY

General

In a broad sense the Central Champlain Valley can be divided into two structural provinces. The first is an area of simple tilting and attendant gentle and local folding; the second is that part of the region which was affected more directly by the overthrusting from the east and in which the structural relations are somewhat more complicated. In the second province the many slices of rocks lying beneath the Champlain Thrust have been cut transversely by two systems of high-angle faults, giving a patch-work appearance to the rock distribution. Also within this province are a few overturned folds that may be traced for some distance along strike, but the dominant structural feature is the thrusting and high-angle faulting paralleling the Champlain Thrust.

Evidence of more than one period of deformation exists although accurate dating of the movements and warping occurring subsequent to the thrust faulting is impossible. Cady (1945, p. 579) dates the westward movement of the Taconic allochthone as later than middle Trenton deposition and before late Silurian; he places the formation of the other structures in West-Central Vermont in this time interval. The author has found no evidence to contradict this concept except that the Iberville which forms the upper part of the Trenton sequence has been affected also, placing the movements into the Upper Ordovician. Elsewhere (Kay, 1942, p. 1619) Queenston shale has been overridden by the thrust sheets, indicating post-Ordovician age for the movements. Uppermost Silurian rests on the overthrust mass south and west of the Central Champlain Valley.

Subsequent structural events are even less well dated, but they are clearly post-thrusting in age. Whether later events are related to the middle and late Devonian (Acadian Disturbance) (Hawley, 1957, p. 85) or to the Appalachian Revolution, or some integral part of it, is a moot question. In any event, several periods of deformation are indicated.

As a result of the later movements two systems of high-angle faults formed in the area. One, the longitudinal system, trends generally north-south or a little east of north; faults of the second trend approximately east-west but vary somewhat in strike. While some evidence exists for the offsetting of the longitudinal faults by the cross-faults, the obverse is not true; the evidence seems to favor more strongly the essentially simultaneous development of the two systems, as Quinn (1933) has suggested. The pattern of high-angle faults found within the Central Champlain Valley fits with those found by earlier workers (Cushing, 1895; Hudson, 1931; Quinn, 1933; Rodgers, 1937; Buddington and Whitcomb, 1941), although the exact strikes of each system do not agree in all details.

Cleavage-bedding relationships have proved useful in determining the position of the beds. As will be discussed later, the cleavage is deformed, but where the presence of sedimentary structures within the rocks permitted determination of the structural position of the particular outcrops, the evidence thus obtained checked with that determined from the cleavage-bedding relationships. Thus it is believed that the cleavage-bedding relation of any one outcrop is an accurate indicator of the structural position of the outcrop with relation to the initial folding of the rocks; where the cleavage has been warped, secondary folds have been superimposed on the earlier formed ones.

Major Structures

Folding

Structurally the major part of the Central Champlain Valley consists of two synclinoria. The more northerly one, to be called the Shelburne Point Synclinorium, plunges northward from the latitude of a line from Hawkins Bay to Mt. Fuller and disappears beneath the lake at the north end of Shelburne Point. The southern synclinorium, here termed the Addison Synclinorium, is first recognizable at the north end of Snake Mountain where the Iberville formation appears high on the slopes of the mountain. Undoubtedly this synclinorium extends farther north, perhaps as far as Vergennes, or even farther, but it is not recognizable as an entity north of the latitude cited. Likewise, the southern margin of the Shelburne Point Synclinorium may extend farther south than the latitude of Hawkins Bay, but it is unrecognizable south of here. The axial region of the Monkton cross-anticline (Cady, 1945, Plate 10, fig. 5) extends westward to Shellhouse Mountain, and it may be at this position that the dividing line between the two synclinoria should be placed. Distribution of the Iberville, Iberville-transition, and Stony Point sequences outline the general pattern of the folds within the synclinoria.

The axial regions of both synclinoria are overridden by the Champlain Thrust except that the axial region of the Shelburne Point Synclinorium extends along the peninsula some distance west of the Champlain Thrust. It is believed that the anticlinorium which theoretically lies east of the Shelburne Point Synclinorium is beneath the waters of Shelburne Bay and that it is overridden by the upper plate of the Champlain Thrust (cross-section AA′).

On the west the synclinoria are bordered by the Adirondack block, which formed a rigid buttress when the region was subjected to compressive stress but are separated from it by lateral continuations of the rocks found in Vermont. High-angle faults paralleling the regional strike cut these rocks into blocks. North of the Central Champlain Valley several synclinoria and anticlinoria appear between the center of Lake Champlain and the Adirondack block; they lie to the west of the axial line of the Shelburne Point synclinorium. (See maps of Hudson, 1931; Erwin, 1957; Hawley, 1957.) The author once thought that the lower Iberville exposures of Appletree Point described by Hawley (1957, p. 64) belonged to the lower Iberville outcrop belt along the west side of Shelburne Point, but it is now thought more likely that this outcrop is part of another synclinorium lying to the west of the Shelburne Point structure and that the two folds are separated by one or more faults. From studying the regional relationships of the synclinoria and anticlinoria the author has come to the conclusion that the larger structures form a series of *en echelon* folds striking in a general north to north-northeasterly direction except where high-angle faulting has twisted the axial trend to slightly west of north. The trend of the band of folds is in a general west-northwest direction so that the individual folds are offset from one another in a northerly direction as one looks at them from the south.

The synclinoria are broken by both longitudinal faults and cross-faults of major importance as well as by local thrusts, reverse faults, and normal faults. Adjacent to the Champlain Thrust the synclinoria are extensively broken and disrupted. Folding apparently preceded the overthrusting; the relations of the Champlain Thrust to the synclinoria suggest this conclusion. Yet some of the folding is attendant upon the later high-angle faulting, particularly in the blocks along the western edge of the area.

Thrusts and Related Faults

By far the most striking structural feature of the region is the Champlain Thrust. The effects of movement along this rupture dominate the structural relations along the eastern border of the Central Champlain Valley, and the resistant rocks which the movements have brought to the surface over the less resistant shales and limestones have provided the hills and mountains which rise abruptly above the lowlands of the lake.

The plane of the thrust is exposed along the front of Snake Mountain, on the small hill northeast of Crane School, on the east side of the isolated hill at the southwest corner of Shelburne Bay (Plate 4, Figure 2), in a number of places along the ridge extending southward from Buck Mountain as well as on Mt. Philo, Jones Hill and Pease Mountain, and Shellhouse Mountain. In a number of places the author's mapping of the position of the Champlain Thrust is at variance with that shown by Cady (1945, Plate 10). The fault generally dips east at angles up to 20 degrees, but in places, local warping has given it a low westerly dip.

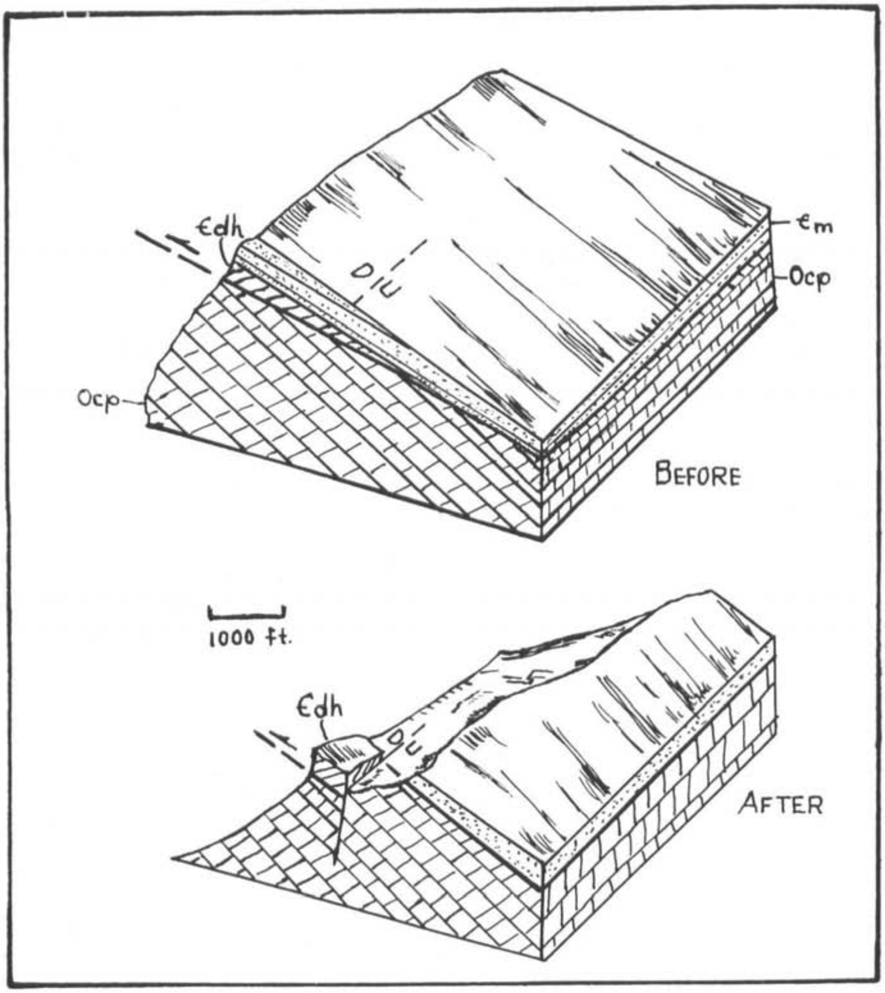
Monkton quartzites lying above the thrust plane dip eastward at low angles in general, but locally folding and faulting in the upper plate have caused tilting of the beds and variations in attitudes.

Some of the folds, such as those exposed on the east side of Jones Hill in Charlotte, plunge down the dip of the beds, the plunge approximating the dip of the thrust; in other cases the folds are at an angle to the strike of the thrust. The author observed approximately 8800 feet N. 37° E. of Crane School at the south end of Snake Mountain one recumbent isoclinal fold of Monkton quartzite lying but a few feet above the thrust plane. The axis of the fold plunges down the regional dip of the beds at an angle near the dip angle of the thrust.

Many of the faults exposed above the thrust plane die out at the thrust. Yet, some continue into the footwall, but these are believed to be related to events subsequent to the thrusting while the folds and faults restricted to the Monkton are features developed as the upper plate moved into position. Without a doubt, a detailed study of the structures in the upper thrust plate would provide important clues to the history of the Champlain Thrust and some of the stresses that were operative as it formed. There can be little doubt but that the upper plate was wrenched and twisted as it moved westward. Subsequent events have added to the complications.

North of Shelburne Point, at Lone Rock Point in Burlington, the Dunham forms the upper plate of the thrust. Between Lone Rock Point and the southwest corner of Shelburne Bay the plane of the thrust has moved upward an undetermined number of feet stratigraphically. At the south end of the Central Champlain Valley the thrust lies some distance above the Dunham; more precisely, it is approximately 450 feet below the contact between the two lithologic units of the Monkton. About 2.5 miles south of Buck Mountain the thrust plane swings down into the Dunham. Along the front of Snake Mountain the plane is probably not far from the Dunham-Monkton contact. The two small outcrops of the Dunham nearer Buck Mountain represent blocks of the overthrust mass which have been dropped down; their base is the downdropped Champlain Thrust, and they are bounded on the east by a normal fault (Text-figure 17).

In the Vergennes area a slice beneath the main thrust extends westward to about the middle of the lowland area where the Bridport lies atop



Text-fig. 17. Downfaulted Dunham block west of Champlain Thrust before and after high-angle faulting. Southwest of top of Buck Mt.

the Stony Point on the hill about 3500 feet west of the Vergennes city line. A well drilled at the house approximately 880 feet northeast of Intersection 172 west of Vergennes encountered 12 feet of cover, "limestone" from cover to a depth of 75 feet, and "slate" from 75 feet to a total depth of 185 feet (Mr. Ball, personal communication, March, 1958). Outcrops of "limestone" in the yard are Bridport. Assuming that the Bridport-

"slate" contact at a depth of 75 feet is the same as the contact exposed on the hill to the west, the dip on the fault plane is approximately 5 degrees to the east. The thrust is believed to have extended eastward once as a continuous plane; however, subsequent faulting has broken the upper plate and brought the fault to the surface. It is believed that the small Bridport outcrop approximately 1700 feet west-southwest of the northeast corner of Vergennes lies just above the plane of the thrust and that the fault lies at the base of the ridge immediately east of this locality. Cross-section FF′ explains the relationship envisioned. The thrust exposed 2100 feet south-southeast of the northwest corner of Vergennes is interpreted as a slice in the larger thrust plate.

Cady (1945, Plate 10, p. 574–575) related the thrust exposed north of Otter Creek to the longitudinal fault which runs along the west face of the ridge extending through the southwest corner of Vergennes. However, the fault south of Otter Creek appears to be a high-angle fault instead of a thrust, and it can be traced northeastward to near the northeast corner of Vergennes. The interpretation presented here is that the Vergennes thrust of Cady (1945, fig. 5, p. 574–575) is in reality two faults: the thrust on the north side of Otter Creek and the high-angle fault which brings the Whitehall against the Stony Point and Glens Falls formations. It is thought that a high-angle, probably normal fault, extends through Vergennes in a southwesterly direction, separating the northern thrust plate, which has been downdropped, from the high-angle fault to the south. Foyles (1928a, map) recognized the fault but had a different interpretation of the thrust faults.

The thrust exposed west of Vergennes is thought to extend northward to Ferrisburg where the Bridport overlies the Stony Point in Little Otter Creek near the railroad crossing. About a mile north of Little Otter Creek high-angle faults apparently cut it off, but the exact relations are hidden by the Pleistocene cover.

Presence of another major thrust, or high-angle fault directly related to the Champlain Thrust, is inferred by the belt of Stony Point shale lying between the Champlain Thrust and the Iberville formation and extending from Shelburne Point south to Jones Hill. The first appearance of the fault is at the Monkton-capped hill near the southwest corner of Shelburne Bay; the shales exposed beneath the Monkton on the east side of the hill are believed to be Stony Point beds while typical lower Iberville beds, right side up, outcrop along the beach and beneath the Monkton at the northwesterly corner of the hill (cross-section BB′).

The thrust disappears beneath the Monkton at the cross-fault immediately north of the hill and does not reappear until about the latitude of the Shelburne Falls-Meach Cove road. The only place that the attitude of the fault has been determined is on Jones Hill where the Iberville-Stony Point contact dips about 45 degrees east. The thrust disappears between Jones Hill and Pease Mountain.

As may be discerned from cross-sections DD′ and EE′, the Stony Point-Iberville thrust is believed to extend southward to Mt. Philo where the calcareous shales lying between the Monkton capping Mt. Philo and the noncalcareous shale on the south slope are interpreted as Stony Point thrust over the Iberville, which in turn lies in normal stratigraphic position over the Stony Point below. The Iberville exposures are considered to be the south end of the north-plunging Shelburne Point Synclinorium, except that the last remnant of the structure is believed to be represented by the Iberville outcrops in Lewis Creek near the U. S. Route 7 bridge.

Along the west face of Snake Mountain a similar thrust outcrops, bringing Stony Point beds over the Iberville. Whether the two thrusts represent the same rupture or different breaks at about the same horizon is a moot question. In the absence of evidence the two faults are considered as separate. Both, however, are moderately high-angle breaks, and above each the beds of the westward-moved mass are right side up.

The Glens Falls formation is placed over the Stony Point shales from Jones Hill in Charlotte southward to a position about 1.65 miles south of Lewis Creek. The fault dips eastward at a high angle, but it is thought to be related to the thrusting stage rather than to a later event. The only exposure of the fault is in the tributary to Lewis Creek approximately .4 mile S. 25° E. of the U. S. Route 7 bridge over Lewis Creek. Upon a cursory examination of the outcrop it may be thought that the contact is depositional, but study of it shows an increase of contortions and overturned folds in the Glens Falls limestones as the contact is approached. The inference is that movement has occurred. Dip of the contact is 80° E., and the beds have the same inclination immediately adjacent to the contact. All evidence indicates that both formations are essentially right side up away from the zone of faulting. Water well information from about .3 mile slightly south of west (Cardinal Cottages) of the outcrop indicates that the fault plane probably dips closer to 45 degrees in depth.

Between the southern boundary of Vergennes and the north end of Snake Mountain two major faults, one a reverse, the other a thrust, related to the Champlain Thrust, dominate the structure; a host of minor slices occur between them. The more easterly of the two extends intermittently from approximately a half mile north-northwest of the southwest corner of Vergennes to the latitude of Buck Mountain where it is cut off by a southwesterly striking high-angle fault. This fault has placed the Crown Point beds over the Glens Falls, and it is believed to lie beneath the Crown Point limestones exposed at the southeast corner of Vergennes since a later reverse fault, seen at the quarry entrance, has caused the upfaulted block to be dropped down against the Glens Falls to the west.

The second fault is best exposed on the small hill at the north end of Snake Mountain where the Bridport may be seen lying atop the Stony Point shale. The fault is also exposed northeastward across Otter Creek where it has been warped up slightly in conjunction with movement along a cross-fault. It too disappears at the southwesterly trending fault west of Buck Mountain. Speculation suggests that the slice of Bridport west of the top of Marsh Hill and the thrust on the hill to the northwest of Marsh Hill are northward continuations of this fault, or at least represent a rupture at approximately the same horizon.

The Orwell Thrust, interpreted as a subsequent shear thrust (Cady, 1945, p. 572, Plate 10), extends into the area. Instead of being continuous, it is broken into segments by cross-faulting. Possibly the westernmost of the two major thrust faults between Snake Mountain and Vergennes represents a northward continuation of the Orwell Thrust, or at least a rupture at nearly the same horizon.

High-angle reverse faults obviously related to the major thrust faults shear the beds of Crown Point limestone immediately west of Shellhouse Mountain. The movement along any one of the faults within the Chazy mass is probably small, but the cumulative effect may be of some magnitude. The faults are associated with overturned, isoclinal folds such as that pictured in Plate 9, Figure 3. Southward the faults pass into small, tight folds which are brought out by the Day Point outcrop pattern a half mile north of Little Otter Creek. Others of the faults die out within the mass of Crown Point.

On the west face of Buck Mountain the upper limb of the overturned syncline is sheared by several faults. They appear to be of low dip, but some evidence does exist to indicate that they may slope eastward at moderate angles. An eastward-dipping (42°) shear between the Orwell limestones and the Glens Falls on the upper limb of the syncline is exposed near the 680-foot level due west of the top of Buck Mountain.

In the small valley 1800 feet north-northeast of Buck Mountain the Crown Point lies structurally above overturned Orwell. (Stratigraphic evidence within the Orwell indicates overturning.) The contact is faulted, the fault surface dipping eastward at an angle of 35 to 40 degrees which is somewhat lower than that of the beds. The Bridport higher on the west face of Buck Mountain is thrust over the Crown Point.

From the stratigraphic relations alone one would not think that the faults exist; however, cleavage-bedding relations within the Crown Point indicate that the massive limestones are right side up, and the exposures of the fault surfaces further substantiate the structures.

At the northwest corner of Buck Mountain (elevation 420 feet) subsidiary reverse faults and small folds are exposed. Gash features in some of the massive limestones of the Crown Point suggest emplacement of the beds by underthrusting.

Longitudinal Faults

The area is cut into blocks by a series of north-northeast striking faults, presumably high-angle. These faults are in addition to any meridional faults cutting the overthrust masses along the eastern margin of the area. Some strike west of north. Some are reverse faults, but most are probably normal faults. In only three places have surfaces of faults belonging to the longitudinal system been seen. Two of these are normal faults, the fault north of Arnold Bay in Panton, and a small fault on the west side of Bluff Point in Ferrisburg. The Arnold Bay fault dips 50 degrees west and that at Bluff Point dips 60 degrees east. Movement on both has been almost entirely dip-slip. The third fault is seen at the quarry about 2000 feet northwest of the southwest corner of Vergennes where the Glens Falls has been moved up against the overthrust Crown Point beds in a high-angle, west-dipping reverse fault. This latter fault may be more closely related to the breaking of the overthrust blocks than to the longitudinal faults. Movement on the longitudinal ruptures is considered to be essentially dip-slip in the absence of contrary evidence.

The surface of the fault extending southward from Vergennes to the latitude of the south end of Snake Mountain may be closely approached in the old canal west of Route 22A (adjacent to Canal Street) and south of the Vergennes bridge. This particular fault, termed the Vergennes thrust by Cady (1945, p. 574, fig. 5) has long been considered a thrust fault. According to Cady (1945, p. 574) ". . . upper Beekmantown beds lie in thrust position on middle Trenton shales . . .". However, the Beekmantown beds are actually basal Beekmantown, and even some upper Cambrian (Ticonderoga dolostone) is exposed on the upper block of the fault. Furthermore, the relative positions of the massive Whitehall beds and the shales in the ditch exposures on the west side of Otter Creek (between Canal Street and the power-house on the west side of the falls in Vergennes) preclude the presence of a shallow-dipping fault plane; on the contrary, the exposure suggests a fault plane dipping approximately 70° to 80° E. While this fault is discussed with the longitudinal faults, in reality it may be related to the thrust faults and high-angle faults associated with them. Its stratigraphic throw is of the order of 2500 feet, a value which probably is close to the actual throw of the fault.

The massive dolostone beds change from a gentle eastward dip below the buildings at the intersection of Route 22A and Canal Street to a steep dip to the west; in the ditch the dip of the dolostones is 70° W., suggesting drag as the older beds moved upward. In addition, the author has recognized bedding in the shales adjacent to the fault and has found that it dips approximately 20° to 30° W., both in the exposures in the ditch and in the exposures on the east side of Otter Creek in banks cut by the road to Weeks School from Route 22A. The relations of the massive dolostones to the shales north of Otter Creek suggest more a reverse fault than a thrust.

While Cady (1945, p. 574) would limit the southern end of the fault to about the latitude of Addison, the presence of Whitehall limestones just west of the East Branch of Dead Creek, about 1.3 miles north of the Addison-Bridport town line, points to the southward continuation of the fault. It disappears in the limestone and shale terrane west of the south end of Snake Mountain.

The Vergennes fault extends northeastward to a position near the northeast corner of Vergennes where it apparently is truncated by a cross-fault approximately paralleling the railroad tracks. It is conceivable, of course, that the fault disappears beneath the thrust fault which brings the Bridport-Chazy sequence to the surface, but the overall distribution of the rocks around the northeast corner of Vergennes and westward to near the middle of the north boundary points to a cross-fault. Possibly one of the north-trending, high-angle faults between Vergennes and the Ferrisburg railroad station may be a northward and stratigraphically upward continuation of this fault. No certain proof exists.

A series of longitudinal faults, some well-authenticated, others shown by physiographic evidence on the lake bottom[3] provide a horst and graben sequence between the Adirondacks and the western half of the

[3] Marked steepening of the slopes on the lake bottom is taken as evidence of faulting; such steepening has been found to occur along projections of faults known to exist on land.

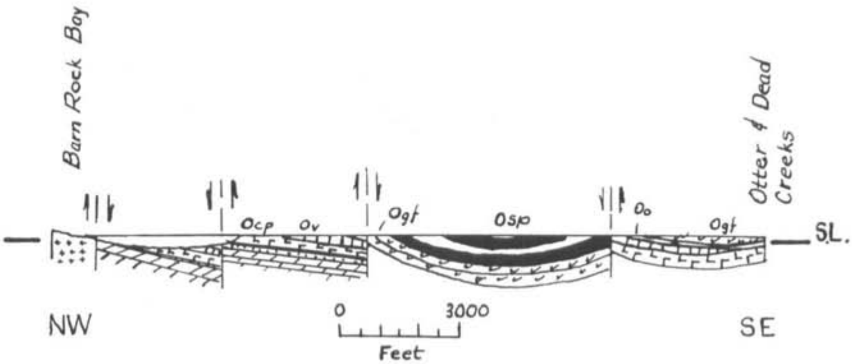
Central Champlain Valley in the latitudes of Ferrisburg and Panton. Quinn (1931; 1933, fig. 5) suggests the presence of a fault, or faults, near the Adirondack shore of Lake Champlain between Mullen Bay and Split Rock Point, the northward continuation of a boundary fault(s) extending from Bulwagga Bay near Crown Point. (See also Kemp and Ruedemann, 1910, cross-section GH.) The presence of such a line of faulting is supported by the bottom contours of the lake (U.S. Lake Survey, Corps of Engineers, Lake Champlain Charts, Nos. L.S. 171-174) as well as the topography of the eastern edge of the Adirondacks.

Existence of a second fault is suggested by physiographic evidence, namely the moderate declivity of the lake bottom along the eastern edge of Lake Champlain; moreover, the presence of Orwell beds on Scotch Bonnet, an islet a few yards from shore and a half mile south of Basin Harbor, provides evidence for a fault between it and the shore. Apparently the fault curves westward and passes west of Diamond Island. The throw, assuming that the fault plane is vertical and that the base of the Orwell lies just below the water surface, is approximately 250 feet. It is possible that the fault between Scotch Bonnet and the shore is a fault subsidiary to the major fault. Quinn (1933, fig. 5) failed to note this fault and thus includes the area in a westward-tilted block.

Outcrop patterns east of the lake shore denote the existence of a third and fourth fault; one extends south from Kellog Bay to Button Bay, and the more easterly one extends from Kingsland Bay south to White Bay. Stratigraphic throw of the Kellog Bay fault decreases southward from a value of approximately 200 to 225 feet whereas the stratigraphic throw of the Kingsland Bay fault increases in this direction to a maximum of approximately 450 feet. Existence of a fault in the Stony Point .5 mile east of the shore of Button Bay is suggested by data from a well at the farm approximately .6 mile west of Webster School. The offset of the Glens Falls and the Valcour beds east of Arnold Bay point to its presence in this latitude.

Local physiographic evidence implies that the faults are high-angle, although the minor faults associated with them suggest moderate dips. If the smaller faults reflect the movements and attitudes of the larger faults, than the larger ones appear to be normal faults. Text-figure 18 is a diagram illustrating the relations of the several blocks to one another.

During the tilting and lifting of the various blocks, a shallow syncline with a westward-striking axis formed. Quinn (1931, p. 106) assigns a value of 2800 feet to the stratigraphic throw between the Pre-Cambrian



Text-fig. 18. Diagrammatic cross-section from Barn Rock Bay, N.Y., to juncture of Otter Creek and Dead Creek, Ferrisburg, to show horst and graben structure.

of the Adirondacks and the mid-Ordovician beds of the Vermont shore in the vicinity of the horst and graben structures, a value which seems reasonable.

A second series of faults, trending more northeasterly than those just discussed, bounds Thompson Point; they may be more closely related to the cross-faulting than to the longitudinal faults. The west side of Thompson Point is separated from Garden Island and Cedar Island by a fault. Cady (1945, Plate 10) and Quinn (1931, maps) would connect this fault with the northeasterly striking fault on the north side of Split Rock Point (Quinn, 1931, 1933; Buddington and Whitcomb, 1941), but it is the author's contention that the Split Rock fault is connected to neither the Thompson Point fault nor to the fault in Converse Bay, but rather dies out before it reaches the Vermont shore or is cut off by one or more faults in the lake.

Some physiographic evidence exists for a fault on the south side of Thompson Point, extending northeastward into the low area between the last Cutting exposure and the first exposure of the Cassin formation on Thorp Point. Physiographic evidence also points to a north-striking longitudinal fault west of Flat Rock. If the faults are as outlined, then Thompson Point is a horst. In the scheme of faulting presented here the fault on the north side of Thompson Point is interpreted as a cross-fault which extends westward between Cedar and Garden Islands. Its stratigraphic throw increases westward while that of the fault on the north side of Wings Point seemingly increases inland.

John Rodgers (oral communication, December 1958) has mapped a north-striking fault along the eastern edge of the Crown Point peninsula in the Ticonderoga quadrangle; the position and direction of movement on this fault accords with that of the fault required to explain the relationships found east of Crane Point. Throw of the fault (± 2500 feet) decreases northward, and it apparently dies out in the shaly sequence somewhere in the latitude of West Addison or Potash Bay. It too may be cut off by a cross-fault. The configuration of Lake Champlain south of Chimney Point together with the relations of the bed rock outcrops on either side of the lake suggest that the lake lies in a graben.

The fault on Crown Point peninsula, first recognized by Brainerd and Seely (1886), is understood to be a minor fault in the longitudinal system. The throw is approximately 250 feet. Brainerd and Seely (1886), Quinn (1931), and Cushman (1941) viewed the rupture as a major longitudinal fault which brings Valcour through Glens Falls beds down against the Stony Point shales. In addition, the change in attitude on Coffin Point suggests the presence of another fault which cuts the Chazy sequence west of Coffin Point.

Quinn (1931, p. 106) points to the probable existence of a fault in the lake at the latitude of Port Henry. The present writer feels that there is not only the Adirondack boundary fault striking northward from Bulwagga Bay, but also a second fault near the Vermont shore downdropped to the east.

North of Thompson Point high-angle, longitudinal faults have not been recognized on land. Physiographic evidence from the bottom configuration of the lake suggests the presence of a north-striking fault immediately west of Sloop Island, west of Wings Point in Charlotte. This fault probably extends south to the northeasterly striking fault in Converse Bay and is downdropped on the west. Thompson Point and Garden Island are believed to be bordered on the west by a southward continuation of this fault (physiographic evidence; Quinn, 1931).

Another north-striking zone of faulting is thought to bound the western margin of Juniper Island. A northeast-striking fault, or zone of faulting, seems to lie between Rock Dunder and Juniper Island. This conclusion is based not only upon the configuration of the bottom but also upon the structural trends on the two islands.

The author has been unable to trace the several longitudinal faults shown, or suggested, by Hudson (1931) into the Central Champlain Valley. Some, if not all, may be present, but the evidence for them has not been recognized.

TABLE 5

THROWS OF CROSS-FAULTS

Fault	Approximate Throw—Feet
Southwest corner Shelburne Bay	1000–1500
Mutton Hill, Charlotte	1500
North end Wings Point	500–750
North end Thompson Point	500
North of Mt. Philo	1700; decreases to the east
North Ferrisburg	1300
North end Shellhouse Mt.	1000; decreases to the west
Vergennes—Otter Creek	1000; minimum value
1 mile north of Buck Mt.	750
North end Snake Mt.	2000; decreases to the west
Willmarth School—west of Snake Mt.	500
South side of St. George Hill (approx. 2 miles northeast of Hemingway Hill, Bridport)	250–300

CROSS-FAULTS

Many of these faults, intersecting the northerly striking structures of the thrust-belt, the folded areas, and the longitudinal faults at approximately right angles have been mapped. They are thought to be nearly vertical despite Quinn's (1933, p. 123) suggestion to the contrary. All are obviously later than any of the above-mentioned structures, for the cross-faults offset them in one place or another; yet the longitudinal faulting and cross-faulting may belong to the same period of deformation. Kay (1958, fig. 8) shows cross-faults offsetting the Highgate Springs Thrust near St. Albans, and Cady (1945, p. 571) recognized the offsetting of the Orwell Thrust near Orwell village. Cushman (1941) suggested also that the cross-faults cut the thrust faults although he cited no concrete evidence. Earlier Foyles (1928a, map) had explained the relations at the north end of Shellhouse Mountain by means of a cross-fault extending westward to the vicinity of Hawkins Bay. He also indicated the presence of the cross-fault in the latitude of Gage School, Ferrisburg. The amount of movement on most of the cross-faults can not be determined although reasonable approximations can be made for some (Table 5).

Because of the lack of other evidence and because the evidence from the Adirondack border (Quinn, 1931, 1933) indicates that the high-angle faults are essentially normal faults, it is assumed that the cross-faults of the Central Champlain Valley are normal faults. In only two places have the planes of cross-faults been seen. The first, a small reverse fault dipping 42° N. and having a throw of 30 to 40 feet is located approximately 3500 feet S. 28° E. of the southwest corner of Waltham. The second, located between 350 and 400 feet north of the south boundary of Waltham, south of Buck Mountain, and exposed at an elevation of 400 feet, is a normal fault dipping 47° S. The small cross-fault which forms the northern boundary of the isoclinally folded mass west of Mt. Fuller is complementary to the main cross-fault, and is nearly vertical.[1]

Differentiation of the Monkton formation into two lithofacies permits recognition of some of the smaller cross-faults which intersect the Champlain Thrust. In a number of cases the lower white quartzite and dolostone unit terminates against the upper red quartzite unit in a manner that can be explained satisfactorily only as a consequence of faulting. Thin slices of Bridport, Crown Point, or Glens Falls lying beneath the Monkton also terminate, either against another formation brought up from beneath the Monkton, against the Monkton itself, or against the formation over which it has been thrust. That there has been vertical movement seems inescapable. These small faults are more prevalent on the west face of Snake Mountain than elsewhere and are excellently displayed south of Snake Mountain, near the southern margin of the area where they cut the Orwell Thrust east of Pratt School. Somewhat larger cross-faults offset the Orwell Thrust south of Route 125, and they also apparently truncate some of the folds of the autochthonous shales west of the thrust.

Table 5 lists major cross-faults and their approximate throws. In all cases the assumption is made that the cross-fault is vertical and that movement has been essentially dip-slip with little or no strike component. For purposes of comparison the approximate throws of the Snake Mountain and Mutton Hill cross-faults are 1200 and 1600 feet respectively, assuming that they are reverse faults and that they dip 60° to the north.

The northernmost cross-fault shown on the map, one whose existence can not be incontrovertibly demonstrated, strikes through Shelburne Point in the small bay just south of the shipyard. Physiographic evidence from the lake bottom suggests the presence of an escarpment about in the latitude of the bay while the warping of the shales and the small

[1] In East Creek approximately 1.25 miles west of Orwell Village the surface of another cross-fault is exposed, dipping 85° to the east and striking slightly west of north. In the same area the flat nature of the thrust plane is suggested by the window of the Glens Falls limestone.

north-dipping faults on either side of the peninsula point to a zone of rupture. The small faults are viewed as subsidiary faults in a zone of faulting. The islands known as the Four Brothers lie north of what appears to be an eastward-striking escarpment which may or may not indicate a fault. Such a fault could be contiguous with the fault believed to be cutting Shelburne Point.

East of Shelburne Point, at Redrock Point in Burlington, whitish-weathering dolostones, presumably part of the lower Monkton, grade upward into Monkton red quartzite as on Shelburne Point. At the southern edge of the Redrock Point escarpment an eastward-plunging anticline can be seen from the west. The presence of this fold, the steep, straight escarpment on the south side of Redrock Point, the upward warp of the Iberville shale to the southerly dip on the northeast side of Shelburne Point all suggest the presence of a cross-fault north of Shelburne Point.

The reason for the shift of the Champlain Thrust from the Dunham at Lone Rock Point to the Monkton in the Shelburne Point area is an unanswered question, but it is suggested that part of the cause is related to post-thrusting cross-faulting as well as to a curvature on the plane of the thrust. The implication is that upward movement along the cross-faults has brought a lower part of the thrust plane to the surface.

At the southwest corner of Shelburne Bay a north-northeast-striking fault offsets the Champlain Thrust and the Stony Point-Iberville contact lying farther west. On both sides of the cross-fault the dolomitic lower part of the Monkton lies immediately above the thrust. At the south edge of the hill, in the downthrown block, southward dipping red Monkton quartzite abuts against Stony Point shale, although the actual contact is covered.

On the lake shore approximately 3500 feet north of Wings Point, the Stony Point shales are notably contorted, the cleavage having been warped and ruptured by a series of minor thrusts and small high-angle normal faults. Some of the warping may be related to intrusion of the dikes, but the bulk is believed to represent a zone of rupture in the shales. Inland about a mile slightly north of east, in Holmes Creek, another contorted zone outcrops. Bottom contours of the lake show the presence of a small easterly trending escarpment offshore from the contorted zone. All three localities fall approximately into a straight line, suggesting the presence of a cross-fault or zone of rupture. It is possible also that the fault which cuts the Champlain Thrust and the Stony Point-Iberville contact northwest of Jones Hill in Charlotte continues to the west and passes through this area, either as a different zone of rupture or as a continuation of the implied fault.

The fault north of Wings Point has been extended southeastward through the shales to die out south of Barber Hill. However, across the lake at Essex (Buddington and Whitcomb, 1941, map), an easterly striking fault lies between Chazy beds and the Glens Falls to the north. If this fault is projected eastward, it will intersect the Vermont shore at the position of the Wings Point fault; both are downdropped to the north. On the other hand, Quinn (1933, p. 123) does not note the Essex fault, but emphasizes the northeast-striking fault half a mile to the south.

The fault on the north side of Thompson Point cuts between Cedar Island and Garden Island on the west and extends eastward into the shales where it becomes lost. However, it is thought that this fault extends to the Champlain Thrust and the relationship has been so indicated on the map. A well drilled at the house approximately 3500 feet southeast of the top of Pease Mountain apparently encountered only Pleistocene and Quaternary cover in 200 feet; yet a few yards to the north the Monkton red quartzite is visible, and across the stream valley both Monkton and the autochthonous sequence crop out. The picture is one of a deep, narrow valley, one that probably represents a zone of structural weakness. Thus a fault is believed to exist at this locality.

The fault shown along the north side of Mt. Philo is important in the understanding of the geologic history of the Central Champlain Valley. Cady (1945, Plate 10) shows a large re-entrant in the Champlain Thrust on the north side of Mt. Philo. However, investigation of the Winooski outcrops east and northeast of Mt. Philo disclosed the twofold lithologic division discussed earlier. The boundary between these two lithologies is offset 800 to 1000 feet at a locality 1.5 miles northeast of Mt. Philo, the south side of the fault having been downdropped. Westward projection of this fault along the north side of Mt. Philo is based upon circumstantial evidence, including the projection of the Monkton-Winooski contact from the Charlotte-East Charlotte road southward to a position east of the northeast corner of Mt. Philo, the apparent presence of the Glens Falls-Stony Point fault on the north side of Mt. Philo, and the apparent continuation of the Champlain Thrust along the ridge at the northwest corner of Mt. Philo. In the latter case there are no bedrock exposures on the southern one-half of the ridge, and the presence of the Glens Falls on the north slope of Mt. Philo is based upon a few soil fragments and fragments found around animal burrows.

Several pieces of evidence point to the presence of the northeasterly trending fault east of Mt. Philo. The first is the fact that the noncalcareous shale which outcrops on the south side of Mt. Philo stops abruptly along a line which closely approximates the strike of the fault as drawn. The second is that the Monkton of the overthrust sheet terminates approximately parallel to the same line and dips away from it, as if drag had tilted the beds. Finally, the fault seems necessary to explain the relationship between the Glens Falls-Stony Point thrust on the north side of Mt. Philo and the outcrop of the same thrust east of Mt. Philo. The relationships envisioned for this area are diagrammed in cross-section EE′.

The North Ferrisburg cross-fault is based upon the offset of the Stony Point-Glens Falls contact and the Champlain Thrust. Red quartzites of the upper unit of the Monkton are tilted south adjacent to the road east from North Ferrisburg. A few hundred feet north of the road the lower unit of the Monkton outcrops, the beds striking approximately north-south. In addition severe crumpling of the Stony Point north of the bridge at North Ferrisburg implies the presence of a zone of disturbance which either is located fortuitously in line with the offsets to the east or represents the same zone of faulting which has offset the thrusts to the east.

In the Vergennes area distribution of the several blocks is related to the pattern of thrusting, including the shearing and internal faulting of the overthrust sheet as it moved westward and to the high-angle faulting which post-dates the thrusting. The small stream valley approximately a half mile southwest of the northeast corner of the city is thought to be underlain by Glens Falls; the Stony Point-Glens Falls contact beneath the thrust sheet is believed to be slightly west of the stream (section FF′), for a very small outcrop of what appears to be Glens Falls was found some 600 feet west of the Whitehall cliffs and approximately 700 feet northeast of the junction of the stream with Otter Creek. Glens Falls limestone outcrops along the northern edge of the city are part of the overthrust sheet.

A cross-fault rather than an erosional re-entrant as suggested by Cady (1945, p. 565) causes the offset of the Champlain Thrust at the north end of Snake Mountain. First the thrust plane between the Monkton and the Bridport beds on Snake Mountain approximately a half mile west of Otter Creek is believed to be the same plane represented by the Dunham-Bridport contact on the hill east of Otter Creek and immediately north of Route 17. Cady (1945, plate 10) mapped the lower part of the dolostones here as Dunham, but they are definitely Bridport.

Thus the thrust fault on Snake Mountain is at approximately the same elevation as the lower part of the underlying thrust plate which is exposed on the hill immediately to the north.

The second reason for believing that a cross-fault, or rupture zone, lies at the north end of Snake Mountain is the fact that the Glens Falls, Stony Point, and Iberville formations which lie beneath the Champlain Thrust appear to be truncated at about the latitude of Route 17. Furthermore, the Beekmantown beds outcropping on the ridge extending southwestward from the southwest corner of Vergennes appear to be offset to the west at about the same latitude.

A third reason is the existence of a zone of disturbance in Potash Bay. Previously (Quinn, 1931; Cushman, 1941) the irregular attitudes of the beds at Potash Bay have been related to longitudinal faulting, but the results of the present work suggest more strongly that the structural disturbances are connected with the east-west faulting.

Finally, Kemp and Ruedemann (1910, map in pocket) have mapped two faults at Mullen Bay on the west side of the lake, almost due west of Potash Bay. While it is not thought that these faults represent the Snake Mountain fault itself, they are suggestive of a zone of weakness in this latitude.

In the flatland west of Snake Mountain the Stony Point and Glens Falls formations have been warped into a series of north-plunging folds, some of which appear in low hills and in the stream beds. However, north of the latitude of Potash Bay and Addison the lowland area lacks exposures of these formations. While it is most probable that the relationship noted is attributable to the pre-glacial and glacial erosion of the area rather than to structural features, part of the erosional effects may have been structurally controlled, and the change may represent a structural change to an area of more simply folded rocks north of the latitude of Addison.

The relationships of the Stony Point and Iberville formations in the Crane School area, at the south end of Snake Mountain, suggest the presence of cross-faulting; apparent offsets of the Champlain Thrust, especially the offset shown by the exposure of the Champlain Thrust on the small hill approximately 1.25 miles northeast of Crane School, and the seeming truncation of structures, both in the Monkton and in the autochthonous shales to the west, along a line east-southeast from Crane School point to the presence of cross-faulting in this area.

The cross-fault extending east-southeast from Crane School is thought to continue eastward into the Monkton. However, the generally poor exposures and the fact that the Monkton-Winooski contact on the east side of the Snake Mountain ridge is gradational renders recognition of the cross-fault, if present, virtually impossible. The best evidence seems to be physiographic, namely the presence of a low spot in the ridge. Faults to the northeast of Crane School apparently continue into the Monkton, for the quartzite beds are warped and tilted along lines coincident with the projections of the supposed zones of rupture west of the Monkton.

Grabens and Horsts

If one examines the several blocks outlined by the cross-faults, he finds that some are simply tilted, that some represent horsts, and that others are grabens. The prominent grabens are the Jones Hill-Pease Mountain block, itself apparently broken by a fault between the two eminences, the north part of Shellhouse Mountain, and the Snake Mountain block while the prominent horsts are the Mt. Philo and Buck Mountain blocks. The area between Shellhouse Mountain and the cross-faulting at the southern boundary of Vergennes is believed to represent another horst, but cover in combination with the complicated pattern of thrust faults and post-thrusting faults obscures the details of the block. Where blocks within or between the horsts and grabens have been simply tilted, the southern part has been moved upward, effecting a tilting to the north, except for the small block between Pease Mountain and Mt. Philo which has been tilted southward.

Relative Ages of Faulting

Clearly the thrust faulting of the Champlain Valley preceded development of the cross-faults. Offsets of the Champlain Thrust and the subsidiary thrusts beneath it demonstrate this. The relative ages of the longitudinal and cross-faults is a matter open to conjecture, but some indirect, though not conclusive evidence does exist. The longitudinal faults in the Basin Harbor area apparently are truncated and offset by the general northwesterly trending cross-faulting of the Hawkins Bay area. The northeasterly trending faults of the Thompson Point area may represent continuations of the faults south of Hawkins Bay, or they may represent entirely different faults within the same general pattern. Cross-faults north of Thompson Point appear to disrupt the longitudinal fault pattern. Cross-faulting at Vergennes has apparently cut the high-angle fault extending southward from Vergennes. This fault is also apparently offset by the zone of disturbance which lies at the north end of Snake Mountain and probably by smaller cross-faults between Vergennes and Addison.

Disappearance of the Vergennes high-angle fault near the northeast corner of the city can be explained in several ways. Either this fault, and possibly other longitudinal faults, preceded the thrust faulting or formed essentially at the same time and were overridden by the advancing upper plate of the Champlain Thrust and its subsidiary thrusts, or the cross-faulting has terminated the fault in some manner. A third possibility is that the stresses causing the fault were inhibited by the overthrust rock mass forming the slice at Vergennes so that the rupture bringing the Ticonderoga and Whitehall beds up could commence only at the northeast corner of Vergennes.

Hudson (1931) suggests that the cross-faults post-date the longitudinal faults which he interprets as probably originating prior to any of the thrust faulting. He relates the cross-faults (1931, p. 49) to late Paleozoic thrusting in the Champlain Valley area. On the other hand Quinn (1931, 1933) ascribes both the meridional faults and cross-faults to the same pre-thrusting event, having failed to recognize the offsets of the Champlain Thrust, but he did recognize (1933, p. 121) that the cross-faults offset the longitudinal faults in places.

Stone (1957, p. 94–96) suggests on the basis of a study of breccias in the northern part of the Champlain Valley that the longitudinal faults may have initially been wrench faults formed prior to thrusting. He envisions that they were carried westward by a low-angle "Isle la Motte Thrust". Subsequent erosion, he thinks, has moved the front of the upper plate eastward. He also suggests that the faults were the loci of post-thrusting relaxation movements. No evidence for such a sequence of events seems present within the Central Champalin Valley.

From the evidence at hand the faulting sequence seems to be thrusting followed at some later, ill-defined date by high-angle faulting parallel to the regional structural trends and those at approximately right angles to them. Both systems of high-angle faults are believed to be related in time and cause, although the cross-faults are interpreted as occurring slightly later. Disappearance of the Vergennes fault at the northeast corner of the city, the disappearance of both the fault east of Chimney Point and the fault paralleling the East Branch of Dead Creek, about 1.75 miles west of Bridport, at cross-faults or zones of rupture would seem to imply that the strain shifted from a longitudinal pattern to an east-west pattern in the position of the cross-faults.

The relationship between the cross-faulting and the structure east of the Champlain Thrust is unknown. Cady (1945) did not recognize the cross-faults at the thrust except in the Orwell area, and found no evidence for their existence in the structures to the east. However, the presence of the Monkton cross-anticline east of the thrust suggests the possibility of upbowing of the region between Vergennes and Charlotte which may in turn be related to the high-angle faulting. Whether or not some of the apparent irregularities in the folded structures east of the thrust belt (Cady, 1945, Plate 10) are related to the cross-faulting is an unanswered question.

It appears that the cross-faults decreased in throw when they entered the region of the massive quartzite and dolostones east of the thrust. The overthrust mass of rock is looked upon as a resistant body which was able to absorb the stress energy and to be affected by the stresses only to the extent that a number of small faults and/or folds formed. In other words, the well defined faults found in the shales and limestones of the present-day Champlain Valley broke into a number of smaller faults and folds when they passed into the resistant mass of Cambrian rocks. In places the movements may have had little effect on the massive quartzites and dolostones. Thus the faults, or zones of faulting may be recognizable only with some difficulty east of the thrust belt.

Cleavage

The rocks of the area are cut in varying degrees by a fracture cleavage which generally dips eastward at moderate angles and which in many instances may be mistaken for bedding, particularly in the argillaceous limestones of the Stony Point and the Glens Falls formations, and in the intensely sheared parts of the Crown Point. Dip angles vary, but average between 45 and 55 degrees over much of the area. A few angles as low as 10 degrees have been found, but many more between 60 to 70 degrees occur than below 30 degrees. No attempt has been made to plot the orientation of the cleavage on a regional scale since local conditions affect the orientation to a marked degree.

There has been slippage along the cleavage planes, and thus the fracturing might more aptly be described as slip cleavage (Billings, 1954, p. 339). Some of the movements undoubtedly took place at the time of the formation of the cleavage, but other deformational events have probably caused some rotation.

Within the shale beds of the Stony Point and Iberville formations the cleavage is closely spaced, but where the cleavage passes through the argillaceous limestones and the dolostones of these formations, the cleavage becomes more widely spaced, and the dip angles become less. Many excellent examples of the effect of lithology on both spacing and dip angle may be seen in these formations.

Where limestones form the bulk of a given sequence in these formations, the cleavage breaks the beds into layers from .5 to 6 inches thick separated by thin, black, argillaceous laminae or seams. The overall relationship is such that unless the rocks are closely examined the cleavage can be easily mistaken for bedding. However, sedimentary structures and bedding laminae inclined to the plane of the cleavage and offset along the cleavage point to its secondary origin.

Where the fracture cleavage cuts the Glens Falls limestones, "beds" 4 to 6 inches thick may be seen, separated by thin, black, apparently argillaceous and carbonaceous layers. The cleavage actually permeates all of the rock but is well developed at intervals; it is along the thin black zones that most of the slippage occurred. Again, close attention to the detail of these rocks discloses the inclined relationship of the bedding and cleavage. Layers of fossils are particularly useful in recognizing the bedding. On the other hand, there are many places where the bedding and cleavage, if developed, are essentially parallel. For the Crown Point beds the distribution of the dolomitic and silty stringers in the massive limestones outlines the bedding, although the movements along the cleavage have dragged some of this material into the planes of rupture.

In the shales of the Stony Point and Iberville formations warping, folding, and faulting of the cleavage rather than the contortions of the bedding bring out the many minor structures. In many instances the drag structures along the faults are warpings of cleavage, the bedding having been obliterated. Where the bedding has not been obscured by the cleavage, slippage along the cleavage planes may be seen to have offset the beds. Locally the slippage has superimposed small-scale folding on the structures caused by earlier deformation of the region.

Excellent examples of cleavage warping are to be seen along the coast south of the mouth of the Holmes River, and in particular about 3500 feet north of Wings Point (Plate 12, Figure 1). At this latter locale one of the hypothesized easterly trending rupture zones is believed to outcrop. A second area in which folded cleavage is excellently displayed is in Lewis Creek. The folds are all small, seem to plunge easterly, and are best developed north of the Addison-Chittenden county line near North Ferrisburg.

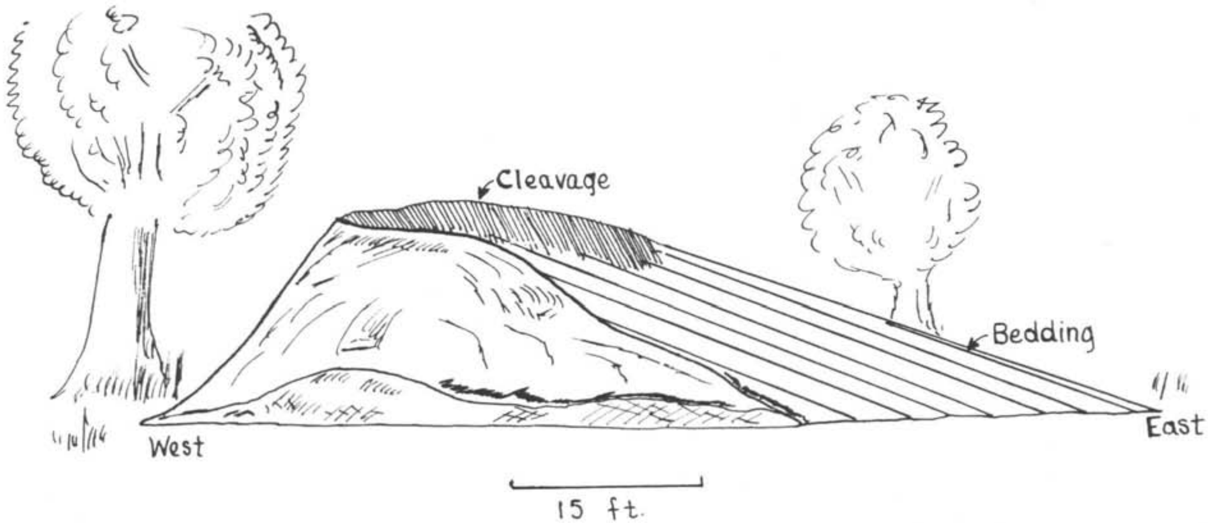
Since fracture cleavage obeys the laws of shear fracture (Billings, 1954, p. 141), it is inclined to the direction of maximum compression at approximately 30 degrees. If the average regional dip of the fracture cleavage is from 45 to 55 degrees, then the direction of maximum compressive stress is presently inclined so that it slopes 15 degrees in an easterly direction. Thrusting along "Logan's Line" and the formation of the cleavage are the result of the same series of events; the overriding of the upper thrust plates does not seem to have caused the formation of the cleavage in the autochthonous sequence. Hawley (1957, p. 82) believes that most of the rotation along the cleavage surfaces occurred at the time of their formation.

Study of the nature of the cleavage and its distribution suggests several possibilities regarding the structural history of the area, but the data at hand are inadequate for more than mere speculation. A detailed study of the cleavage and the many minor structures associated with it might give an insight into the post-Ordovician tectonic history of the area. Clearly the high-angle faults, both longitudinal and transverse, post-date the cleavage.

Minor Structures

As noted before, outcrops of the Iberville and Stony Point shales in the Central Champlain Valley resemble closely the exposures of these formations in the northern part of the Champlain Valley (Hawley, 1957). Likewise, the minor structures associated with them are much as described by Hawley. The shales between Wings Point and the northern tip of Shelburne Point are folded into a series of minor folds; locally the beds are literally twisted with accompanying flowage structures. Also they are broken by small thrusts, normal, reverse, and a few strike-slip faults. Shore exposures in the southern part of the area lack these structures, the beds being gently dipping and relatively undeformed.

Slickensides on bedding and cleavage planes attest to the shearing of the rock mass. The northwesterly trend to the slickensides found by Hawley (1957, p. 84) seems to continue into the Central Champlain Valley. Development of extensive slickensiding and other structures of the shales is related to their proximity to the belt of thrusting, for in the southern part of the area, south of Snake Mountain and along its west face, the shales are contorted and closely folded whereas west of a line through Nortontown School and Palmer Corner the shales and argillaceous limestones are only gently tilted. Bedding slickensides are present, though, in the relatively undeformed areas. The slickensides attest to the slippage of parts of the rock mass past one another along planes,



Text-fig. 19. Generalized cross-section showing limited penetration of cleavage developed beneath Champlain Thrust. Note obliteration of bedding by cleavage. Location: 1.25 miles S. 31° E. of southeast corner of Vergennes.

mostly fracture cleavage, that were properly disposed to the compressive forces.

The limited effectiveness of the overriding Monkton mass in deforming the beds beneath it is graphically illustrated on a small knoll a few yards west of the Champlain Thrust and almost due south of Intersection 409, approximately a mile southeast of the southeast corner of Vergennes. Here the shaly Glens Falls dips eastward at a moderate angle. On the lower part of the knoll the bedding is distinct and very little cleavage is present. However, on the upper part of the knoll the bedding is all but obliterated by a fracture cleavage which probably formed as the Monkton moved westward over the shale. The cleavage dies out vertically within approximately 3 feet. Monkton quartzite no longer rests on the shale, although it outcrops but a few yards to the east. Text-figure 19 is a sketch of the relations.

In this same general area northeast of Buck Mountain the fault pattern shows clearly the main overthrust with an overturned syncline lying beneath the thrust. The west limb of the fold is broken by a high-angle reverse fault formed during the thrusting period. Other faults have broken the overthrust mass and dropped beds carried westward in it down against beds which were overridden during the initial period of thrusting.

No attempt has been made to map systematically the joint pattern in the massive limestones or in the quartzites and dolostones above the thrust zone. Cady (1945, p. 577) has noted a north-trending set of joints on Snake Mountain and Buck Mountain; many of the massive limestones show gash features which have been filled by white calcite veinlets.

A few small strike-slip faults have been detected. It is recognized that some of the cross-faults may be of this type, but the preponderance of the evidence seems to point to a different type of fault for most of them.

SUMMARY OF SEDIMENTOLOGICAL AND STRUCTURAL HISTORY

Throughout much of the Ordovician the Central Champlain Valley appears to have been inundated by shallow seas whose maximum depth probably never exceeded 600 feet. In fact it is believed that the sediments east of the Champlain Thrust indicate environments from the neritic zone also. Much of the deposition undoubtedly occurred at depths of only a few tens of feet. Beginning with the uppermost Cambrian, marine waters covered the area until uppermost Middle Ordovician time. No definitely recognizable breaks of regional importance seem to be present. The seas covered continuously, except perhaps for short periods in small areas, the gently sloping eastward extension of the Adirondacks. The eastern boundary of this topographic feature of the ocean bottom has not been delineated, but it is suggested that to the east of the Champlain Thrust trace the waters were somewhat deeper and that approximately in this meridian the crust flexed downward slightly. Whether the relations outlined were developed at the time the Ticonderoga dolostone was deposited or whether they came into being with the advent of the Ordovician is an unanswered question. It is suggested, though, that the eastern boundary of the shelf may have been less prominent in the uppermost Cambrian than at a later date.

The Ticonderoga dolostone records the earliest history of the area. Apparently currents were active in the shallow seas of the Upper Cambrian, rolling small accumulations of carbonate about, channelling locally the sedimentary interface, and forming innumerable laminations within the massive dolostone and sandy dolostone beds of the formation.

Distribution of the Lower Ordovician deposits indicates the existence of a landmass in the site of the present-day Adirondack Mountains, a positive area which formed an effective border during all of Canadian time and much of Mohawkian time. Marine waters extended around the southern margin of the Canadian Shield, down the St. Lawrence River Valley, southward along the eastern edge of the Adirondack landmass, and down into the present-day Hudson River Valley. The eastern extent of the sea is not known, but a barrier or low-lying landmass now represented by the Green Mountain Anticlinorium is plausible.

Thinning of the Beekmantown deposits southward (Text-figure 11) seems to point to the existence of a low barrier, or less rapidly downsinking area at the southeast corner of the Adirondacks. Such a barrier might explain some of the Canadian stratigraphic differences between the Mohawk Valley and the Champlain Valley of Vermont.

While the bulk of Beekmantown deposition is considered to have been in a shelf-type of environment, the general tendency within the Central Champlain Valley seems to have been one of downsinking. A local trough on a shelf may then be pictured as having occupied the area during much of Lower Ordovician time. The shallowness of the sea and possibly the configuration of the bottom probably led to a concentration of magnesium in the waters which in turn led to the deposition of the multiplicity of Beekmantown dolostones.

Sediments forming successively the Ticonderoga, Whitehall, and Cutting formations were formed and came to rest under very similar physical and chemical conditions. The many breccias of the Whitehall are believed to be submarine in origin, but some could have been derived through erosion of temporarily exposed surfaces. Perhaps they reflect slight oscillations of the crust. Near-shore deposition is implied by the basal Cutting breccia and the associated dolomitic, cross-laminated sandstones. Distribution of the breccia may outline the configuration of the shoreline at this moment in geologic history.

East of the Central Champlain Valley area the Cutting is succeeded by the lower limestone and dolostone divisions of the Bascom (Cady, 1945); the interval is covered within the area of immediate concern, but the assumption may reasonably be made that the sediments deposited between the Cutting and the Cassin of the Central Champlain Valley area are like those found to the southeast in Shoreham.

The Cassin formation probably reflects a shift in currents, perhaps a slight deepening of the waters so that the magnesium concentration requisite for primary dolostone was not attained. The Bascom-Cassin-Bridport sequence may record oscillatory movements of the shelf and adjacent areas.

At the time the Cassin formation was accumulating, the ocean bottom and waters were teeming with trilobites, gastropods, brachipods, and cephalopods. At first fine sand was poured into the area, almost rhythmically apparently, becoming mixed with the fossil fragments and the precipitating carbonate. Currents disrputed the newly formed sediments, leading to the formation of the flat, discoidal pebbles of the intraformational conglomerates, cut the surfaces of the sediments with channels, and swept up the trilobite fragments into masses and into the channels and distributed generally the fossil fragments. A period of relative quiet is recorded by the sublithographic and lithographic limestones of the Emerson School member while the dolostones of the Cassin reflect local concentrations of magnesium.

The Bridport dolostone records a return to conditions favoring formation of dolostone, and in doing so the formation tells of the shoaling of the seas and perhaps of the restriction of circulation. Bridport dolostones differ in color and general texture from those of the lower Beekmantown formations and thus reflect a somewhat different set of conditions. Yet, they contain evidence for many of the sedimentological phenomena that occurred earlier.

Once again a shallow shelf appeared with deeper water limestone deposits forming to the east; these latter are the limestones of the Beldens formation. At the same time the environmental conditions within the Central Champlain Valley did not preclude formation of current-marked limestone beds containing fossil fragments; the relations suggest that currents may have removed magnesium-rich waters and allowed the precipitation of calcium carbonate for short periods of time before magnesium-rich waters returned and dolomite precipitation became the order. The Weybridge clastics, thickening to the east and wedging out before they reach the western limb of the Middlebury Synclinorium, suggest the presence of a landmass to the east. Within the Bridport of the Central Champlain Valley there is no readily discernible evidence concerning the origin of the very fine silts that are found in many of the dolostones, and there is little reason to believe that the clastics did not move into the area from the west as apparently had the detritus of the earlier deposited Beekmantown sediments. As with the older formations of the group, much evidence may be found indicating gentle currents which rolled small accumulations of carbonate grains about prior to their coming to rest. Some currents were strong enough to break semi-consolidated dolostone into small fragments and to transport them.

As Canadian time drew to a close, the seas lapped against the Adirondack landmass across a shallow shelf and probably extended to a low landmass on the east which is presently recorded as the Green Mountain axis. To the north the sea extended out the St. Lawrence River Valley, and to the south it extended across a low submarine barrier near the southeast corner of the Adirondacks into eastern New York and Pennsylvania to connect with the main part of the Appalachian Geosyncline.

No special event marked the close of the Canadian; in fact the evidence strongly suggests that no interruption of deposition is recorded in the rocks and that Canadian deposits blend into Champlainian and Chayzan deposits without a hiatus. If a stratigraphic break did occur here, it is not recorded within the Central Champlain Valley and immediately adjacent areas except in the form of a paraconformity. On the other hand, local warping of the Bridport suggests that some tectonic activity may have taken place late in the Canadian and early in the Champlainian. Probably deposition continued while the deformation transpired.

With the advent of Chazyan time the waters covering the Central Champlain Valley area deepened slightly and circulation was less restricted than in the preceding uppermost Canadian. To the north, low organic structures, reefs, appeared, influencing the currents and the history of the whole Champlain Valley area. In the Central Champlain

Valley the components of the fossil-fragmental limestones accumulated, and very fine-grained carbonate crystals were precipitated as lime mud; some of the grains became aggregated and were rolled about the bottom by currents. Occasional silty dolomitic horizons formed, and currents brought quartz sand from the west and southwest. A lower sandy and dolomitic sequence is succeeded by a fossil-fragmental limestone sequence.

Apparently environments favorable to the Crown Point type lithology predominated to the east of the area through much of the Chazyan but made an incursion into the area during the middle Chazyan. The presence of a low barrier or less rapidly downsinking zone near the eastern border of the area is suggested by the thickness data and the distribution of the formations of the Chazy group. Perhaps this line marked the boundary between a shallower area and a deeper or more rapidly downsinking area to the east. Such a feature is but a continuation of the flexure hypothesized for the Canadian.

The fine detritus of the Crown Point is absent generally from the Valcour formation, and the uppermost Chazyan formation in the Central Champlain Valley grades eastward into Crown Point-Middlebury-type beds; its distribution infers the presence of a local basin within the borders of the shelf (Text-figures 15 and 16).

Chayzan deposits were succeeded by the fine-grained deposits of the Orwell; continuity of deposition within the Central Champlain Valley seems well established. The nature of the Black River deposits indicates a quiet, moderately shallow shelf which was stable and on which conditions favoring formation of lime muds with an abundant brachipod and gastropod fauna occurred. Currents rolled aggregates of calcium carbonate grains about, the aggregates being the only indication of current activity aside from the distribution of the fossil layers in the limestones.

The transition from the Black River deposits to the lowermost Trentonian deposits seems to have been gradual also. Within the Central Champlain Valley the change from the Orwell to the Glens Falls seems abrupt; yet there are localities where the impression is given that one grades into the other. In particular, in the type area of the Larrabee member of the Glens Falls at Larrabee Point, Shoreham, the massive beds of the Black River deposits seem to become more thinly bedded toward the top and to grade upward into the Larrabee. Perhaps the variations in thickness of the Orwell record local basins of deposition or varying rates of sediment formation.

Glens Falls deposition and that of the subsequent formations of the Trenton group records an increased downsinking rate in the Central Champlain Valley, perhaps the formation of a local depressed area. Also the Glens Falls, the Stony Point, and the Iberville record the rising of a landmass to the east or southeast and perhaps the tilting of the crust so that the shelf lay to the east and so that the Middle and Upper Mohawkian deposits were accumulating in a trough bounded on the east by the shelf area and on the west by the submerged Adirondack mass.

Glens Falls deposition records relatively shallow water and an environment in which the various forms of invertebrate life abounded. With passage of time a flood of mud came into the Champlain Valley area, changing the environment and obliterating the life. At first the detritus was largely argillaceous and was deposited in an environment favoring precipitation of calcium carbonate, a fact attested to by the abundance of limestones in the Stony Point and by the fact that many of the shales border on 50 per cent calcite. Origin of the clay minerals comprising the Stony Point shales is unknown, but plausibly they may represent materials deposited earlier in the area out of whcih Vermontia (Kay, 1937, 1942) rose. The change of the clastics from the predominantly argillaceous material of the Stony Point to the micaceous, quartzitic material of the Iverville probably is related to the continued uplift of the area to the east. It must be understood, however, that this eastern landmass must have been rather extensive to supply the large amount of material that it did, for the Iverville extends from somewhere south of the Central Champlain Valley northward to well beyond the Canadian border in the St. Lawrence River Valley. Throughout this area the formation seems uniformly in excess of 1000 feet thick.

Upper Ordovician history is lost within the Champlain Valley. However, adjacent areas tell us that orogenic movements affected uppermost Ordovician deposits and preceded deposition of Upper Silurian formations. It is from this information that the folding and faulting of the Central Champlain Valley are dated and placed at the close of the Ordovician, in the Taconic Disturbance. The folding of the rocks in the Middlebury Synclinorium and in the Central Champlain Valley preceded the thrust faulting. It was in conjunction with the folding that the wide-spread fracture cleavage developed. Close to the present exposure of the Champlain Thrust, the main zone of rupture in the latitude of the Central Champlain Valley, the rocks are intensely folded and sheared by high-angle thrusts; away from the main zone of fracture, the rocks are simply tilted at low angles. Presumably the rocks exposed in the lowland area were once covered by younger rocks which have been stripped off by erosion. These rocks may have been highly contorted when the overthrust block extended farther westward. There is no evidence extant to indicate the amount of westward transport of the overthrust Monkton mass. In fact it is suggested that the overthrust mass moved only a relatively short distance and that the rocks along the western edge of the area may never have been beneath a thrust plate.

Compression seems to have been active from a generally easterly direction and to have crushed the sediments between the pincers of the Green Mountain axis and the Adirondack mass. Long-continued, the compression eventually brought about the rupture of the folds and the overthrusting that marks the eastern boundary of the Champlain lowland. Below the westward-moving overthrust block thrust faults of moderate dip formed in the shales and limestones; they may have cut the overriding mass into a series of slices, or they may have flattened out as they encountered the resistant mass of the Cambrian sediments. Possibly the high-angle thrusts and reverse faults beneath the Champlain Thrust developed prior to the emplacement of the Champlain overthrust mass, breaking the limbs of the folds as a series of high-angle shears. Continued compression could have then caused the overthrust mass of Monkton to move westward over the earlier formed shears along the Champlain Thrust proper.

Upon relaxation of the compressive forces the area seems to have been broken by a series of high-angle faults. Relations found within the Central Champlain Valley suggest that both the longitudianal and cross-faults represent the same event. The area between the Champlain Thrust and the Adirondack margin is a series of blocks which have been tilted and rotated about one another along the high-angle faults. It is not unlikely that there were several periods of movement along these faults, but evidence for more than one has not been recognized. Possibly some of the faults have been caused by torsion, and certainly some are related to a rise of the Adirondack mass after the Ordovician. The exact dating of the high-angle faulting awaits evidence from outside the immediate area of the Central Champlain Valley, although the author is of the opinion that they are Paleozoic phenomena.

ECONOMIC PRODUCTS

Sand and gravel, limestone for building, and water form the chief geological economic products of the Central Champlain Valley. The sand and gravel accumulated in Pleistocene Lake Vermont, the succeeding Champlain sea, and ancestral Lake Champlain (Chapman, 1942). Limestones from the Chazy beds, the Crown Point limestones in most instances, have been used to face many older homes in the area and to provide foundations. More recently limestone from the Orwell outcrops north of Panton have been used to face buildings at Middlebury College.

The water supply for the isolated farms in the area comes from three sources: Lake Champlain, surface water and near-surface ground water, and ground water at depth, available only from drilled wells. No systematic study has been made of the location of the springs in the area nor has information been compiled concerning the supply of water from shallow dug wells. However, in an attempt to delineate the bedrock surface and the type of rocks beneath the cover, the author compiled information on the general type of water and the depth to bedrock in a number of wells. The map of Plate 3 shows the configuration of the bedrock surface beneath the Pleistocene cover for much of the area. It obviously does not show all of the many variations that exist, but it does delineate the general trends.

Water occurs in the bedrock of the Central Champlain Valley in fractures in the rocks and in solution cavities. As a consequence it is impossible to predict depth to a water-bearing horizon or to predict in more than general terms the volume of water that may be produced from any given well. Predictions can be based only upon empirical evidence from wells drilled nearby, and the variations are such that extrapolations for more than a few feet are unreliable. Water from the limestones is hard, and water obtained from the rocks of the Beekmantown group generally is moderately high in magnesium salts.

The Stony Point and Glens Falls formations more often than not give rise to water that is high in hydrogen sulfide and which thus smells like "rotten eggs." Iberville shales provide this type of water less commonly. Of two wells drilled near one another into the same formation, one may supply water that is highly charged with hydrogen sulfide, and the other may supply only hard water. A well drilled in an area where the Pleistocene cover is thick will often obtain a supply of water from Pleistocene sands, but at the contact between the cover and shale or limestone of the Glens Falls or Stony Point formations the well will encounter a flow of sulfur-rich water.

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APPENDIX I

MEASURED SECTIONS

SECTION 1—*Ticonderoga dolomite* (Rodgers, 1955)

The type section is designated by John Rodgers (*ms.* dated May, 1955) as being "on the east face of Mount Hope within the north edge of Ticonderoga village, from half a mile to a mile due north of the paper mill. This section may be supplemented by the section on the west face of the next hill to the east, where most of the formation is exposed on a different fault block." The section was measured by Rodgers on June 23, 1952, and its top is in woods northeast of north end of Mount Hope cemetery:

	Thickness feet—inches
Whitehall formation—dolomite, non-cherty; 20 to 30 feet exposed	
Ticonderoga dolomite—Upper Member:	
1. Only partly exposed; includes some very cherty dolomite	20–0
2. Dolomite, very cherty, prominent ledge	2–3
3. Dolomite, fairly massive, poorly exposed above; no chert seen.	25–0
4. Dolomite, thin-bedded, laminated, cherty below	1–9
5. Dolomite, laminated, cross-laminated below.	2–0
6. Dolomite, massive, less siliceous than unit 7	2–3
7. Dolomite, very siliceous in middle, less so above and below; hints of cryptozoon structure in middle.	6–4
8. Dolomite, massive, somewhat siliceous	5–0
9. Dolomite, well-laminated, slightly siliceous, a bit silty	2–2
10. Dolomite, fairly light, massive, somewhat siliceous	2–3
11. Mainly chert with but little dolomite	1–6
12. Covered	8–6
13. Dolomite, light, fairly massive but even-bedded, somewhat laminated	8–2
14. Dolomite, light; partly a cryptozoon reef, partly a sedimentary breccia; in part siliceous	3–0 (± 6 in.)
15. Poorly exposed; mainly like unit 16	2–6
16. Dolomite, fine-grained, well-bedded	4–8
17. Dolomite, light, medium-crystalline, massive but partly laminated; full of vugs of calcite and quartz	6–6
18. Dolomite, fairly dark, medium-crystalline, with vugs; transitional between units 17 and 19	1–2
Total thickness of upper member	105–0
Ticonderoga dolomite—Lower Member	
19. Dolomite, fairly light, oölitic; basal zone has dolomite pebbles.	0–9
20. Dolomite, fairly light, oölitic; sandy basal zone	3–6
21. Dolomite, dark, oölitic	2–9
22. Dolomite, fairly light; with edgewise conglomerate	0–8

		Thickness feet—inches
23.	Dolomite, dark, crystalline; sandy below, siliceous and oölitic above	4–2
24.	Dolomite, dark, crystalline; sandy below, siliceous above	4–6
25.	Dolomite, dark, crystalline; sandy below, siliceous above	3–8
26.	Dolomite, dark, crystalline, siliceous; a single ledge	0–11
27.	Dolomite, very sandy and siliceous, cross-laminated	0–3
28.	Dolomite, dark, sandy and siliceous, laminated	1–4
29.	Quartzite, dark, vitreous (appearing cherty)	0–5
30.	Dolomite, dark, siliceous; three layers	1–8
31.	Dolomite, dark, laminated, somewhat sandy; siliceous above grading into unit 30	1–7
32.	Dolomite, dark siliceous	2–2
33.	Dolomite, dark, laminated, somewhat sandy; siliceous above grading into unit 32	2–6
34.	Dolomite, siliceous and sandy	0–9
35.	Dolomite, siliceous, especially at top, thin-bedded	2–4
36.	Dolomite, sandy	1–1
37.	Dolomite, dark, crystalline, sandy at base	2–0
38.	Quartzite, massive, vitreous, strongly cross-stratified (lower 6 inches a separate bed. This bed forms top of supplementary section given below	3–3
39.	Dolomite, massive, very sandy; much cross-stratification	3–3
40.	Dolomite and quartzite, thin-bedded; much cross-stratification	10–0
41.	Dolomite, massive, sandy	2–6
42.	Dolomite, rather light	0–3
43.	Dolomite, massive, sandy	3–6
44.	Dolomite, thin-bedded, silty	1–3
45.	Dolomite, massive, very siliceous	1–0
46.	Dolomite, well laminated; both contacts sharp and irregular	1–0
47.	Dolomite, massive; little sand or silt but somewhat siliceous and laminated	4–7
48.	Dolomite, finely laminated, siliceous and silty	2–3
49.	Dolomite, sandy, or dolomitic quartzite; cross-stratified below.	1–0
50.	Dolomite, fairly massive, very sandy; with thin layers of quartzite	1–8
51.	Dolomite, dark, thin-bedded	2–6
	Total exposed thickness of lower member	75–0

Bottom of quarry; base of formation probably about 5 feet below; probable total thickness of lower member 80 feet, of formation 185 feet.

Supplementary section, measured on southwest spur of Mount Hope below restored blockhouse, beginning at massive quartzite bed (38 of main section) near top of slope.

s1.	Quartzite, vitreous, cross-stratified	2–0
s2.	Covered	1–0

	Thickness feet—inches
s3. Dolomite, full of coarse sand, or dolomitic sandstone; strongly cross-stratified	1–3
s4. Poorly exposed; mainly thin-bedded very sandy dolomite	2–6
s5. Dolomite, dark, very sandy, siliceous, strongly cross-stratified.	3–0
s6. Dolomite, light	0–3
s7. Dolomite, very siliceous, some sandy; in fairly thin layers	1–9
s8. Dolomite, sandy, in thin layers; top 2 inches quartzitic	0–9
s9. Dolomite, very sandy, quartzitic at base; a single ledge	1–3
s10. Dolomite, very sandy, quartzitic at base; a single ledge	1–2
s11. Shaly parting?	0–1
s12. Dolomite, siliceous.	0–4
s13. Dolomite, very sandy; some layers approaching quartzite	1–4
s14. Poorly exposed; mainly dark thin-bedded dolomite	1–0
s15. Dolomite, siliceous; some sand	0–5
s16. Dolomite, dark; full of sand grains below, fewer above; cross-stratified	1–6
s17. Quartzite and sandstone; 3 inches at base with silica cement, 5 inches in middle with dolomite cement, 4 inches above with cement grading into unit s16	1–0
s18. Dolomite, dark; some sand	0–6
s19. Dolomite, sandy, becoming siliceous above; top 3 inches partly quartzite	1–6
s20. Quartzite, dark; fairly massive layer	0–9
s21. Quartzite, dark, thin-bedded; some dolomitic cement.	2–2
s22. Dolomite, dark, fine-grained	0–6
s23. Covered; apparently mainly sandstone with dolomitic cement.	17–0
Total thickness of supplementary section of Ticonderoga dolomite	43–0
Potsdam sandstone (but boundary may be several feet either way):	
s24. Quartzite, vitreous, massive; some dolomitic cement in top 6 inches	2–3

SECTION 2—*Deer Point Section*

Section compiled on small point (known locally as Deer Point) S. 55° E. of the center of Garden Island beginning at water level on the westernmost projection of the point and extending along the south side of the point and up the west-facing escarpment approximately 50 yards south of the point.

	Thickness—feet Unit	Cumulative to top of unit
Dolostone, dark-gray with brownish tinge; dull or dirty-appearing matrix; medium crystalline	1.2	89.7

Top of Ticonderoga dolostone		
Covered	0.8	88.5
Dolostone, calcitic, medium crystalline, very light brownish-gray; 20% .25- to .5-mm rounded quartz grains	2.0	87.7
Covered	1.6	85.7
Dolostone, calcitic, very light-gray, (N8) medium-crystalline; very fine silt- or clay-size matrix	8.0	84.1
Cover; light-gray (N7), coarsely crystalline calcitic dolostone abundant as float in lower 8 feet	12.7	76.1
Dolostone calcitic, fine to medium crystalline, faint reddish-purple weathering light- to very light-gray	3.0	63.4
Dolostone, calcitic, very light-gray to medium light-gray (N8 to N6), finely crystalline	13.6	60.4
Covered	16.3	46.8
Dolostone, weathers very light-brown (5YR7/6) to very light-gray (N8), medium yellowish-brown (10YR5/4); finely crystalline; colorless anhedral secondary quartz fills in the openings, occasional calcite rhombs; no bedding; local concentrations of fine- to medium-sized quartz grains	6.0	30.5
Dolostone, very light-gray, very finely crystalline containing up to 10% .25- to .5-mm quartz grains evenly distributed through interval.	3.3	24.5
Dolostone, calcitic, medium-gray with brownish tint, finely crystalline; smooth-weathering, massive bed of medium-gray color	1.4	21.2
Cover	2.0	19.8
Dolostone, dark-gray (N3), medium crystalline; contains .5-inch fragments of dark-gray, medium crystalline material cemented by lighter gray matrix; isolated 4- to 6-inch fragments of drab- and smooth-weathering, finely crystalline material cemented by medium crystalline dolomite grains	2.0	17.8
Sandstone, medium-grained, dolomitic, with brown, earthy-appearing matrix; contact with underlying bed is a wavy zone containing some chert and intraformational conglomerate	1.8	15.8
Dolostone, calcitic, smooth-weathering, light-gray, very finely crystalline; medium-size quartz grains distributed evenly through bed; local concentrations of quartz grains isolate small dolomite masses; thin, irregularly distributed chert layers	1.0	14.0
Dolostone, calcitic, weathers yellowish-gray (5Y8/1), light-gray, finely crystalline; streaks of quartz grains	0.6	13.0
Dolostone, sublithographic, dark-gray; 2- to 3-inch layers or laminations separated by sutured contact lines; upper portion of bed is a sandy limestone; intraformational conglomerate formed of sublithographic material in a finely crystalline matrix. A thin section of material from this bed discloses the presence of rounded, dark-colored, 1-mm masses set in a light colored matrix; carbonate grains molded around .1- to .2-mm quartz grains	1.6	12.4

Dolostone, dark-gray (N3), finely crystalline	3.0	10.8
Covered	1.6	7.8
Dolostone, medium-gray (N3) medium to finely crystalline; rounded .5-mm quartz grains, as thin bands set in calcitic cement	1.9	6.2
Dolostone, calcitic, weathers yellowish-gray (5Y8/1), medium to finely crystalline; lower part is dark-gray (N4), upper part very light-gray (N7½); occasional pods of white calcite and abundant blue-black chert nodules	4.3	4.3
Water level		0

SECTION 3—*East of Converse Bay*

Section begins in barnyard, west of barn on west side of north-trending road, approximately 5600 feet N. 73° E. of Cedar Island, and was measured (June, 1957) from cover west of barn eastward across road to cover at base of slope 50 to 75 yards north of barn.

	Thickness—feet	
	Unit	Cumulative to top of unit
Crown Point Limestone		
Limestone, light bluish-gray (5B7/1)-weathering, medium bluish-gray (5B5/1); dull luster and "salted" appearance; fossil fragments common on weathered surfaces; rocks dominantly sublithographic in texture, being composed of over 50% .01-mm calcite grains; the sequence has fewer silt and dolomitic partings than sequence lower in section; some of limestones have up to 10% ± .06-mm dolomite rhombs scattered through them in addition to the partings	18	156.4
Cover	15.5	138.4
Limestone, medium bluish-gray-weathering with yellowish-gray tints in places; dark bluish-gray (5B4/1); generally sublithographic with .01-mm calcite; fossils, including *Maclurites* operculi, "*Orthoceras*", *Girvanella*, brachiopods common; pockets of fossils suggest current activity; approximate horizon of fossil locality 51	4.7	122.9
Limestone, sublithographic with abundant silty, dolomitic partings and a few fossil fragments; light bluish-gray weathering with a few patches of yellowish-gray coloration; dull luster; in some beds the small rhombs of dolomite scattered through the rock approach 40% of the rock.	7.7	118.2
Cover, probably much as below	6.8	110.5
Limestone, light gray-weathering with some pale yellowish-gray tints; composed of .01-mm calcite grains; sublithographic fracture	2.3	103.7
Cover, probably limestone much as below	29.5	101.4
Limestone, light bluish-gray-weathering, dark-gray to black; sublithographic texture; traces of silty partings	10.9	71.9

Cover	4.7	61.0
Limestone, light medium bluish-gray-weathering, dark-gray to black; sublithographic texture with .01-mm calcite grains; *Maclurites* operculi; few silt partings	3.9	56.3
Cover	7.9	52.4
Limestone, light bluish-gray-weathering, dark bluish-gray; sublithographic fracture; black silt partings prominent; composed dominantly of .01-mm calcite grains with a few quartz silt and dolomite rhombs scattered through the calcite mass in addition to the material in the partings	1.5	44.5
Cover, mostly limestone like that above	23.5	43.0
Limestone, sublithographic with a few rounded fossil fragments; medium light-gray-weathering and dark bluish-gray on fresh surface	4.7	19.5
Limestone, light bluish-gray-weathering, medium to dark bluish-black; "salted" appearance; weathered surfaces show *Girvanella* and fossil fragments; sublithographic texture and fracture; rock is composed of .01-mm calcite with a few salty and dolomitic black partings and traces to moderate amounts of fossil fragments locally	2.5	14.8
Limestone, fossil-fragmental, medium-grained	3.0	12.3
Limestone, as below; approximate horizon of fossil locality 139.	7.0	9.3
Top of Day Point Formation		
Limestone, medium bluish-gray- to light medium bluish-gray-weathering, dark bluish-gray; fossil fragments appear on the weathered surface; bulk of rocks are sublithographic in texture; some have ellipsoidal masses of .01-mm calcite suggestive of a pellet-like accumulation; abundant black silty and very fine sand partings .5 inch apart and approximately 1-mm thick; horizon of fossil locality 141	2.3	2.3
Cover, Day Point limestones probably lie beneath the cover; fossil locality 138 approximately 600 feet north of line of section is in lower half of Day Point		0

SECTION 4—*Whitehall dolostone*

Section measured across the northwest corner of Thompson Point, beginning at water's edge S. 30° E. of Cedar Island and extending to small hillock approximately .5 mile S. 25° E. of Cedar Island.

	Thickness—feet Unit	Cumulative to top of unit
Sandstone breccia, calcareous, very fine-grained; base of Cutting formation		
Top of Whitehall—Whitehall thickness = 209 feet		
Dolostone, dark-gray (N4) medium to coarsely crystalline with dirty matrix and fetid odor; some finely crystalline, light-gray dolostone	6.5	226.5

Cover	13.5	220.0
Dolostone, medium-gray (N5) finely crystalline to very finely crystalline	5.5	206.5
Dolostone, very light-gray (N8) coarsely crystalline	3.0	201.0
Dolostone, light-gray, very finely crystalline.	2.0	198.0
Dolostone, medium dark-gray (N4) medium crystalline	4.0	196.0
Dolostone, medium light-gray (N6) coarsely crystalline with fetid odor	2.0	192.0
Cover	74	190.0
Limestone, dolomitic, medium light-gray (N6) very finely crystalline	1.0	116.0
Cover	8.5	115.0
Dolostone, dark-gray, medium crystalline with fetid odor	1.0	106.5
Cover	12.0	105.5
Dolostone, dark-gray with slight bluish tint (N3), medium to finely crystalline	3.0	93.5
Dolostone, medium- and dark-gray, medium crystalline with earthy or dirty matrix	5.0	90.5
Cover	3.0	85.5
Dolostone, medium gray (N5) finely crystalline	2.0	82.5
Dolostone, dark grayish-black (N2) finely crystalline	1.0	80.5
Dolostone, medium dark-gray (N4), medium crystalline with dirty matrix; mottled with dark-gray and medium dark-gray	3.0	79.5
Covered	5.0	76.5
Limestone, dolomitic, finely crystalline, medium-gray (N5)	2.0	71.5
Cover	12.0	69.5
Cover, small outcrops of dark-gray, finely and medium crystalline dolostone	10.0	57.5
Cover, small outcrops of finely to medium crystalline dark-gray dolostone	8.0	47.5
Cover, occasional outcrops of massive dark-gray medium crystalline dolostone with dirty matrix and "friable" appearance.	11.0	39.5
Cover, in middle of covered interval a medium crystalline brownish-gray (5YR4/1) to gray with reddish tint dolostone with dirty matrix	7.0	28.5
Dolostone, calcitic, medium light-gray (N6) mottled with white and gray, coarsely crystalline	2.0	21.5
Dolostone, dark-gray (N3) finely crystalline; brecciated and recemented with white calcite veinlets	2.0	19.5
Top of Ticonderoga Formation		
Sandstone, medium-gray (N5) with coarse, rounded quartz grains comprising 75% of the rock	3.0	17.5
Sandstone, massive, light-gray weathering (N7–N8), calcareous with interbedded sandy dolostone; sandstone is coarse-grained with concentrations of .5 to 1 mm diameter quartz grains in light-colored, silty, calcareous matrix; overall bedding massive with dolostone and sandstone in individual layers .5 to 1 inch thick, much evidence of current activity	3.5	14.5

Dolostone, light-gray (N6½), medium to finely crystalline; scattered rounded .5 to 2-mm frosted quartz grains, clots of white calcite and medium-gray nodules of chert common; knots of white quartz; pyrite	5.5	11.0
Sandstone, calcareous, massive, medium-grained drab weathering	5.5	5.5
Water level		0

Section 5—*Top of Whitehall*

Section compiled from northwest face of small knoll approximately 3500 feet S. 5° E. of Cedar Island, Thompson Point area.

Sandstone breccia, base of Cutting formation, blocks of tough, very fine dolomitic sandstone 6 to 9 inches long and 2 to 3 inches thick set in matrix of similar material, but with much finely crystalline silty dolostone	
Dolostone, finely crystalline (.1 to .2 mm) medium light-gray (N6), veinlets of calcite; whitish oval-shaped brown-rimmed spots, 3.5- to 5-mm by 1- to 2-mm, composed of calcite (.01- to .05-mm) crystals; .01 mm calcite crystals which apparently rim dolomite rhombs	2
Cover	1
Dolostone, medium light-gray (N6), medium crystalline	1.5
Cover	2
Dolostone, slightly silty; medium to finely crystalline, light-gray (N7); calcite in areas between dolomite crystals forms approximately 5% of rock; secondary quartz, some of which stands up on a weathered surface; silt- and clay-size angular quartz fragments; secondary quartz makes up 20–30% of insoluble residue	5
Cover	1
Dolostone, medium crystalline, silty and argillaceous, dull-lustered, medium-gray (N5), but mottled with lighter gray masses 1 to 7.5 mm in diameter; .05- to .1-mm subangular quartz grains closely associated with concentrations of .02- to .05-mm secondary calcite rhombs; insoluble residue 10 to 20% of rock, containing clay minerals and clay-size fragments of quartz	2
Dolostone, dark gray (N3) dull-lustered, coarsely crystalline (.5 to 1 mm), white calcite veinlets, small percentage of .01- to .02-mm calcite between dolomite rhombs; many dolomite rhombs surrounded by brownish film, presumably organic or argillaceous, which accentuates the crystal boundaries	1.8
Cover	3
Dolostone, calcitic, coarsely crystalline (.5 to 1 mm), light-gray (N7); secondary quartz grains up to .6 mm; calcite forms matrix, comprises approximately 20% of the rock, and is apparently more closely associated with the secondary quartz than	

	Unit	Cumulative to top of unit
with the dolomite crystals, suggesting that it is of secondary origin also		3.5
Dolostone, coarsely crystalline (1 mm) light brownish-gray (5YR5/1 to 5YR7/1); very fine calcite rhombs form matrix between dolomite grains which are subhedral to euhedral		2
Cover		

SECTION 6—"*Cartmell Point*"

West shore of southeasternmost small point, Thompson Point, beginning in center of shore.

	Thickness—feet	
	Unit	Cumulative to top of unit
C-2 member of Cutting formation		
Note: northward along the point large masses of chert appear at or slightly above this horizon.		
Dolostone, silty, medium-gray (N5) finely crystalline with .5-mm rounded reddish spots which are concentrations of iron-stained silt-size quartz	3.0	41.0
Covered	3.3	38.0
Dolostone, finely and medium crystalline, medium dark-gray (N4) in 1- to 3-foot beds	9.2	35.7
Dolostone, silty, finely crystalline, medium-gray; 6% insoluble residue of silt-size angular quartz	5.0	26.5
Covered	±2.0	21.5
Dolostone, silty, finely to medium crystalline with films of well-cemented silt-size grains between carbonate rhombs and in isolated masses; isolated carbonate rhombs within quartz masses; quartz = 15% of rock; some pyrite masses up to 2-mm	5.7	19.5
Dolostone, silty, finely crystalline; well-cemented quartz masses more or less evenly distributed through the rock = 30%	1.2	13.8
TOP OF C-1 MEMBER		
Dolostone and dolomitic siltstone, fine-grained, like 4.3-foot interval below but thicker beds	1.2	12.6
Dolostone, silty, drab to pale reddish-brown-weathering, medium dark-gray (N4) finely crystalline; fine lines on weathered surface represent concentrations of .05-mm angular clear quartz which comprises about 35% of rock	1.5	11.4
Dolostone and dolomitic siltstone, 6- to 8-inch beds, light blue-gray (5B8/1)-weathering, medium-gray (N5), finely crystalline; .05-mm quartz grains 35% to 60%; laterally one of the beds contains small intraformational breccia; other beds with fine lines indicating current action	4.3	10.9
Dolostone, silty, dull-lustered, light-gray (N6) with gray-orange (10YR7/4) laminae; finely crystalline (.1 to .15 mm); quartz		

as films on carbonate rhombs and as .01- to .05-mm grains forms approximately 30% of the rock; small penecontemporaneous slump structures	0.8	6.6
Dolostone, silty, dull-lustered, medium-gray (N5), finely crystalline (.1 to .15 mm); quartz silt films between carbonate rhombs; insoluble residue of quartz silt=6%	2.1	5.8
Dolostone, silty, medium crystalline, medium-gray (N5); quartz silt distributed as patches through the rock and not as films on carbonate constitutes approximately 10% of the rock . .	2.7	2.7
Water Level. Note: The three horizons immediately above the water level lack fine current lines common in the other horizons of this sequence		0

SECTION 7—*North end Fort Cassin headland*

Measured from 30 to 40 yards south of northernmost tip of land at north end of Fort Cassin headland eastward to the small cove behind house and thence eastward along shore to the northeast corner of the headland. Lowest part of the section begins approximately 6 feet below water level of September 12, 1957. Cassin formation only.

	Thickness—feet Unit	Cumulative to top of unit
Limestone, sublithographic to lithographic with dull to slightly sparkling luster and conchoidal, chert-like fracture; dark bluish-gray (5B3/1)-weathering, light bluish-gray (5B7/1); irregular black silt laminae composed of .025- to .05-mm quartz grains distributed through the limestone and protruding on weathered vertical surfaces; subspherical and ovoid bodies .5 to 1.0 mm in diameter, brownish and composed of .001- to .005-mm calcite crystals similar to matrix material of rock; material composing rounded masses resembles brownish, silty matter forming the borders of the silt laminae; .2-mm dolomite rhombs, some in center of oval-shaped (in section) areas, and some rhombs in clusters with brownish film between individual rhombs; few fossil fragments; beds 6 inches thick near base of sequence, becoming 3 to 4 inches near the top. Contact with underlying dolostone is irregular, and the limestone appears to have been deposited on a slight erosional surface developed on the underlying dolostone; erosional surface believed to be of local importance only; on eastward dip slope from house at northeast corner of point outlines of small nautiloids can be seen	2.5	67.6
Dolostone, silty, very finely crystalline (±.05 mm), yellowish-gray (5Y7/1)-weathering, light-gray (N7); 10 to 40% .01- to .02-mm clear quartz occurring as clusters and masses up to		

.05-mm whose shapes are controlled by the rhombohedral faces of the carbonate crystals; massive beds with fine raised lines and intraformational conglomerate; irregular base	3.5	65.1
Limestone, dark-gray, very finely crystalline	0.5	61.6
Limestone, medium-blue-weathering, dull to slightly sparkling luster, shaly, sublithographic with conchoidal, chert-like fracture	1.8	61.1
Limestone, sandy, dolomitic, sublithographic, medium bluish-gray (5B5/1), drab-weathering; raised .1-inch lines on weathered surfaces; intraformational conglomerate near center of bed formed of material similar to that of the raised lines; .1-mm rhombs of dolomite comprise approximately 10% of rock; some dolomite clusters formed inside fossils; most of rock is ±.005-mm crystals of calcite; .1-mm clear, angular quartz grains comprise about 20% of rock; fossil fragments = 10 to 15%; irregular contact with bed below a function of changing conditions rather than erosion feature; amplitude of ridges is 6 to 12 inches	1.7	59.3
Limestone, sublithographic with conchoidal, chert-like fracture; moderate-blue-weathering, light to dark bluish-gray (5B7/1 to 5B4/1). Irregularly distributed .25-mm black, silty laminae, also silt distributed throughout rock and as thin layers on fossil fragments and as filling on concave side of some fossil fragments; a few .15-mm dolomite rhombs; a few .6-mm ovoid bodies composed of .001- to .005-mm calcite crystals with dark, iron-stained rims; bulk of rock is composed of .001- to .005-mm calcite crystals.	1.7	57.6
Dolostone, finely crystalline (.05 to .1 mm), medium-gray (N5), yellowish-gray (5Y7/1)-weathering, slightly calcitic in part with calcite-rich portions as lighter colored fine lines on a fresh surface	2.6	55.9
Cover	3.5	53.3
Limestone, finely crystalline to sublithographic, medium dark-gray (N4 to N5); silty laminae 3 to 4 inches apart in 1-foot beds; matrix composed of subspherical and ovoid bodies composed of .001- to .005-mm calcite crystals .25 to .5 mm in diameter; bodies cemented by .025-mm calcite crystals and .001- to .005-mm crystals. Rock is 50 to 60% .005-mm crystals and 50 to 40% .25- to .5-mm calcite crystals; several percent dolomite as isolated crystals and as clusters some of which represent fillings of interiors of fossils	3.3	49.8
Limestone, finely crystalline, medium bluish-gray (5B5/1) light bluish-gray (5B7/1)-weathering; lacks black silty laminations; lower 6 inches grades laterally into more shaly material	1.5	46.5
Limestone, sublithographic, conchoidal, chert-like fracture; dark bluish-gray (5B3/1) light bluish-gray (5B6/1)-weathering. .1- to .15-mm dolomite crystals in small clusters and as		

fillings in brachiopod and gastropod shells. In the clusters many of the dolomite rhombs are separated by quartz silt films .01 inch thick; black quartz silt laminae composed of ±.005-mm quartz; some subspherical masses composed of ±.005-mm calcite crystals. Bulk of rock is .12- to .2-mm recrystallized shell fragments cemented in matrix of .005 mm calcite	1.3	45.0
Limestone, dolomitic, coarsely crystalline (1 to 1.5 mm), dark-gray to dark bluish-gray (N3 to 5B3/1); 15 to 20% .2- to .3-mm clusters of .05- to .1-mm dolomite crystals with quartz silt films between many of the dolomite rhombs; recrystallized trilobite fragments; grades laterally into nodular-weathering bluish-gray-weathering, sublithographic limestone with conchoidal fracture and .01 inch thick black silt partings. . . .	2.9	43.7
Limestone, dolomitic, medium-gray (N5)-weathering, medium dark-gray (N4), coarsely crystalline; 9- to 12-inch beds; dolomite (30%) distributed uniformly with yellowish, iron-stained quartz silt films between many rhombs. .05-mm raised lines show cross-laminations; upper portion of bed grades into overlying 2.9-foot sequence	2.6	40.8
Limestone, very finely crystalline, dark-gray (N4), gray-drab-weathering; 2- to 3-inch laminae stand slightly above .15-inch depressions on weathered vertical surface; .25-mm black quartz silt laminae with yellowish stain on fresh surface; between laminae rocks contain approximately 5% .01- to .05-mm quartz silt in general distribution. Some .15-mm dolomite crystals are present in the silt laminae	2.3	38.2
Limestone, dolomitic, finely crystalline, medium-gray (N5), gray-drab-weathering; increase of .01-inch black silty laminae over number in 1.3-foot interval below; pockets of fossil fragments and silty material	2.0	35.9
Limestone, dolomitic, silty, finely crystalline, dark olive-gray (5Y3/1), gray-drab-weathering; .5-inch laminae stand up on weathered vertical surface these are separated by .15-inch slightly lower areas; black-weathering silt laminae; composition is approximately 50% dolomite and 50% calcite; possibly a calcitic dolostone	1.3	33.9
Dolostone, finely crystalline, medium-gray (N5), yellowish-gray (5Y7/1)-weathering with .1-inch lines of light-gray-weathering material; grades upward into overlying dolomitic limestone .	1.3	32.6
Limestone, medium crystalline, medium-gray (N6), medium bluish-gray (5B6/1)-weathering; .1-inch black silty partings and .1-inch brownish-weathering laminae similar to those in limestone at base of section but less prominent; a few dolostone interbeds appear near the top	1.9	31.3
Limestone, dolomitic (±50% dolomite), medium to coarsely crystalline, medium-gray (N5)-weathering, medium- to light-		

gray (N5 to N6). Dolomite rhombs, ±.15-mm, in clusters and as isolated rhombs; all more or less evenly distributed through rock. Shapes of boundaries between clusters of dolomite crystals and the larger anhedral calcite grains seem controlled by the dolomite cluster shape; single dolomite crystals have impressed themselves on the larger calcite grains . . .	1.6	29.4
Dolostone, calcitic, silty, finely crystalline (.1 to .15 mm), yellowish-gray (5Y8/1)-weathering, medium bluish-gray (5B6/1) to dark olive-gray (5Y6/1); 8- to 12-inch beds; approximately 15% .01- to .15-mm calcite grains scattered through rock . .	3.0	27.8
Limestone, finely crystalline, dark bluish-gray (5B3/1) to dark-gray (N3), drab-weathering; .5- to 1.0-mm blocks of .05- to .1-mm silty dolostone; a few black silt laminae	0.3	24.8
Covered. The contact between the Thorp Point and Emerson School members of the Cassin formation lies about in the middle of this interval	11.8	24.5
Limestone, sandy, finely to medium crystalline, medium gray-weathering (N5), medium dark-gray (N4) with olive-gray (5Y5/1) laminae which are raised on weathered surfaces. .1- to .15-mm quartz occurs in laminae ±.25 mm thick and as isolated angular grains in rest of rock; sand-rich laminae with .15-mm isolated dolomite rhombs	0.7	12.7
Limestone, sandy, medium crystalline, medium light-gray to light bluish-gray (N6 to 5B6/1)-weathering, medium- to dark-gray (N5 to N6) with raised ridges. The characteristic raised ridges of more sandy material weather very light-brown (5YR6/6 to 5YR7/6), are olive-gray (5Y5/1) on a fresh break, are .1- to .12 inches thick, and are separated by .5 to 1.0 inches of less sandy material. A few of the ridges are 1.5 inches thick. The clear, angular quartz silt and sand grains are concentrated in the brownish-weathering ridges, but are also present in amounts up to 20% in the less sandy portions	12.0	12.0
Base of section, 6 feet below water level		0

SECTION 8—*Center of Fort Cassin headland*

Section compiled from the bluffs approximately 600 feet south of the northwest corner of the headland, beginning approximately 2 feet below lake level of September 12, 1957, and continuing to exposures at the north end of the summer cottage 20 yards east of the bluff edge.

	Thickness—feet	
	Unit	Cumulative to top of unit
Emerson School member		
Cover, end of section at north end of cottage		
Limestone, medium crystalline, light bluish-gray (5B7/1)-weathering medium-dark bluish-gray (5B5/1)	1.0	41.3

Limestone, medium to finely crystalline, some with conchoidal chert-like fracture; light-blue- to bluish-gray-weathering	0.7	40.3
Cover	1.6	39.6
Limestone, dolomitic, silty, medium and finely crystalline, medium bluish-gray; a few silty partings; .25 to 1-mm laminae are mixtures of dolomite and quartz, varying from 40 to 60% quartz; individual layers between 2 and 6 inches thick. Some fossil fragments; up to 25% .05-mm dolomite crystals	6.3	38.0
Cover	3.0	31.7
Limestone, dolomitic, medium to coarsely crystalline with fossil fragments, medium bluish-gray (5B6/1). Laminae of .05-mm quartz silt; dolomite rhombs .1- to .15-mm comprise up to 40% of rock in places; flat .5-mm pebbles of calcareous quartz silt; within areas of dolomite rhomb concentration calcite grains .2- to .5-mm	1.0	28.7
Dolostone, very finely crystalline, light medium-gray (N6) with slight bluish tint	0.7	27.7
Limestone, medium to finely crystalline, medium light-gray (N6)	0.5	27.0
Dolostone, very finely crystalline, light medium-gray (N6) with bluish tint	0.5	26.5
Limestone, medium to finely crystalline, medium light-gray (N6)	0.5	26.0
Dolostone, finely crystalline, light medium-gray (N6) with bluish tint	0.5	25.5
Cover, probably similar to material lying immediately below	±2.0	25.0
Limestone, coarsely crystalline with abundant fossil fragments; medium to dark bluish-gray (5B3/1 to 5B5/1) with vitreous luster. Possibly correlates with the dolomitic limestone and overlying 1.9-foot medium crystalline limestone which occur between 27.8 and 31.3 feet above the base of the section at the north end of the headland	2.5	23.0
Limestone, coarsely crystalline, dark-gray (N3), abundant trilobite fragments; in part possibly correlative with dolostone and limestone between 31.3 and 33.9 feet above base of section at north end of headland	3.1	20.5
Limestone, very finely crystalline to sublithographic, dark bluish-black (5B2/1) to medium bluish-gray (5B5/1); laminae of dolomitic siltstone and silty dolostone separate 1- to 2-inch beds. .25- to .5-mm circular reddish-brown masses composed of .001- to .005-mm calcite crystals.	2.5	17.4
Dolostone, silty, light olive-gray (5Y6/1)-weathering, light yellowish-gray (5Y8/1); .06-mm average grain-size; approximately 30% quartz silt evenly distributed through rock; 6-inch beds separated by .5-inch silt partings; becomes more calcareous towards the top	3.3	14.9
Dolostone, finely crystalline, dark bluish-gray (5B3/1)-weathering, bluish black on fresh surface; thin, .5-inch beds resembling shale beds	1.1	11.6

Limestone and siltstone, interbedded 1- to 2.5-inch limestone beds separated by slaty black siltstone in beds up to 1 inch thick; also thin layers of silty dolostone and dolomitic siltstone. Limestone layers are medium to coarsely crystalline with abundant fossil fragments; dolostones are finely crystalline (.05 mm). Silty limestone occurs as fossil fillings. Upper part of this interval is horizon of Fort Cassin fossils described by Whitfield (1889, 1890, 1897), and see Text-figure 7	3.3	10.5
Limestone, coarsely crystalline (.5 to 1 mm), dark-gray (N3) to medium-gray (N5), weathers medium bluish-gray (5B5/1); abundant rounded fragments and complete shells of trilobites and brachiopods; .25- to 1.0-mm black silt partings in which .05-mm quartz grains are well cemented; pebbles of calcareous silt and silty limestone	2.3	7.2
Top of Thorp Point Member		
Limestone, dolomitic, finely crystalline, medium light-gray (N5), weathers drab gray; .1- to .15-mm calcite grains; similar-sized dolomite rhombs comprise 30% of rock. Outlines of *Calaurops lituiformis* Whitfield common; this is the "*Calaurops*-bed" of Whitfield (1890)	0.5	4.9
Limestone, sandy and silty, finely crystalline, medium-gray (N5); thin ridges of silt and very fine sand weather brownish; fewer ridges in upper third of interval than below	4.4	4.4
Water level		0

SECTION 9—*Thorp Point*

Section begins approximately 20 yards west of large bostonite dike at northwest corner of Thorp Point, approximately 1 mile S. 42° E. of Cedar Island, and extends south along the shore to the south side of first cove south of dike and thence southeastward up slope to position 20 yards west of barn. Type section Thorp Point member Cassin formation; supplemental section for Emerson School member.

	Thickness—feet Unit	Cumulative to top of unit
Exposed thickness Emerson School member = 94.6 feet		
Limestone, aphanitic, medium-gray, light-gray-weathering, silty with irregular .1- to .15-inch silt laminae; blue-black chert	1.0	174.8
Sandstone, fine-grained, calcareous; and dolostone, finely crystalline, silty, olive-gray (5Y5/1)	2.5	173.8
Cover	17.3	171.3
Limestone, very finely crystalline, light-gray, fossiliferous	2.0	154.0
Limestone, sublithographic, with conchoidal, chert-like fracture, dark-gray (N3), light-gray-weathering (N7)	1.0	152.0
Limestone, dark bluish-gray (5B4/1), finely crystalline with brownish-weathering raised ridges of fine sandstone like that found near base of section	1.3	151.0

Limestone, finely crystalline medium-gray (N5), thin-bedded; fossil fragments distributed through rock and in pockets of comminuted material; .5-mm subspherical bodies composed of .01-mm calcite crystals together with .5-mm rounded fossil fragments comprise bulk of rock	2.7	149.7
Limestone, finely crystalline (±.01 mm) medium dark-gray (N4); ±.5-mm ovoid masses of .01-mm calcite crystals; rounded fossil fragments, abundant trilobite fragments	4.5	147.0
Cover	4.5	142.5
Limestone, medium and finely crystalline, dark-gray (N4); common .2-mm subspherical and ovoid bodies composed of .001- to .005-mm grains; abundant rounded and angular fossil fragments; all set in very finely crystalline and sublithographic calcite matrix	2.1	138.0
Cover	1.0	135.9
Limestone, sandy and silty, very finely crystalline to sublithographic with chert-like fracture; light- and medium-gray (N7 to N5), with a few sandy laminae; weathers, light-gray (N7). Fossil localities 80 and 81 are near the top of this interval but laterally away from line of section	24.5	134.9
Limestone, sandy, finely crystalline, medium-gray (N5); prominent brownish-weathering .5 to 1.5-inch ridges of calcareous sand on weathered surfaces; rock is similar to "ribbed" limestone at north end of Thorp Point ridge and in lower part of Fort Cassin section	15.0	110.4
Limestone, sandy and silty, dark bluish-gray (5B3/1), finely crystalline; abundant trilobite fragments, some fine-grained calcareous sandstone	2.7	95.4
Cover	10.0	92.7
Limestone, sublithographic to lithographic with conchoidal fracture, bluish-gray (5B6/1), light-gray-weathering (N7); small percentage of quartz silt scattered through .001- to .005-mm matrix material; a few irregular silty layers which weather brownish; silty laminae in some cases enclose and surround limestone; small percentage of .01- to .02-mm dolomite crystals in clusters or aggregates; individual dolomite rhombs separated by quartz silt films	2.5	82.7
Top of Thorp Point member—2 to 3 feet below edge of bluff; exposed thickness of Thorp Point member = 80.2 feet.		
Limestone, silty and sandy; upper half has raised laminae of siltstone and fine sandstone on weathered surfaces; lower half lacks the ridges but grades laterally into material with ridges	3.3	80.2
Dolostone, silty, calcareous, with dolomitic quartz siltstone pebbles; raised network-like structures on weathered surfaces show variations in silt and sand concentrations; dolomite (.03- to .06-mm) ±60%, clear angular quartz (.03- to .06-mm) ±40%; 1- to 2-foot beds; a few fossil fragments. Medium bluish-gray (5B5/1), weathers light olive-gray (5Y6/2)	4.0	76.9

Dolostone, finely crystalline, silty; medium bluish-gray (5B5/1); thin irregular silty laminae (.25- to 1.0-mm) separate massive exposure into beds 6 inches thick; near bottom of interval limestone with trilobite fragments; base of interval at base of bluff on south side of small cove	6.0	72.9
Cover, beach	13.8	66.9
Limestone, finely crystalline, medium-gray (N5) with a few raised lines on weathered vertical surfaces	3.5	53.1
Limestone, finely crystalline, medium-gray (N5), trilobite fragments common	0.5	49.6
Sandstone, calcareous, very fine-grained, fine lines on weathered surface; in part sandy limestone	1.6	49.1
Limestone, finely crystalline, medium-gray (N5), trilobite fragments common; 1- to 2-foot beds	1.3	47.5
Limestone, finely crystalline, silty, trilobite fragments; silty laminae up to 1 inch thick	1.1	46.2
Limestone, sandy and silty, finely crystalline; bluish-gray (5B5/1)-weathering, dark bluish-gray (5B3/1); silty and sandy areas in limestone weather light-brownish; may be fine-grained calcareous siltstone	1.3	45.1
Cover	1.5	43.8
Limestone, silty and calcareous siltstone, medium bluish-gray (5B5/1)-weathering, dark bluish-gray (5B5/3), finely crystalline; up to 90% .05-mm clear angular quartz in some laminae and larger layers; one horizon olive-gray (5Y5/2)-weathering. Some fossil fragments with quartz silt filling them	1.6	42.3
Limestone, very finely crystalline, dark-gray (N3 to N4), bluish-gray (5B5/1)-weathering; 3- to 6-inch beds, irregularly distributed light olive-gray (5Y5/2)-weathering silty laminae and fine lines; may be in part calcareous siltstone or very fine sandstone	1.8	40.7
Limestone, sandy and silty, finely crystalline; fine raised lines on weathered surfaces. 1- to 2-foot beds	3.5	38.9
Limestone, silty, very finely crystalline, medium-gray (N5); fresh break displays fine lines; some trilobite fragments; bed is similar to 2.8-foot bed below	2.7	35.4
Limestone, silty, finely crystalline; trilobite fragments common	1.0	32.7
Limestone, silty with .04- to .06-mm clear angular quartz grains; quartz approximately 40%, calcite 60%. On weathered surfaces .12 to .25 inch thick ridges composed of quartz silt; medium bluish-gray (5B6/1), finely crystalline; beds 9 to 12 inches thick	2.8	31.7
Dolostone, silty, calcitic, very finely crystalline, light-gray to medium dark-gray (N7 to N5), yellowish-gray (5Y7/1), yellowish-orange (10YR7/6)-weathering; ±65% dolomite in .02- to .04-mm rhombs; ±25% quartz silt distributed throughout rock; ±10% calcite. Weathered surface displays silty and		

sandy lenticular-shaped raised areas approximately .06 inches thick and 1 to 2 inches long and which are approximately parallel to bedding, although some are tilted	2.3	28.9
Limestone; finely crystalline, medium bluish-gray (5B5/1), common trilobite fragments	1.8	26.5
Limestone, silty, finely crystalline, medium bluish-gray (5B5/1)	0.3	24.8
Limestone, silty, very finely crystalline to sublithographic medium-gray (N5); trilobite fragments common; silty, lined pebbles in layers and distributed irregularly throughout bed which grades laterally into sandy-silty limestone with +.5 inch-raised ridges on weathered surface	0.4	24.5
Shale, black, silty	0.4	24.1
Limestone, silty, very finely crystalline to sublithographic, medium-gray (N5); common trilobite fragments; abundant silty, lined pebbles in layers and distributed irregularly through bed; grades laterally into sandy limestone with raised brownish ridges on weathered vertical surfaces	1.5	23.7
Sandstone, slightly calcareous, dark bluish-gray (5B2/1) to black. Shale and silt interbeds 1 to 2 inches thick	1.1	22.2
Limestone, silty, light medium-gray (N6), finely crystalline, discoidal and lenticular pebbles in layers. Pebbles are sandy limestone and calcareous sand; trilobite fragments common	2.0	21.1
Siltstone, quartzose calcareous; trilobite fragments	0.6	19.1
Limestone, sandy and silty, very finely crystalline to sublithographic, medium-gray (N5) .5-inch rounded discoidal pebbles of calcareous quartz sandstone, some with iron-stained rims; matrix is .75-mm fossil fragments (trilobite mostly) and .005-mm calcite grains, probably a small amount of fine-grained calcareous sandstone	1.0	18.5
Limestone, silty and sandy, finely crystalline, medium-dark bluish-gray (5B4/1) with thin laminae of dark shale; in part probably calcareous siltstone	2.3	17.5
Limestone, finely crystalline, medium-dark bluish-gray (5B4/1); rounded pebbles of calcareous siltstone and sandstone; trilobite fragments; fossil locality 77 in this horizon	1.3	15.2
Sandstone, calcareous, fine-grained (.075 to .1 mm), medium-gray (N5), light yellowish-gray (5Y9/1)-weathering; fine raised lines on weathered surface	0.8	13.9
Shale, black, noncalcareous	0.1	13.1
Limestone, aphanitic, grayish-black (N2); trilobite fragments and ellipsoidal, black, rounded limestone pebbles up to 1.25 inches in diameter	0.5	13.0
Limestone, sublithographic to very finely crystalline, black; silty and sandy; some is calcareous sandstone; black, slaty laminae; trilobite fragments and some coarsely crystalline material. Some of black, noncalcareous, silty, slate-like layers are ±.5 inch thick. Beds average 3 inches thick with thin		

laminations and beds of shale between. Fossil locality 76 in this horizon	2.0	12.5
Sandstone, dolomitic, very fine-grained (±.06 mm), dark bluish-gray (5B3/1), yellowish-orange (10YR7/6) to yellowish-gray (5Y7/1)-weathering; 4- to 6-inch beds; dolomite rhombs ±40%, grayish clear angular quartz ±60%	2.0	10.5
Cover	7.5	8.5
Limestone, silty, very finely crystalline, dark-gray (N3), light olive-gray (5Y6/2)-weathering; lenticular 4- to 6-mm quartz silt masses or aggregates; 75% of rock is trilobite fragments set in .005- to .01-mm calcite; some trilobite fragments filled with quartz silt	1.0	1.0
Cover		0

SECTION 10—*Emerson School*

Section measured on compass traverse running S. 40° E. and beginning at base of ridge which is approximately 1 mile S. 19° E. of Cedar Island. Traverse starts about 100 yards south of road to Thompson Point. Uppermost part of traverse northeast of road intersection. Type section of Emerson School member of Cassin formation; supplemental section for Thorp Point member.

	Thickness—feet Unit	Cumulative to top of unit
Dolostone, finely crystalline, very light-gray (N8), tough; Bridport formation		
Top of Emerson School member; thickness = 102 feet		
Limestone, sublithographic, dark-gray; also bluish-gray, finely crystalline with ±.25-mm black silty laminae	± 5	207
Cover	±20	202
Limestone, sublithographic with conchoidal fracture, light-gray-weathering, dark-gray; blue-black chert on weathered surface	1	182
Dolostone, calcitic, coarse-grained, brownish-gray; 1-foot beds, massive	3	181
Cover, from base of dip slope to outcrop at southwest end of pasture	17	178
Limestone, as below; 2- to 3-foot interval at top is sublithographic limestone, dark-gray, with .1-mm silty partings or laminae giving a chained appearance to bedding surfaces; laminae are less than 1 inch apart	15	161
Limestone, finely crystalline, sandy, thin-bedded, light-gray, light bluish-gray-weathering; intraformational conglomerate; lower 1 to 2 feet of interval show evidence of "ribbing" on weathered surface	16	146
Limestone, finely crystalline, medium light-gray; sandy, raised 1-inch ridges of brownish-weathering, calcareous sandstone	16	130
Cover	5	114

	Unit	Cumulative
Limestone, sandy, finely crystalline, medium light-gray; raised ridges of brownish-weathering, calcareous sandstone on weathered vertical surfaces	2	109
Limestone, sublithographic, dark-gray with black-weathering silty laminae giving a "chained" effect on the bedding surface; limestone is medium bluish-gray-weathering and contains fossil-bearing horizons which are coarse-grained fossil-fragmental	2	107
Top of Thorp Point member; exposed thickness = 105 feet		
Limestone, as below	1	105
Limestone, as below, sandy	2	104
Limestone, sandy, weathering light medium-gray with "granular" surface; thin (±.1 mm) layers of silty material; some parts of interval are calcareous sandstone	11	102
Limestone, sandy, medium to coarsely crystalline, medium gray; a few dark-gray pods of sublithographic limestone; intraformational breccia; approximate stratigraphic position of fossil locality 88	5	91
Limestone, as 16-foot interval below; thin intraformational conglomerate at top	11	86
Limestone, fossil-fragmental (chiefly trilobite fragments), medium- to coarse-grained, medium-gray, beds 2 to 3 inches thick; very light-gray, fine-grained calcareous sandstone rare	16	75
Limestone, sandy and silty, very finely crystalline, medium-gray to medium bluish-gray; raised brownish-weathering ridges 1- to 2-inches; beds 6 to 12 inches thick; interbeds of medium-gray (N4 to N5) finely crystalline limestone and thin bands of trilobite fragments; fossil locality 89 in upper 5 feet of this interval	59	59
Base of hill		0

SECTION 11—*Ellsworth Ledge*

2.2 miles N. 17° E. of West Cornwall and N. 35° W. approximately 1 mile from Cornwall. Section begins at base of ridge and extends eastward across road for a distance of approximately .75 mile.

	Thickness—feet Unit	Cumulative to top of unit
Dolostone, buff-weathering, very finely crystalline, various shades of gray. Bridport dolostone		
Cover, Bridport-Bascom contact lies near the middle of the interval	72	659
Limestone, very finely crystalline to sublithographic, medium light-gray; black, irregular, platy silty laminae ±.1 inch thick give a "chained" appearance to weathered outcrops; upper 10 to 15 feet contain fewer laminae, with light buff-weathering,		

finely crystalline, medium dark-gray dolostone in irregular patches and .5 to 1 foot thick lenses and beds; also dolomitic, fucoid-like masses. Dolomitized outlines of *Maclurites* and other fossils near top of interval.	70	587
Cover	39	517
Limestone, very finely crystalline to sublithographic, medium light-gray; .1-inch black silty laminae; intraformational conglomerate near top; rusty-weathering, dolomitic silt and silty dolostone horizons of dark bluish-gray color, very finely crystalline	10	478
Top of "D-3" unit of Bascom (equivalent of Thorp Point member of Cassin)		
Cover	65	468
Limestone, sandy, thin to moderately thick-bedded	3	403
Cover, contact between Emerson School member of Cassin formation (D-3 of Bascom) and D-2 unit of Bascom lies near base of this interval	44	400
Limestone, very finely crystalline, sandy	19	356
Limestone, finely crystalline, sandy; zones of calcareous sandstone stand up as ridges on weathered surfaces	26	337
Cover	5	311
Limestone, sublithographic, medium bluish-gray weathering, light-gray; very fine sand as laminae and scattered grains	16	306
Top of "D-1" horizon of Bascom		
Limestone, sublithographic, medium bluish-gray, a few 1-foot very finely crystalline dolostone beds	16	290
Limestone, sublithographic with conchoidal fracture, medium-blue-weathering, light-gray thin buff dolomitic stringers and laminae; thin silty beds; fossil outlines in lower 3 to 4 feet	16	274
Top of Cutting formation		
Dolostone, medium- and dark-gray, drab-weathering, very finely crystalline; beds moderately scored	8	263
Cover	31	255
Dolostone, very finely crystalline, medium- and dark-gray, weathers white and yellowish-white	34	224
Top of C-3 unit of Cutting		
Dolostone, very finely crystalline, light-gray, silty	45	190
Cover, contact between C-2 and C-3 units is covered, lying near the middle of the covered interval; to north of line of section transition from "soft-appearing" dolostones of C-2 to very finely crystalline, silty material of C-3 may be seen	115	145
Dolostone, medium crystalline, light- and medium-gray, some with vitreous luster, but most dull-lustered; small amount of blue-black chert. There may be a small amount of C-1 unit at base	30	30
Cover	..	0

SECTION 12—*East of Dean Island*

Section measured up west face of slope due east of Dean Island.

	Thickness—feet Unit	Cumulative to top of unit
Cover, crest of ridge; from crest eastward to open pasture there are occasional outcrops of drab dolostone; approximately a dip slope		
Dolostone, yellowish-gray weathering (5Y8/1) medium dark-gray (N4); very finely crystalline (±.01 mm); slightly silty, massive beds 1 to 2 feet thick	8	149
Dolostone, silty, yellowish-gray-weathering dark to medium bluish-gray (5B4/1) very finely crystalline; 8- to 12-inch beds; bed of grayish black (N2), very finely crystalline limestone in upper third; beds 1- to 2-feet, massive	13	141
Dolostone, silty and dolomitic siltstone; yellowish-gray-weathering, dark-gray to dark bluish-gray (N3 to 5B3/1); 3- to 4-foot massive beds	6	128
Dolostone, yellowish-gray-weathering dark-gray (N3), very finely crystalline; 2- to 3-foot beds; massively bedded.	9	122
Dolostone, yellowish-gray weathering, dark-gray (N3), very finely crystalline; massive beds	11	113
Dolostone, silty, and dolomitic siltstone, grayish-orange to pale yellowish-brown (10YR6/4–10YR7/2)-weathering, dark bluish-gray to bluish-black (5B5/3 to 5B2/1); finely crystalline (.02 to .05 mm) with approximately 50% very fine (.005 mm) quartz silt; thick, massive beds. Near center of interval a light bluish-gray, smooth-weathering (5B8/1), grayish-black silty, sublithographic limestone; 1 foot bed	11	102
Dolostone, silty, and dolomitic siltstone, grayish-orange to pale yellowish-brown (10YR6/4 to 10YR7/2)-weathering; dark bluish-gray to bluish-black (5B5/3 to 5B2/1); very finely crystalline; moderately thick, massive beds	8	91
Dolostone, light yellowish-brown-weathering (10YR7/2), dark-gray (N3); sublithographic to very finely crystalline; thick, massive beds	16	83
Dolostone, light yellowish-brown-weathering, dark-gray, very finely crystalline to sublithographic; thick, massive beds	9	67
Dolostone, light yellowish-gray-weathering, dark-gray to black, sublithographic to very finely crystalline; 2- to 3-foot beds (thick)	12	58
Covered	28	46
Limestone, blue-weathering, black, sublithographic; 2-inch beds separated by .5- to 1-inch beds of dolostone	7	18
Dolostone, pale yellowish-brown (10YR7/2) to yellowish-gray (5Y8/1)-weathering, dark-gray to medium dark-gray (N3 to		

N4), sublithographic to very finely crystalline; tracer of silt 1- to 3-foot beds with 4-inch shale interbeds	11	11
Water line		0

SECTION 13—*County Line Section*

Section compiled (July, 1957) from shore and bluffs beginning approximately 1900 feet S. 50° E. of Dean Island and extending southward to slightly beyond intersection of county line with coast. This is the locality of basal part of Chittenden-Addison Section (No. 22) of Oxley and Kay (1959).

	Thickness—feet Unit	Cumulative to top of unit
Limestone, medium-bluish-gray; sublithographic, nodular-weathering with black quartz silt partings and interbedded coarse- and medium-grained fossil-fragmental limestone. Crown Point limestone.		
Top of Day Point is near center of covered interval		
Cover	6	150.8
Limestone, fossil-fragmental gray to yellowish-gray (5Y7/2)-weathering bluish-gray (5B7/1); nodular-weathering; rounded fossil fragments ±.3 mm=70%; dolomitic quartz silt=25%; ±5%> .005- to .01-mm calcite as matrix.	4.2	144.8
Dolostone, sandy, sublithographic, drab to light yellowish-brown (10YR6/4)-weathering; light-gray; 1.5- to 2-foot beds; .1-mm subrounded quartz grains set in dolomite matrix or cement; ±.01-mm calcite = 5%; subround and round ±.1- to .25-mm quartz grains = 35%; dolomite, ±.07 mm, = 60%	4.8	140.6
Limestone, sublithographic, silty, dolomitic; dark bluish-gray, weathers very light bluish-gray (5B8/1); *Girvanella* sp.; massive bed with only sign of bedding being irregular yellowish-brown silty streaks; in part may be calcitic silty dolostone	4.8	135.8
Shale and sandstone, interbedded dolomitic sandstone very fine-grained and in 1-inch layers	0.5	131.0
Shale, thin-bedded dark gray, noncalcareous; probably quartzitic	3.5	130.5
Limestone, fossil-fragmental, slightly dolomitic, medium bluish-gray (5B5/1)-weathering dark bluish-gray (5B3/1); also dolostone, sublithographic, sandy, moderate yellowish-brown (10YR5/4)-weathering, tenacious; calcareous siltstone at base in 1 inch beds	3.8	127.0
Shale and sublithographic Dolostone, interbedded	1.3	123.2
Limestone and Sandstone, medium bluish-gray (5B5/1), very fine-grained; 2- to 4-inch beds	1.3	121.9
Shale, noncalcareous, medium dark gray to black	5.4	120.6
Limestone, sublithographic, sandy and slightly dolomitic; light bluish-gray-weathering, dark bluish-gray; a few fossil fragments	2.0	115.2
Shale, noncalcareous, dark-gray (N3) to dark olive-gray (5Y3/1);		

with 1-inch laminae of orange-brown-weathering dolomitic siltstone	1.3	113.2
Limestone, light bluish-gray-weathering, sublithographic with some fossil fragments	0.7	111.9
Sandstone, very fine-grained, dolomitic and calcareous, light-gray to light bluish-gray (5B7/1); thin layers of fossil-fragmental limestone	2.0	111.2
Limestone, light bluish-gray-weathering, silty, sublithographic	3.1	109.2
Shale, noncalcareous with yellowish-brown silty dolomitic 2- to 4-inch laminae	1.8	106.1
Sandstone, both noncalcareous and dolomitic and Dolostone, sandy; sandstone, fine-grained; rounded quartz grains, yellowish-gray (5Y8/1) and yellowish-orange (10YR7/6)-weathering; 75% quartz; 25% .06-mm dolomite rhombs. Dolostone, similar-appearing but with more than 50% dolomite; thin 1- to 2-inch shale interbeds separate 9- to 18-inch beds of sandstone and dolomite	5.8	104.3
Limestone, sublithographic, light bluish-gray-weathering, dark bluish-gray (5B3/1); quartz present as rounded, frosted .1- to .25-mm grains; a few rounded fossil fragments, all set in matrix of .005- to .01-mm calcite	4.5	98.5
Limestone, sublithographic, light bluish-gray-weathering; similar to overlying 4.5-foot bed	2.5	94.0
Shale, noncalcareous, medium dark-gray	3.3	91.5
Limestone, sublithographic, light bluish-gray-weathering with dolomitic, silty raised ridges	1.0	88.2
Shale, noncalcareous, dark gray	2.5	87.2
Limestone, sublithographic, light bluish-gray	3.8	84.7
Shale, noncalcareous, medium dark-gray	3.3	80.9
Limestone, sublithographic, light bluish-gray-weathering with raised dolomitic-silty ridges; brownish tint on fresh surface	1.3	77.6
Shale, noncalcareous, interbeds of light bluish-gray, yellowish-brown-weathering silty dolostone; grades upward into overlying limestone	2.3	76.3
Limestone, as in 5-foot bed below, but becoming more shaly toward top	4.0	74.0
Shale, dark gray	3.5	70.0
Limestone, sublithographic, dark- to medium-gray; black silty laminae and partings	2.5	66.5
Shale	1.0	64.0
Limestone, fine- and medium-grained fossil-fragmental, quartz silt 10%; .005- to .01-mm calcite approximately 10%; 5% .06-mm dolomite rhombs scattered through rock; silt and dolomite in small irregular masses scattered through rock. 18-inch beds and some 6-inch shale beds	5.0	63.0
Shale, noncalcareous, medium dark-gray (N4)	1.8	58.0
Limestone, sublithographic, dark to medium-gray, silty laminae and partings	5.5	56.2
Shale, noncalcareous, dark- to medium-gray	5.0	50.7

Limestone, fossil-fragmental, dark bluish-gray (5B3/1); ±15% .06-mm dolomite; ±10 to 15% .075- to .1-mm subrounded frosted quartz grains; fossil fragments are subrounded . . .	3.0	45.7
Shale.	3.0	42.7
Limestone, fossil-fragmental, dolomitic, silty ridges.	2.3	39.7
Shale, noncalcareous, fissile, dark-gray	3.0	37.4
Sandstone, calcareous, very fine-grained, dark bluish-gray (5B3/1); may be in part sandy sublithographic limestone . .	2.3	34.4
Shale, noncalcareous, fissile	1.8	32.1
Sandstone, calcareous, dark bluish-gray, very fine-grained; may be in part sandy sublithographic limestone	1.5	30.3
Limestone, sublithographic, pale yellowish-orange (10YR7/6)-weathering, dark grayish-blue (5PB4/2); raised yellowish-brown-weathering dolomitic silt ridges on weathered surface; ±.1-mm rounded frosted quartz grains 15%; .06-mm dolomite rhombs = 10%; ±.01-mm calcite = 75%	4.8	28.8
Limestone, dark grayish-blue (5PB4/2), sublithographic, with some dolomitic silty horizons which weather yellowish-brown	2.3	24.0
Shale.	0.1	21.7
Limestone, sublithographic, dark grayish-blue (5PB4/2) with some reddish-weathering spots.	2.5	21.6
Shale.	0.3	19.1
Limestone, fossil-fragmental, dark grayish-blue (5PB4/2) to medium bluish-gray (5B5/1), interbedded yellowish-brown-weathering silty dolomitic zones; fossil fragments are rounded, .5- to 1.0-mm and are set in .01-mm calcite matrix	4.8	18.8
Sandstone, dolomitic very fine-grained, pale yellowish-orange (10YR8/6)-weathering dark bluish-gray (5B3/1); in part a sandy dolostone	3.0	14.0
Limestone, fossil-fragmental, coarse-grained, silty with 1-mm layers of silt; light grayish-blue (5PB6/1); grades upward into overlying sandstone and dolostone	1.5	11.0
Shale, noncalcareous, dark olive-gray (5Y3/1), fissile; grades upward into overlying limestone	6.3	9.5
Sandstone, calcareous and Limestone, sandy, rounded, frosted, quartz .07- to .08-mm, from 40 to 90%; bed is light brownish-gray- to dusky-yellow-weathering, dark bluish-gray (5PB4/2) to dark-gray (N3); calcite as .005- to .01-mm rhombs; small percentage rounded fossil fragments	1.0	3.2
Shale.	0.1	2.2
Sandstone, very fine-grained, dolomitic, .06- to .1-mm subrounded quartz grains, larger ones frosted; quartz = 60 to 70%; .06-mm dolomite rhombs = 30 to 35%; calcite and a few trilobite fragments = ±5%	1.3	2.1
Shale and Sandstone, weathers yellowish-brown; shale is olive-gray (5Y4/1) noncalcareous, lies on dolostone of Bridport. Sandstone, light bluish-gray (5B6/1) fine-grained with approximately 10% .5-mm quartz grains, 60% .06-mm quartz		

	Unit	Cumulative
grains, and 30% .06-mm dolomite rhombs which serve as the cementing material for the rock	0.8	0.8
Bridport dolostone		0

SECTION 14—*Hawkins Bay*

Section compiled (September, 1957) in bluff near mouth of Little Otter Creek, approximately 3900 feet S. 75° E. of Bluff Point and 20 to 30 yards east of bostonite dike.

	Thickness—feet Unit	Cumulative to top of unit
Limestone, fossil-fragmental, coarse- and medium-grained; scattered quartz grains; some sublithographic limestone beds with moderate amounts fossil fragments; occasional layers of limestone pebbles and what appear to be *Girvanella* masses which have been rolled around; fossil fragments lined in finer grained limestones by .01-mm crystals similar to those forming matrix, a relation suggesting accumulation of the smaller crystals on the fragments as they moved across the bottom; bedding varies, but black silty laminae in abundance give thin-bedded, slightly nodular-weathering aspect to the weathered surfaces. Crown Point limestone	86	124
Top of Day Point—Thickness exposed = 39 feet		
Limestone, fossil-fragmental, very coarse-grained (1.25 to 1.5 mm), rounded fossil fragments; scattered quartz grains; soft-appearing on fresh surface, medium dark bluish-gray (5B4/1); bryozoan, brachiopod, and pelmatozoan fragments expecially prominent; massive bedding but locally broken by silty laminae into nodular-weathering, thin-bedded layers; locally layers of sublithographic, probably autochthonous limestone pebbles	16.1	38.6
Shale, noncalcareous, thin-bedded, dark-gray	0.2	12.5
Limestone, fossil-fragmental, coarse- to very coarse-grained, rounded fragments; moderate amounts of quartz scattered throughout; small amounts of dolomitic and silty material; bluish-gray, weathers brownish-gray	0.5	12.3
Limestone with Dolostone, and Sandstone interbedded. Dolostone is calcitic, smooth-weathering, light-gray, very finely crystalline to sublithographic; Limestone beds and laminae are composed of .2-mm fossil fragments with .06-mm dolomite and quartz silt in 1-mm or less layers; Sandstone laminae composed of .1-mm subrounded quartz grains with a few as large as 1 mm; cemented by calcite of comparable size	0.7	11.8
Limestone, sublithographic, dolomitic; silty and sandy; in part fossil-fragmental; thick-bedded, massive, medium-gray-weathering; silty laminae toward top; grades laterally into fossil-fragmental limestones	3.6	11.1

Shale, noncalcareous, dark-gray; grading upward into overlying limestone	0.3	7.5
Limestone, sublithographic, dolomitic, dark-gray, weathers brownish-gray	1.6	7.2
Limestone, sublithographic, silty, light-gray-weathering, dark bluish-gray (5B3/1) to bluish-black (5B2/1); up to 10% fossil fragments; thin-bedded, nodular-weathering	0.6	5.6
Limestone, dolomitic, silty sublithographic with a few fossil fragments and calcitic Dolostone; dolomite, up to 60% of rock, is intimately mixed with the small quantity of quartz silt; massive bed, dark olive-gray (5Y3/1)-weathering, bluish-gray, subvitreous luster	1.0	5.0
Limestone, fossil-fragmental, silty, coarse-grained (.5 to 1.0 mm), interbedded with sublithographic (.005- to .01-mm calcite) silty limestone with small percentage of fossil fragments; bluish-gray-weathering, medium-gray (N5); thin-bedded (1 to 2 inches) with crenulated bedding planes; sublithographic limestones are more dolomitic than fossil-fragmental types, containing up to 25% subhedral ±.05-mm dolomite grains	3.1	4.0
Shale, silty, black, noncalcareous, thin-bedded	0.9	0.9
Cover		0

Section 15—*Summer Point*

Section compiled (July, 1958) from exposures along shore beginning approximately .5 mile south of Summer Point. This is the locality of Section 23 of Oxley and Kay (1959). Section begins where the lowest sandstone bed forms the top of the bluff.

	Thickness—feet Unit	Cumulative to top of unit
Limestone, nodular-weathering, thin-bedded, dark bluish-gray (5B3/1 to 5B4/1); varying amounts of fossil fragments set in matrix of .01-mm calcite grains; wisps and irregular masses of silt-size quartz. Crown Point limestone		
Top of Day Point—Thickness of Day Point 76.4 feet		
Cover	2	81.5
Shale, noncalcareous, olive-gray	1.5	79.5
Limestone, fossil-fragmental and very finely crystalline, dolomitic; various components irregularly distributed and mixed; dolomite as .04- to .06-mm rhombs; calcite as .04- to .06-mm rhombs and as .2- to .3-mm crystals within silty dolomite patches fossil locality 479A	2.5	78.0
Cover	2.0	75.5
Limestone, fossil-fragmental, coarse-grained, as 1.3-foot bed below	2.5	73.5
Limestone, fossil-fragmental, coarse-grained; light-gray (N7)-		

weathering, medium bluish-gray (5B4/1); a few dolomitic silt seams irregularly distributed through the rock; dolomitic silt material surrounds some fossil fragments	1.3	71.0
Dolostone, silty, calcitic, light-brown (5YR6/6)-weathering, light-gray (N5 to N6); very finely crystalline, dolomite rhombs .06- to .08-mm = 40 to 50%; .04- to .06-mm subangular to subround grains of quartz = 35 to 45%; ±.06- to .08-mm rhombs of calcite mixed with the dolomite	2.5	69.7
Limestone, oölitic and fossil-fragmental; bluish-gray (5B5/1)-weathering, light bluish-gray (5B6/1), very finely crystalline to finely crystalline; oölites composed of ±.01-mm calcite up to .3 mm in diameter; small amount of scattered quartz-silt grains; .03-mm rhombs of dolomite scattered through rock	5.8	67.2
Limestone, silty and dolomitic, dark bluish-gray (5B4/1)-weathering, dark-blue (5B5/6); sublithographic with dull luster; silty laminae with admixed ±.06-mm dolomite rhombs irregularly distributed; 2- to 3-foot massive beds with silty material at approximately 1-foot intervals; calcite as ±.01-mm crystals, some aggregate or pellet-like structures and a few fossil fragments	4.5	61.4
Limestone, dolomitic, silty; blue to bluish-gray, sublithographic; sparkling or vitreous luster; a few thin calcareous shale lenses; fossil fragments in varying proportions; beds 6- to 12-inches	10.0	56.9
Limestone, dolomitic, silty; gray-weathering, medium dark-gray (N4), vitreous luster; sublithographic, but with some fossil fragments, especially brachiopods; irregularly distributed silty and dolomitic films .01 to .05 inches thick cause nodular-weathering; fossil locality 324 from this bed	2.1	46.9
Shale, noncalcareous, black	0.3	44.8
Sandstone, dolomitic, very fine-grained, yellowish-gray (5Y7/2)-weathering, medium bluish-gray (5B5/1); *Lingula* fragments	0.7	44.5
Shale, noncalcareous, black	0.5	43.8
Dolostone, silty and sandy, very finely crystalline; yellowish-gray (5Y7/2) to grayish-yellow (5Y8/4)-weathering, medium bluish-gray (5B5/1); *Lingula* fragments; increase in silt content toward top and beds become .5 to 1 inch thick upward; quartz, subrounded to angular, ±.06-mm = 25%; dolomite, ±.06-mm rhombs = 75%; pyrite	1.5	43.3
Shale.	0.2	41.8
Dolostone, silty, sublithographic, yellowish-gray (5Y7/2)-weathering, medium bluish-gray (5B5/1); 1- to 2-inch beds; grades northward into shale	1.3	41.6
Dolostone, silty and sandy, very finely crystalline, dark yellowish-brown (10YR4/2)-weathering, medium-gray (N5); some .1- to .2-inch silty laminae	1.1	40.3
Shale, noncalcareous, black	0.5	39.2
Sandstone, dolomitic, fine-grained, pale-orange (10YR7/2)-weathering, medium-gray (N4)	0.8	38.7

Shale, noncalcareous, black	0.5	37.9
Sandstone, as in next lower sandstone bed	0.2	37.4
Shale, noncalcareous, silty	0.1	37.2
Sandstone, dolomitic, medium- and coarse-grained; weathers pale-orange (10YR7/2) to grayish-orange (10YR7/4); medium-gray (N4); *Lingula* and trilobite fragments	0.2	37.1
Shale	0.3	36.9
Sandstone, dolomitic, fine-grained, yellowish-orange-weathering	0.9	36.6
Siltstone	0.3	35.7
Sandstone, dolomitic, fine-grained; yellowish-orange (10YR7/4)-weathering, medium-bluish-gray (5B5/1) with grayish-orange streaks; streaks of .5-mm and larger rounded to subrounded quartz grains	2.0	35.4
Sandstone, dolomitic, beds ±1 foot thick; grayish-orange (10YR7/4)-weathering, light-gray and light yellowish-brown (10YR5/2); very fine-grained to silt-size; fine and medium clear rounded quartz grains = ±60% in some layers; other layers .07-mm angular quartz grains form 40 to 60%; dolomite rhombs, ±.06-mm form 60 to 40%; laterally the sandstone is replaced by thin-bedded siltstone or silty dolostone	6.8	33.4
Sandstone, dolomitic, very fine-grained; beds 4 to 6 inches thick separated by 2- to 3-inch silty shale beds; sandstone is yellowish-brown (10YR4/4)-weathering; quartz = ±90%; dolomite matrix = ±10%; *Fucoid*-like markings on base of beds	6.7	26.6
Sandstone, dolomitic, yellowish-orange-brown (10YR4/6)-weathering, light olive-gray (5Y4/2); rounded and subrounded .7-mm quartz grains = ±80%; ±.06-mm dolomite rhombs of matrix = ±20%	0.5	19.9
Shale, noncalcareous, silty, dark-gray, thin-bedded	2.7	19.4
Sandstone, coarse-grained, rounded quartz grains and quartz pebbles up to .25-inch; whitish-weathering; thin (.05 inch) silty or argillaceous laminae	1.9	16.7
Sandstone and Shale, sandstone beds ±6 inches thick separated by 2- to 3-inch shale layers; sandstone weathers a light rusty color; quartz, fine- to medium-grained	2.0	14.8
Sandstone, coarse- and medium-grained, grayish-orange (10YR7/4)-weathering, whitish, rounded, clear and frosted quartz grains with rusty-appearing coating of silt-size quartz; cross-bedding prominent; shale interbeds 3 to 4 inches thick separate ±1-foot sandstone beds	3.2	12.8
Shale, noncalcareous, dark-gray, silty, highly fractured, thin-bedded	4.5	9.6
Top of Bridport		
Dolostone, silty, dark-gray (N3), gray-weathering, sublithographic as in .7-foot bed below	2.0	5.1
Shale, noncalcareous, dark-gray, silty	1.2	3.1
Dolostone, silty; sublithographic, .01- to .02-mm rhombs, dark-		

gray (N3); with films of silt-size quartz and a few .05- to .1-mm rounded quartz grains; dolomite = ±90%; quartz = ±10%	0.7	1.9
Dolostone, silty, sublithographic to very finely crystalline, medium light-gray (N6)-weathering, dark-gray (N3); quartz silt as films distributed irregularly through rock; dolomite = ±90%; quartz silt = ±10%	0.9	1.2
Shale, noncalcareous to slightly calcareous, black, silty	0.3	0.3
Dolostone, yellowish-gray (5Y8/1)-weathering medium-gray (N5), sublithographic to very finely crystalline at water level		0

SECTION 16—*Intersection 146 Southeast of Kellog Bay*

Section compiled (May, 1959) from exposures north of Intersection 146 approximately 1 mile S. 40° E. of the east shore of Kellog Bay, beginning at the base of the west-facing escarpment approximately 125 yards north of the gully and extending eastward to the last outcrops on the east side of the north-trending road and approximately 250 yards north of the intersection.

	Thickness—feet Unit	Cumulative to top of unit
Crown Point limestone		
Limestone, dolomitic and silty, very finely crystalline to sublithographic, dark bluish-gray, thick, massive beds	27.5	167.0
Limestone, fossil-fragmental, medium- and fine-grained, medium bluish-gray (5B5/1), thick-bedded; medium- to coarse-quartz grains abundant toward bottom; sublithographic and dolomitic toward top; exposed in low, west-facing escarpment approximately 50 yards west of the road north from Intersection 146	14.0	139.5
Cover, probably thick, massive beds of sublithographic limestone and fossil-fragmental limestone similar to overlying beds. Sandstone lens approximately 800 feet north lies about in the middle of this interval, although it does not extend south to the line of the section	45	125.5
Limestone, reefy, *Stromatolite*-bearing, similar to reefy material at gully to south, but overlies the horizon at the gully and the *Maclurites*- and *Stromatocerium*-bearing bed on the north side of the gully which is the same bed as that described immediately below	2	80.5
Limestone, fossil-fragmental, very fine-grained to medium-grained, medium bluish-gray (5B5/1); upper 2 feet approximately the same horizon as the *Maclurites*- and *Stromatocerium*-bearing bed near crest of west-facing escarpment on north side of gully	7	78.5
Top of Day Point—Contact between Day Point and Crown Point placed where the limestone beds become more massive and apparent dolomitic and silty-sandy materials disappear		

Limestone, dolomitic, silty, very light-gray (N8)-weathering, bluish-black (5B2/1); very finely crystalline to sublithographic with some fossil-bearing horizons and fossil-fragmental limestone horizons; fossil locality 460 near center of this interval	5.5	71.5
Limestone, dolomitic, silty and sandy; pale yellowish-orange (10YR8/6)- to gray-weathering, medium bluish-gray (5B5/1); very finely crystalline to sublithographic; in part coarse-grained, fossil-fragmental; thin-bedded (1 to 3 inches) but up to 1 foot beds also; fossil locality 459 from near top	11	66
Limestone, dolomitic and silty, nodular-weathering, in part fossil-fragmental, in part very finely crystalline to sublithographic; medium-gray-weathering, dark bluish-gray; distribution of silt gives rise to the thin-bedded and nodular-weathering characters	33	55
Limestone, dolomitic and silty; medium- and coarse-grained, fossil-fragmental limestones as well as sublithographic to very finely crystalline ones; medium-gray-weathering (N5), dark bluish-gray (5B3/1); 1- to 3-foot beds; brachiopod and trilobite fragments common; some horizons with as much as 30% .06-mm dolomite rhombs; thick, massive beds; fossil locality 461 is at top	22	22
Cover, at base of west-facing escarpment		0

SECTION 17—*Spaulding Bay Area*

Compiled from north end of ridge approximately 1 mile S. 50° E. of Mud Island, southwest of Panton. Section ends at road leading north to Panton.

	Thickness—feet	
	Unit	Cumulative to top of unit
Valcour formation—exposed thickness ±85 feet; additional 25 to 30 feet believed present but covered		
Dolostone, calcitic very finely crystalline to sublithographic, medium-gray (N5)	2.2	301.5
Dolostone, calcitic, medium bluish-gray (5B5/1) very finely crystalline to sublithographic	1.5	299.3
Limestone, dolomitic, sublithographic; very light-gray (N8)-weathering, medium light-gray (N6); dolomite in wisp-like masses of rhombs and as scattered ±.07-mm rhombs = 15%; and ±.01-mm calcite = 85%; grades upward into overlying bed	2.0	297.8
Dolostone, calcitic; very light-gray-weathering (N8), medium dark bluish-gray (5B5/1), very finely crystalline to sublithographic with bands of coarser fossil fragments; dolomite = ±60%; calcite, .005- to .01-mm = ±40%	0.3	295.8
Limestone, dolomitic, very light-gray (N8) to very light yellowish-gray (5Y9/1)-weathering, medium dark-gray (N4); very finely crystalline to sublithographic; varying percentages of		

.03-mm dolomite and .01-mm calcite; some of rock is calcitic dolostone	2.5	295.5
Cover	1.0	293
Limestone, dolomitic, silty; whitish-weathering, medium bluish-gray (5B5/1); sublithographic; *Maclurites* operculi; decrease in silt and dolomite towards top	3.0	292
Limestone, as above	6.0	289
Cover	12	283
Dolostone, silty, calcitic; very light-gray (N8)-weathering, medium-gray (N5), sparkling luster, very finely crystalline to sublithographic; quartz, angular, ±.06- to .08-mm, scattered through rock = ±10%; dolomite rhombs, ±.05-mm, = ±80%; calcite, ±.01 mm, = 10%	1	271
Cover	25	270
Limestone, fossil-fragmental and dolomitic, slightly silty; medium-gray (N5) to olive-gray (5Y5/1)-weathering, medium bluish-gray (5B5/1); sublithographic varieties more dolomitic and have a sparkling luster on fresh break; those beds composed dominantly of ±.5-mm, rounded fossil fragments in matrix of .01-mm calcite grains have dull luster; dolomite present in scattered rhombs and in very thin laminae; small amount of ±.06-mm angular quartz; faint cross-lamination	12	245
Crown Point limestone—approximate thickness 200 feet		
Cover. Contact between Crown Point limestone and Valcour formation lies within this interval, probably near the middle	±37	233
Limestone, silty, sublithographic, olive-gray (5Y5/1)-weathering, dark bluish-gray (5B3/1); silt as black films and laminae of quartz; bulk of rock composed of ±.01-mm calcite grains	11	196
Cover, probably limestone as above and below	±94	185
Limestone, fossil-fragmental, silty, dark bluish-gray (5B3/1); silty, buff dolomitic raised areas on weathered surface and black silt films; brachiopod fragments common	11	91
Cover, probably Limestone, fossil-fragmental of medium-grain size and sublithographic limestone with silty, dolomitic, black-weathering films	±50	80
Limestone, fossil-fragmental, silty and dolomitic; bluish-gray (5B6/1)-weathering, dark bluish-gray (5B4/1); sublithographic to very finely crystalline with medium- to coarse-grained, rounded fossil fragments; matrix = ±.01-mm calcite grains; proportions of matrix and fossil fragments varies; silt and dolomite content expressed as buff and reddish-buff, slightly raised areas on weathered surface	13	30
Day Point formation—approximate exposed thickness = 15 feet		
Cover. Contact between Crown Point and Day Point lies in this interval	3.4	17
Limestone, silty, partially fossil-fragmental, partially sublithographic; medium bluish-gray (5B5/1) to medium-gray (N5)-weathering, dark bluish-gray (5B3/1); silty and dolomitic		

material as films; varying proportions of ±.01-mm calcite grains and rounded ±.5-mm fossil fragments but with calcite grains dominant	3.0	13.6
Limestone, sandy, may be in part a calcareous sandstone; very finely crystalline with fine-grained quartz; has yellowish-brown silty and dolomitic films	0.5	10.6
Limestone, sandy and Sandstone, calcareous; very fine-grained to sublithographic with some rounded and frosted quartz grains up to .5 mm; light olive-gray (5Y7/1)-weathering, medium-gray (N5); thin-bedded, vertical surfaces weathering into 2-inch layers with crenulated or nodular appearance; bulk of calcite is ±.01-mm; some pellet-like structures composed of ±.01-mm calcite grains and with silt films on the surface of the aggregates	3.5	10.1
Sandstone, calcareous, light-gray to very light-gray (N7 to N8)-weathering, medium light-gray (N6); .25- to .75-mm, rounded, frosted quartz grains set in matrix of ±.01-mm calcite; calcite = ±30%; quartz = ±65%; dolomite, .06-mm, as scattered rhombs = ±5%; *Girvanella* sp. and fossil fragments common	0.3	6.6
Sandstone, dolomitic, very fine-grained, medium-gray (N5) to dusky-brown (5YR2/2) and very pale-orange (10YR8/2)-weathering; quartz, ±.7-mm, = 80%; dolomite rhombs, ±.06 mm, = 20%; silt concentrations about 6 inches apart and .1 inch thick give crenulated appearance to rocks; some fossil fragments, mostly pelmatozoan columnals	1.3	6.3
Limestone, fossil-fragmental, dolomitic; sublithographic texture with ±25% fossil fragments and ±30% .06-mm dolomite rhombs; .01-inch brownish films of silty material	1.0	5.0
Limestone, dolomitic, sandy, and fossil-fragmental; very finely crystalline to sublithographic; ±30% subrounded and rounded, frosted, .15- to .75-mm quartz grains; dolomitic rhombs up to 30%, but concentrated in .25 to .5 inch thick irregular zones appearing as raised ridges on vertical weathered surfaces; fossil fragments less than 25% of rock; ±.01-mm calcite grains form bulk of rock; grayish-orange (10YR7/4) to pale yellowish-orange (10YR8/6)-weathering, medium-gray (N5); black pebbles .15 to .25 inch in diameter show a roughly concentric structure with layers or bands of .01-mm calcite and silt-size quartz; some of pebbles with quartz grains as a core, others with calcite grains which are slightly coarser and lighter colored than rim grains as core	2.5	4.0
Dolostone, calcitic, silty, and Limestone, dolomitic, silty, medium bluish-gray (5B5/1) and grayish-yellow (5Y7/4)-weathering, medium bluish-gray (5B5/1) to medium dark-gray (N4) and moderate yellowish-brown (10YR6/4), sparkling luster; dolomite, ±.07-mm rhombs, = 40–60%; calcite, +.01-mm grains, = 25–50%; quartz, angular, ±.06-mm grains and in silt films between dolomite rhombs, = 15%; also		

a few rounded quartz grains; a few fossil fragments scattered through rock	1.5	1.5
Cover—section starts in small pit at extreme north end of ridge		0

Section 18—*Thorp Brook*

Compiled across north end of ridge approximately 4200 feet N. 65° E. of Dean Island, beginning at base of west slope approximately 20 yards south of the north end of western prong of ridge. Section ends at north end of ridge on dip slope.

	Thickness—feet Unit	Cumulative to top of unit
Crown Point limestone—145 feet exposed; a quarter of a mile south of this section 220 feet of the Crown Point is exposed.		
Limestone, sublithographic, composed primarily of .005- to .01-mm calcite grains with some fossil fragments; bluish-gray (5B6/1), light bluish-gray (5B8/1)-weathering; massive beds, ±2 feet	4.5	164.4
Cover	4.7	159.9
Limestone, sublithographic, bluish-gray-weathering and darker bluish-gray on fresh surface; beds 1 to 3 feet thick	9.8	155.2
Cover	2.3	145.4
Limestone, sublithographic, primarily composed of ±.01-mm calcite grains; light bluish-gray weathering, bluish-gray (5B6/1); conchoidal, chert-like fracture; darker ovoid masses of ±.01-mm calcite; lesser amount of black silty laminae than seen lower in section	13	143.1
Limestone, sublithographic .005- to .01-mm calcite; small percentage of rounded fossil fragments; laminae and splotches of reddish-tinted silt and dolomite as well as hair-like dolomite-silt laminae; weathers very light bluish-gray (5B7/1); outline of fossils on weathered surface; *Maclurites* operculi common	4.7	130.1
Limestone, dolomitic; sublithographic to very finely crystalline, dark bluish-gray (5B4/1)-weathering, light bluish-gray (5B7/1) with a luster between vitreous and dull; drab-colored, raised .1-inch reticulating ridges occurring about every .5 to 1 inch where seen on a weathered vertical face; average composition: ±.1-mm calcite grains = ±65%; ±.06-mm dolomite rhombs scattered through rock and concentrated in thin laminae which are represented by raised ridges = ±35%	16.1	125.4
Cover	1.0	109.3
Dolostone, silty and calcitic, dark bluish-gray (5B3/1) to medium dark-gray (N4); reddish tint to drab-weathering surface; massive beds 2 to 3 feet thick; approximate composition: ±.06-mm dolomite rhombs = ±60%; silt-size angular quartz = ±30%; ±.01-mm calcite = ±10%; rock is even-grained and dense-appearing	4.8	108.3

Cover, across small valley separating the two northerly prongs of the ridge	39.7	103.5
Limestone, sublithographic, dark-gray to bluish-black; large percentage of black, silty reticulating laminae	4.0	63.8
Cover	4.7	59.8
Limestone, dolomitic, sublithographic, dark-gray to bluish-black, conchoidal, chert-like fracture and vitreous to dull luster	5.5	55.1
Cover	4.5	49.6
Limestone, sublithographic and fossil-fragmental; very light bluish-gray (5B8/1)-weathering, light bluish-gray to dark-gray; silty and dolomitic laminae and splotches with silty and dolomitic material filling some fossil fragments; dolomite, ±.06-mm; *Maclurites* and *Girvanella;* abundant black silty laminae; beds vary from 4 inches to 3 feet in thickness with 6 inches being the average thickness. Top of interval is at crest of east prong of ridge	5.5	45.1
Cover	3.0	39.6
Limestone, sublithographic, dark bluish-gray (5B3/1) with speckles of white or "salted" appearance on fresh surface; pebbles of lithographic limestone	1.5	36.6
Cover	2.5	35.1
Limestone, sublithographic, light bluish-gray (5B6/1); generally like 9.8-foot interval below	1.5	32.6
Cover	1.0	31.1
Limestone, sublithographic and fossil-fragmental, light bluish-gray (5B6/1) to yellowish-gray (5Y8/1)-weathering, bluish-gray on fresh surface; dull luster; yellowish-brown or rusty-appearing horizons which stand out as thin ridges; varying proportions of ±.01-mm calcite and rounded fossil fragments which are as large as .75 mm; fossil fragments = ±55%, .01-mm calcite = ±40%; dolomitic silty laminae = ±5%; thick, massive bedding	9.8	30.1
Limestone, sublithographic, dull luster; grayish-black to dark bluish-gray (N2 to 5B3/1); yellowish-brown-weathering zones replace reddish ones of the lower horizons	1.3	20.3
Top of Day Point		
Limestone, sublithographic, fossil-fragmental and oölitic; dull luster, grayish-black (N2) to dark-gray, weathers yellowish-gray (5Y8/1) to very light bluish-gray (5B8/1) with some reddish tints; fine 1-mm wavy raised lines on weathered surfaces; several bands in which oölites composed of ±.01-mm calcite grains and .25 to .5 inch in diameter comprise 25 to 30% of rock; other layers with .75-mm oölites, oölitic or ovoidal masses frequently have rims of yellowish-stained material; oölites with from 1 to 2 bands to as many as 4; fossil fragments = ±40%; many with yellowish and reddish silty rims; matrix of ±.01-mm calcite = ±60%; oölites and splotches of yellowish-orange dolomite and silt comprise minor		

amounts of limestone, except as noted; thick, massive bedding, but laterally becomes thin-bedded	3.3	19.0
Limestone, silty, sublithographic and fossil-fragmental, massive beds; grayish-black to dark-gray (N2 to N3) with reddish tints on grayish weathered surface	5.0	15.7
Cover, probably similar to underlying and overlying beds	2.7	10.7
Limestone, sublithographic and fossil-fragmental; gray-weathering, grayish-black to dark-gray (N2 to N3); weathered surface has many reddish zones which are ±.01-mm quartz and a little dolomite and which stand up on a weathered surface; typical composition: rounded fossil fragments averaging ±.2 mm diameter but up to .75 mm = ±30%; ±.01-mm calcite grains = ±60%; reddish laminae and stringers of silt-size quartz with a little dolomite = ±10%	2.5	8.0
Cover, probably underlain by material similar to that above and some limestone with black silty partings; also probably contains a noncalcareous shale bed approximately 4 feet thick, for one outcrops to the south about 50 to 100 yards; fossil locality 134 comes from middle of this interval	5.5	5.5
Base of west-facing escarpment		0

SECTION 19—*Kimball Brook*

Measured near center of west face of small ridge immediately south of Kimball Brook and approximately .4 mile east of Dean Island.

	Thickness—feet Unit	Cumulative to top of unit
Cover		
Crown Point limestone		
Limestone, light-gray-weathering, medium bluish-gray, dull-lustered; abundant black silty partings; fossil-fragmental to sublithographic; some is dolomitic	42.3	216.1
Limestone, as above; *Maclurites* common and slightly less shale than lower in the section; the limestones are a little more smooth-weathering, reflecting a decrease in the proportion of fossil fragments	10.5	173.8
Cover	64	163.3
Limestone, as above, exposed on a dip slope.	4.5	99.3
Limestone, as above, exposed on a dip slope.	8	94.8
Limestone, in part fossil-fragmental, and in part sublithographic; sand scattered through beds; light-gray-weathering, medium to medium-dark-bluish-gray (5B5/1 to 5B4/1) with "salted" appearance; thin-bedded with irregular, looped or "chained" black silty partings more prominent in the lower part of sequence and becoming less prominent in the upper part of the section	51.5	86.8
Top of Day Point—Total thickness Day Point = 35.3 feet		
Cover. Fossil localities 146, 147 located in fossil-fragmental lime-		

	Unit	Cumulative
stones of lower part of this interval but exposed south of line of section and north of locality 148	6.5	35.3
Limestone, medium-grained fossil-fragmental, medium-gray with some reddish spots; oölitic in part. Generally thin-bedded with 1- to 2-inch beds grouped within an overall more massive bed; fossil locality 148 from this horizon or top of covered interval below, but near south end of ridge	1.5	28.8
Cover	3.3	27.3
Limestone, medium-grained fossil-fragmental, very light-gray- to medium-gray-weathering, weathered surface rough with quartz grains standing out; medium to dark bluish-gray (5B3/1); stringers of quartz silt and dolomite rhombs	4.0	24.0
Limestone, dark bluish-gray, sublithographic and medium-grained fossil-fragmental	13.5	20.0
Limestone, dark bluish-gray, very finely crystalline to sublithographic; arenaceous and dolomitic in part	6.5	6.5
Top of Bridport dolostone		0

SECTION 20—*North of Panton Village*

Approximately 1.35 miles N. 5° E. of Panton Village (Intersection 192). Base of section lies at foot of west-facing escarpment and line of section runs eastward.

	Thickness—feet Unit	Cumulative to top of unit
Orwell limestone		
Limestone, black, lithographic, conchoidal fracturing, dull luster; dolomitized outlines of fossils; massively bedded and beginning of well defined scoring on weathered surfaces	2.5	89.4
Top of Valcour formation—thickness of Valcour = 64 feet		
Limestone, dark bluish-gray, lithographic and sublithographic; a few dolomitic and silty films irregularly distributed; slightly sparkling luster	3.2	86.9
Limestone, dark-gray (N3 to N4), very finely crystalline to sublithographic in appearance; interval probably contains some fossil-fragmental limestones	1.6	83.7
Cover, dip slope lies to the west of this interval	1.9	82.1
Limestone, fossil-fragmental, coarse-grained, medium light-gray (N6)-weathering, dark bluish-gray (5B6/1); sparkling luster; thin laminae of dolomitic and silty material shown by wavy or rippled lines on weathered surface; some of limestones contain .25-inch, rounded sublithographic limestone pebbles; by increase of the matrix material and lessening of the shell fragments the limestones grade into sublithographic limestones with varying amounts of shell detritus; beds average 3 feet thick	11.3	80.2
Cover, followed to east by dip slope	18.9	68.9
Limestone, light medium-gray, fossil-fragmental with vitreous		

luster; thin films of silt distributed irregularly through the limestone; 1- to 2-foot beds	5.0	50.0
Limestone, sublithographic and very finely crystalline with small proportion of fossil fragments; light-gray-weathering (N7), medium light-gray with a sparkling luster; subspherical masses of .01-mm calcite set in a matrix of .01-mm calcite grains; a few brachiopod and trilobite fragments; occasional styolitic seam of quartz silt. *Maclurites* outlines abundant on weathered bedding surfaces	5.7	45.0
Limestone, sublithographic to very finely crystalline; abundant subspherical masses of .01-mm calcite set in .01-mm matrix; a few fossil fragments and traces of styolitic silty seams . .	11.5	39.3
Limestone, very finely crystalline to medium crystalline and fossil-fragmental; silty in part; light-gray with vitreous luster	4.8	27.8
Top of Crown Point		
Limestone, sublithographic, slightly silty and dolomitic, small percentage of .1-mm angular, clear quartz grains; a few fossil fragments; light-gray-weathering, dark bluish-gray (5B3/1); faintly nodular-weathering and with more or less a dull luster	11.5	23.0
Limestone, sublithographic with dolomitic and silty stringers or laminae; dark bluish-gray (5B3/1)-weathering light to medium bluish-gray (5B7/1). Dolomite occurs not only in thin laminae but in .2- to .5-mm subspherical areas intermixed with quartz silt, the silt being more abundant	11.5	11.5
Base of west-facing escarpment		0

SECTION 21—*Intersection 151 West Ferrisburg*

Section compiled (October, 1957) from small knoll on east side of north-trending road, approximately .75 mile southeast of Kellog Bay and .25 mile south of Intersection 151, east of Fort Cassin. Section begins at base of knob on its west side and extends eastward down the dip slope. This is area of reefy Valcour, in upper part of Section 24, Ferrisburg, of Oxley and Kay (1959).

	Thickness—feet Unit	Cumulative to top of unit
Valcour formation		
Limestone, dolomitic; grayish-orange (10YR6/4)-weathering, medium-gray (N5) with a sparkling luster; very finely crystalline; dolomite, ±.03-mm grains; calcite as .01- to .05-mm grains mixed with the dolomite and as fossil fragments; some of the material is calcitic dolostone and fossil fragments are less abundant in this lithology. The mixture of limestone and dolostone continues to the base of the hill in a more or less uniform dip slope; it is possible that another 5-foot thickness may be represented in exposures a few yards north of the line of this section; fossil locality 463 is at the top of this interval	2	21.7
Limestone, sublithographic and in part with fine-grained fossil fragments; dolomitic with dolomite grains occurring as .03-mm		

grains mixed with calcite grains in small clusters of irregular shape; light bluish-gray (5B7/1)-weathering with subconchoidal fracture; more dolomitic toward the base of the interval; local pods of dolostone; fossil locality 363 from upper part of this interval	4.0	19.7
Limestone, dolomitic, sublithographic; mottled in medium-gray (N5) and yellowish-gray (5Y7/1); 30 to 40% .03-mm dolomite crystals	2.3	15.7
Limestone, coarse-grained, fossil-fragmental with approximately 10% .06-mm dolomite grains in clusters up to 2 mm in diameter; small amount of silt mixed with the dolomite clusters; this and 5-foot interval below = "reef zone" of Oxley and Kay (1959)	2.0	13.4
Limestone, dolomitic, coarse-grained, fossil-fragmental and sublithographic, with some calcitic fossil fragment-bearing dolostone; light-gray to medium-gray; beds approximately 2 feet thick; several large *orthoceraconic* nautiloids; channels filled with shell debris; irregular distribution of the several lithologies	5.0	11.4
Cover, probably very finely crystalline calcitic dolostone	0.9	6.4
Dolostone, calcitic and fossil fragment-bearing; dolomite grains .03- to .04-mm; calcite, .01- to .02-mm grains mixed with the dolomite and as ±.75-mm shell debris; yellowish-gray (5Y6/1)-weathering, medium-gray (N5)	0.8	5.5
Limestone, dolomitic; finely crystalline to sublithographic; medium-gray	0.7	4.7
Limestone, dolomitic, very coarse- to medium-grained, fossil-fragmental; light- to medium-gray, yellowish-gray (5Y8/1)-weathering; distribution pattern of dolomite in the beds gives rise to slight nodularity after weathering; 15% dolomite in clusters; 70% fossil fragments; 15% ±1-mm crystals of calcite	4.0	4.0
Cover, and base of knoll, contact between the Valcour and the Crown Point is placed in the cover near base of the knoll		0

SECTION 22—*East of Porter Bay*

Section measured (August, 1957) across low ridge and small hillock approximately .75 mile east of the north shore of Porter Bay and .5 mile north of Porterboro School, Ferrisburg. Section begins at the base of the low west-facing bluff on the west side of the road south from Kingsland Bay, extending eastward to east edge of small knoll.

	Thickness—feet Unit	Cumulative to top of unit
Valcour formation—Exposed thickness = 24 feet; an additional 5 to 10 feet may be covered		
Limestone and Dolostone, mixture of these two lithologies; the		

limestone is medium-gray, sublithographic; the dolostone is calcitic, sublithographic to very finely crystalline (.03- to .06-mm rhombs); grayish-orange (10YR7/4)-weathering, dark medium-gray (N4). The two lithologies are intimately mixed, each forming pods up to 3 feet across within the lithology of the other type; the bedding surfaces cut across both lithologies and the pods cut across bedding planes also. Approximately 30% of the dolostone is composed of ±.03-mm calcite. Interval also contains some conglomeratic limestone like that described in 2-foot bed below	4.0	65.8
Limestone and Dolostone, as above but with the dolostone forming pods within the more prevalent light-gray-weathering limestone	1.0	61.8
Limestone, pebbly, fossil-fragmental; light-gray- to whitish-weathering, light-gray (N7); 5-mm pebbles of sublithographic and lithographic limestone stand up on the weathered surface and comprise approximately 10% of the rock. Bulk of rock is ±.75-mm rounded fossil fragments.	2.0	60.8
Limestone, fossil-fragmental; very coarse-grained; dark-gray-weathering, light-gray (N7)	1.5	58.8
Limestone, sublithographic, light-gray-weathering medium-gray (N5)	0.3	57.3
Cover	1.8	57.0
Limestone, sublithographic but grading laterally into coarse-grained fossil-fragmental limestones with pinkish pebbles; light-gray (N7)-weathering, medium-gray (N5) with conchoidal fracture	1.6	55.2
Limestone, sublithographic to lithographic, light-gray-weathering, black to medium-gray; with pockets of yellowish-brown (10YR6/4)-weathering very finely crystalline dolostone. Some darker subspherical masses of .01-mm calcite surrounded by lighter colored .01-mm calcite	0.8	53.6
Limestone, sublithographic with small amount of silty material; light-gray-weathering, medium-gray	1.0	52.8
Dolostone, very finely crystalline, calcitic; moderate percentage of fossil fragments cemented by .01-mm calcite; a few pebbles of sublithographic limestone	1.5	51.8
Dolostone, calcitic, very finely crystalline and sublithographic.	1.5	50.3
Limestone, lithographic with an occasional quartz grain; traces of dolomite, and fossil fragments; on weathered surface irregular patches of brownish-weathering material shows irregular distribution of dolomite; weathered surfaces of limestone areas are light-blue; fresh surfaces are dark-gray . . .	1.0	48.8
Limestone, lithographic; light bluish-gray-weathering, medium to dark bluish-gray (5B5/1); irregularly distributed masses of dolomite crystals; one bed	3.0	47.8
Limestone, very finely crystalline to sublithographic; dolomitic; bands of fossil fragments and .5-mm rounded masses of .01-mm		

calcite alternate with bands of .06-mm dolomite (40 to 60%) with similar-sized calcite grains intermixed; medium bluish-gray (5B5/1) with olive-brown (5Y6/6) bands or lenses which represent the dolomite; crenulated upper surface and its relation with the overlying bed shows the gradational nature of the contact between the two beds	1.3	44.8
Limestone, coarse-grained, fossil-fragmental; small amount of .01-mm calcite between fragments and small amount of quartz silt in form of films distributed irregularly through the rock; passes gradationally into overlying rock	2.0	43.5
Top of Crown Point—Exposed thickness = 41.5 feet		
Cover, contact between Valcour and Crown Point placed near base of knoll east of road; cover begins at west edge of road .	10.7	41.5
Limestone, dolomitic and sandy, and in part fossil-fragmental with significant amounts of dolomite; medium light-gray (N6)-weathering, medium-gray (N5); .01-mm calcite forms important parts of many of the rocks while fossil fragments replace the finer material in other horizons within the interval. On bedding surfaces exposed in dip slope to road, outlines of *Maclurites*, *Stromatocerium*, and straight cephalopods may be seen	4.0	30.8
Limestone, dolomitic, sandy; layers of coarse fossil fragments alternate with bands of finer grained material; medium dark-gray (N4)	0.5	26.8
Limestone, sandy, dolomitic, sublithographic; .5- to .75-mm quartz grains distributed throughout	0.8	26.3
Sandstone, medium-grained; clear, rounded quartz well-cemented by calcite; grades laterally and vertically into sandy sublithographic dolomitic limestones with ±.06-mm dolomite rhombs	1.3	25.5
Sandstone, calcareous, coarse- to very coarse-grained with some subrounded to rounded, clear quartz grains; small amount of calcareous cement; well-cemented; weathers whitish	0.8	24.2
Limestone, dolomitic, sublithographic, sandy with important amounts of quartz appearing near the center of the interval; near bottom of interval the sublithographic limestones contain moderate amounts of .1-mm subspherical masses of .01-mm calcite; dark bluish-gray (5B3/1), weathers light-gray .	6.9	23.4
Limestone, sublithographic; thin laminae of silt-size quartz and dolomite rhombs distributed irregularly through rock; generally composed of .01-mm calcite in a mosaic pattern, but a few .1-mm subspherical masses of .01-mm calcite are present also; small amounts of fossil fragments at various horizons; medium bluish-gray, medium to light bluish-gray (N6)-weathering; beds approximately 1 foot thick	16.5	16.5
Base of west-facing escarpment		0

APPENDIX II

FOSSIL LOCALITY DESCRIPTIONS AND FAUNAL LISTS

FOSSIL LOCALITY DESCRIPTIONS

Locality No.	
28	South shore McNeil Cove, approximately S. 30° W. of Essex Ferry landing
51	Outcrop 6500 feet N. 67° E. of Cedar Island, east of road
52	Southeast corner McNeil Cove, at crest of small anticline, S. 13° E. of Essex Ferry landing
53	South shore McNeil Cove, approximately S. 10° W. of Essex Ferry landing
54	5600 feet N. 72° E. of Cedar Island, west of road and near crest of east slope
62	South side Wings Point, Charlotte, in massive limestone behind concrete pier
64	Northwest corner small hill approximately 1.25 miles west of Charlotte and south of Wings Point road
65	West face small hill of locality 64, 5 to 10 feet above cover
66	East edge hill of locality 64, just above cover
76	West edge Thorp Point, Town Farm Bay, 5750 feet S. 53° E. of Cedar Island; approximately 5 feet south of bostonite dike; 5 feet above September water level
77	15 feet south of locality 76 and 3 feet higher stratigraphically; in a conglomerate horizon
80	N. 17° W. of barn at end of Thorp Point, at the south end of outcrop near east-west fence line at elevation of approximately 130 feet
81	Elevation 130 feet, near brow of hill, S. 88° W. of house on map, and east of small point on west side Thorp Point
82	S. 75° W. of house on map, near water level, west side Thorp Point
83	S. 60° W. of barn, 6 feet below old road bed, approximately S. 65° W. of house on map, Thorp Point
84	Small open field approximately 500 feet S. 61° W. of house at intersection 6100 feet S. 80° E. of Cedar Island (Emerson School Intersection)
88	S. 62° W. 500 feet from house at Emerson School Intersection, Thorp Point
89	Approximately 900 feet S. 55° W. from house at Emerson School Intersection; at east edge of first flattening of topography and just above last outcrop of sandy limestone with raised ridges
134	Approximately 4200 feet N. 33° E. of Addison-Chittenden County line-coast intersection, immediately above shale near base of small escarpment, Charlotte
138	Approximately 950 feet S. 19° W. of intersection 1 mile north of Emerson School Intersection and 1.5 miles east of Cedar Beach, and 200 feet N. 80° W. of first house (abandoned) south of the intersection; west face low ledge, Charlotte

139 Small hump almost 150 feet west of barn north of second house south of intersection north of Emerson School Intersection (see locality 138)

141 10 yards west of locality 139

143 Elevation 140, west side ridge 4050 feet N. 32° E. of intersection of Addison-Chittenden County line with coast, Charlotte

146 Approximately 1250 feet N. 18° E. of Addison-Chittenden County line intersection with coast, about a third of the way from bottom of west face ridge, and 20 yards from south end of ridge

148 15 yards north of old fence, approximately 1300 feet N. 18° E. of Addison-Chittenden County line intersection with coast, halfway up escarpment

152 Water level, coast, approximately 1250 feet north of Addison-Chittenden County line intersection with coast

153 West side small point, approximately 750 feet north of Addison-Chittenden County line intersection with coast, in blue 9-inch limestone bed

156 Coast, approximately 400 feet north of Addison-Chittenden County line intersection with it

157 Coast, 200 feet north of Addison-Chittenden County line; 4 feet above July water level

158 Coast line approximately S. 50° E. of island west of Dean Island; a few yards north of Addison-Chittenden County line

159 Coast line, approximately 40 yards north of locality 158

182 Approximately 1.3 miles N. 82° E. of triangulation point, Mt. Philo, in tributary to Lewis Creek

191 Approximately 1.1 miles N. 70° E. of bridge, North Ferrisburg, 150 yards south of house, east side small knoll

197 Approximately .62 mile east of Ferrisburg and south of road 50 yards in massive limestone

220 Approximately 4000 feet S. 80° E. of Triangulation Point 131 east of Grosse Point, Ferrisburg, in field

229 Northeast side small cove approximately 700 feet south of Grosse Point

232 *Calaurops* bed, 700 feet south of north end of Fort Cassin headland

233 Approximately 900 feet west of Triangulation Point 131 east of Grosse Point

234 Coast, approximately 3900 feet S. 72° W. of Triangulation Point 131 east of Grosse Point

235 Same as locality 229

239 Approximately 4900 feet S. 14° W. of Triangulation Point 131 east of Grosse Point at north end of small knoll

242 Approximately 4000 feet S. 73° E. of tip of Bluff Point on coast of south side of Hawkins Bay, 20 yards west of bostonite dike; ±5 feet above September water level

243 Northeast corner hill approximately 4550 feet S. 80° E. of tip of Bluff Point; slightly west of where Crown Point-Day Point contact goes beneath cover on south side Hawkins Bay; upper third of Day Point

247 Halfway down small gully west of Intersection 146 approximately a mile southeast of Kellog Bay

248 10 yards south of gully of locality 247 at about elevation 160; in massive lithographic limestone

250 Approximately 3450 feet N. 26° E. of Intersection 146 southeast of Kellog Bay, in low ledge 30 yards east of road

252 West edge ridge 5600 feet N. 19° E. of Intersection 146 southeast of Kellog Bay; red barn 75 yards to southeast

253 Approximately 5050 feet S. 2° E. of Ferrisburg railroad trestle; easternmost outcrop in low knolls

261 City of Vergennes, shale outcrop in roadcut 200 feet southeast of tributary to Otter Creek, north side Otter Creek and north of falls

277 Approximately .9 mile N. 47° W. of Buck Mt. on small hill

280 Approximately .82 mile N. 54° W. of Buck Mt. in creek at elevation of approximately 270 feet

290A Elevation 650, approximately 880 feet S. 55° W. of Buck Mt.

293 Approximately 1300 feet S. 52° W. of Buck Mt. at elevation of approximately 420 feet

303 Elevation 180 approximately 2100 feet S. 40° W. of Summer Point

305 About elevation 190, approximately 400 feet N. 58° W. of Basin Harbor School

306 Base of ridge approximately 850 feet north of Basin Harbor School

309 Small creek, approximately 6600 feet S. 78° E. of Button Island

310 East coast of Button Bay, S. 55° E. of Button Island

312 Small point on north side of Basin Harbor

313 Approximately 2300 feet S. 29° W. of Webster School north of Panton, elevation 180

316 Coast S. 23° E. of Button Island, on shore

317 Coast S. 20° E. of Button Island, on shore

318 Shore approximately 1200 feet north of Ferrisburg-Panton town line and approximately S. 18° E. of Button Island; Larrabee member Glens Falls

320 Same as locality 318 but from slightly lower beds; approximately 10 yards north of stairs to shore

322 Approximately 1050 feet south of Ferrisburg-Panton town line at coast; S. 12° E. of Button Island

324 Approximately 3650 feet southwest of Summer Point on coast, in 2.1-foot unit of cumulative thickness of 46.9 feet in Section 15, Summer Point section

327 Approximately 5000 feet N. 12° E. of Panton Village, elevation 320

329 Elevation 175, approximately 5200 feet S. 75° W. of Panton Village

334 Elevation 225, approximately 3100 feet S. 30° W. of West Panton School

335 Triangulation Point approximately 2000 feet southwesterly of Potash Point, Panton

337 Potash Bay shore, 800 feet north of Potash School

339 Elevation 200, approximately 3000 feet N. 7° E. of Panton Village, approximately 20 yards from northwesterly road

341 200 yards south of Thompson Point road, west crest of ridge, S. 34° W. of house at Emerson School Intersection

342 Shore, approximately 400 feet north of north shore Owls Head Bay

343 Shore, approximately 850 feet north of cabins on north side Owls Head Bay

344 Shore, approximately 150 feet north of locality 343

346 Shore, 1800 feet north of cabins on north side Owls Head Bay

347 Massive limestone near center of Owls Head Bay
348 Shore, approximately 3500 feet N. 34° E. of Crane Point triangulation point
350 Approximately 750 feet S. 60° W. of house at Emerson School Intersection, Thompson Point area; at west edge ridge
351 Approximately 650 feet S. 42° W. of house at Emerson School Intersection, near fence and in middle of east slope
352 Small knoll few feet south of fence, approximately 800 feet S. 40° W. of house at Emerson School Intersection
353 Near elevation 385, approximately 1950 feet S. 35° W. of house at Emerson School Intersection
354 Approximately 100 yards southwest of locality 353
356 Point 2350 feet south of Crane Point, south of mouth of Hospital Creek
362A Hill, 2700 feet S. 32° E. of Triangulation Point 131 east of Grosse Point
363 East slope hill, approximately 1800 feet N. 27° E. of Intersection 146 southeast of Kellog Bay
364 10 feet down bluff, N. 25° W. of house, Bluff Point
365 N. 70° E. of house at Grosse Point, about halfway down from top of bluff
366 Same as locality 365 but 3 feet above shale bed at July 1958 water level
367 Same as locality 365 but 10 feet above water line and several feet above locality 365
368 Approximately 1500 feet S. 68° W. of Triangulation Point 131 east of Grosse Point in highly fossiliferous horizon northwest of abandoned house
369 Elevation 135, approximately 1300 feet S. 58° W. of Triangulation Point 131 east of Grosse Point, at base of bluff
380 Elevation 180, approximately 4700 feet S. 50° E. of Mud Island, Panton; near center of west-facing escarpment
381 About 5 feet stratigraphically above Crown Point-Day Point contact and 20 yards south of locality 380, elevation 190 approximately
400 Approximately 2600 feet S. 40° W. of Webster School, Panton
419 Approximately .9 mile N. 47° W. of Buck Mt. on small hill
420 Southwest corner Gardiner Island
422 West side Button Island
424 Shore approximately .67 mile south of north shore of Owls Head Bay
425 Near center of Owls Head Bay
427 North shore McNeil Cove, Charlotte, west of ferry landing
455 Hill approximately 5900 feet S. 21° E. of East Panton School
458 South side of gully, stromatolite-bearing horizon near top, west of Intersection 146 southeast of Kellog Bay
459 Approximately 100 yards north of gully at Intersection 146, in 11-foot interval at cumulative thickness of 66 feet, Section 16
460 Same as locality 459 but at 5.5-foot interval at cumulative thickness of 71.5 feet, Section 16
461 Same as locality 459, 22 feet above base of Section 16
462 Approximately at elevation 140, 1550 feet N. 5° W. of Intersection 146 southeast of Kellog Bay

463 Near base of east slope of hill approximately 1800 feet N. 27° E. of Intersection 146 southeast of Kellog Bay

464 Approximately 3900 feet north of Intersection 146 southeast of Kellog Bay, and 20 yards east of road; approximately 400 feet north of locality 250

467 Crest of small ridge near south end of outcrop, approximately 4250 feet N. 86° E. of Nortontown School, Addison; approximately .25 mile west of East Branch Dead Creek

468 Approximately 10 yards north of locality 467

469 Approximately 500 feet north of locality 467, near north end of outcrop

476 Approximately at elevation 190, 3400 feet S. 46° W. of Webster School, Panton; at top of steep, approximately vertical slope and about halfway to crest of ridge

477 West side small closed 220-foot contour approximately 3500 feet S. 44° W. of Webster School, Panton

478 Elevation 150 approximately, east side knoll 3650 feet S. 32° E. of Summer Point

479 Same as locality 478 but at elevation 140 approximately 20 to 30 yards to the east

479A Summer Point measured section (Section 15), 2.5-foot interval at cumulative thickness of 78 feet

480 Crest of hill located approximately 4500 feet slightly west of south of Summer Point

483 Stream, approximately 3400 feet N. 58° E. of West Bridport

484 Southernmost exposure of Glens Falls approximately 650 feet north of the mouth of Hospital Creek, Crane Point area, Addison

491 Approximately 2600 feet S. 30° W. of West Panton School, between elevations 210–230 feet

505 Jones Dock, small point approximately S. 10° W. of Plumies Point, Bridport

WHITEHALL DOLOSTONE

Locality No.[1]	467	468	469
Finkelnburgia sp. cf. *F. armanda* (Billings)	R		
Finkelnburgia ? sp.	R		
Syntrophia ? sp.; resembles *S. gibbosa* Ulrich and Cooper	R		
Maclurites sp.		R	R
Maclurites operculi		R	
Ozarkina ? sp.	R		
Clarkoceras ? sp.	R		
Cyrtoceraconic cephalopod	R		
Trilobite fragments	F		
Ostracoda sp.	R		

[1] Abundance data are indicated by the following symbols:

A abundant
C common
F few
R rare
P present

CASSIN FORMATION

Locality Number	76	77	80	81	82	83	84	88	89	232	341	350	351	352	353	354	455
Diparelasma cassinense (Whitfield)																	F
Diparelasma minimum (Whitfield)												F			F		
Finkelnburgia ? macloedi (Whitfield)	F		F	F		F		F									F
Finkelnburgia parva Ulrich and Cooper																	C
Finkelnburgia sp.								R				R					
Finkelnburgia ? sp.	R																
Polytoechia apicalis (Whitfield)	F		F	R											F		
Pomatotrema ? evadne (Billings)			F														
Syntrophia lateralis (Whitfield)				F				C						R	C		R
Syntrophia sp.																	R
Syntrophinella ? radiata (Whitfield)						R											
Bellerophon sp.									R								
Calaurops lituiformis Whitfield				F						C		R					
Ecculiomphalus compressus Whitfield												R					
Ecculiomphalus perkinsi (Whitfield)								R									
Ecculiomphalus priscus (Whitfield)				C													
Ecculiomphalus sp. cf. *E. volutatus* Whitfield												R					
Ecculiomphalus sp.												P					
Ecculiomphalus ? sp.	R																
Eotomaria ? cassina (Whitfield)																R	
Etrochus ? cf. *E. ? beekmanensis* (Whitfield)								R									
Etrochus ? sp.								R									
Euomphalus circumliratus Whitfield				R													
Hormotoma sp. cf. *H. calcifera* (Billings)				R													
Hormotoma confusa (Whitfield)								R							R		
Hormotoma obelisca (Whitfield)				R				R									R

CASSIN FORMATION—*Continued*

Locality Number	76	77	80	81	82	83	84	88	89	232	341	350	351	352	353	354	455
Hormotoma ? cassina (Whitfield)																R	
Hormotoma ? prava (Whitfield)																	R
Liospira praevia (Whitfield)		R		R													
Liospira ? sp.													P				P
Lophospira cassina Whitfield															R		R
Lytospira sp.											P						
Maclurites acuminata Whitfield								R								R	
Maclurites affinis (Billings)								R									
Maclurites sordida Hall								C									
Maclurites sp.														P			R
Maclurites ? sp.	R			R													
Owenella ? sp.	R																
Plethospira arenaria (Billings)																	F
Plethospira sp. cf *P. arenaria* (Billings)								R									
Plethospira cassina (Whitfield)																	R
Raphistoma compressum Whitfield								R					R		R		R
Raphistoma sp..				R		R											
Straparollina minima Whitfield								R									
Cambelloceras sp. cf. *C. rotundum* (Hyatt)																	R
Cassinoceras explanator (Whitfield)								R									
Centrotarphyceras seelyi (Whitfield)				R		R		R								R	R
Centrotarphyceras sp.												R					R
Curtoceras sp.						R											
Curtoceras ? sp.				R													R
Cyclostomiceras cassinense (Whitfield)				R												R	
Cyptendoceras ? sp.																	R

Endoceras ? champlainensis Ruedemann								R									
Eurystomites kellogi (Whitfield)						F		F			F						
Orthoceracone				P													
Proterocameroceras brainerdi (Whitfield)								P									
Rudolfoceras cornu-oryx (Whitfield)						P	P	R						R	R		R
Tarphyceras perkinsi (Whitfield)			P			P		F									
Boblocephalus seelyi (Whitfield)				R				R				R					
Boblocephalus sp.								R						R			
Goniotelina ? caudatus (Billings)				R													
Hystricurus conicus (Billings)								R									
Isoteloides whitfieldi (Raymond)	R	R		F	C	C			F				R				R
Isoteloides sp. fragments	R					F		C				R			F		C
Trilobite fragments	A							C									
Ostracoda ssp.				F													
Pelmatozoan fragments						R											C
Cryptozoon								R									

DAY POINT

Locality Number	134	138	141	143	146	148	152	153	156	157	158	159	242	243	303	324	364	365	366	367	380	458	459	460	461	462	479A
Zittelella varians (Billings)			R																								
Batostoma sp.																		R									
Dianulites sp.																										C	
Hallopora sp.																					P						
Phylloporina incepta (Hall)																C										R	
Rhinidictya fenestrata (Hall)											A		C													R	
Rhinidictya sp.	F					R						F															
Stictopora ? sp.						R																					
Stromatotrypa ? sp.						R																					
Bryozoa sp.						R									P												
Ateleasma ? *multicostum* (Hudson)													C														
Bilobia ? sp.																							P				
Camarella varians Billings			R																								
Chaulistomella sp.																	R										
Dactylogonia incrassata (Hall)		R									A			R				R	R	C			R				
Dactylogonia sp.												R															
Glyptonema ? *prisca* (Raymond)																					R						
Glyptonema ? sp.																						P					
Hesperorthis ignicula (Raymond)											R		R														
Hesperorthis sp. cf. *H. ignicula* (Raymond)		F																									
Hesperorthis ? sp.											R																
Lingula brainerdi Raymond														R													
Lingula ssp.	R					R			F							R											
Lingulella sp.										R	R																
Macrocoelia champlainensis (Raymond)					F	R					C	F	F														

Mimella vulgaris (Raymond)	C					C				A	C		C	F				F	F	C							C
Multicostella platys (Billings)																	A	F		R			R		F		
Opikina sp.																							R		R		
Opikina ? sp.																		R									
Orthambonites acutiplicatus (Raymond)						R																					
Orthambonites ? *exfoliata* (Raymond)	C	F				C	F			C	C		C			C	R	C	F	C	F	R	F	F	F		C
Platymena sp.																							P				
Platymena ? sp.																								P			
Protozyga ? sp.	R																										
Ptychopleurella porcia (Billings)													E					R		R							
Rostricellula major (Raymond)											R																
R. pristina (Raymond)										R																	R
Schizambon ? *duplicimuratum* Hudson	R									R																	
Sphenotreta acutirostris (Raymond)	A					C				F	C		F			C		F	C	C					R		C
Valcourea strophomenoides Raymond						R							F														R
Whiteavsia ? sp.	R																										
Gyromena sp.						R																					
Lophospira rectistriata Raymond													R														
Maclurites magnus Lesueur																							R			P	
Maclurites sp.				C																							
Raphistoma immaturum (Billings)													R														
R. striatum (Emmons)													R														
Raphistoma cf. *R. undulata* Raymond											R																
Raphistoma sp.																	R								P		
Raphistoma ? sp.																							P				
Trochomena sp.													R														
Orthoceracone																						P					
Orthoceracone, annulated																										P	

Locality Number	134	138	141	143	146	148	152	153	156	157	158	159	242	243	303	324	364	365	366	367	380	458	459	460	461	462	479A
Orthoceracone, cf. *Orthoceras rectiannulatum* Hall													P														
Trocholites ? sp.										R																	
Bascilicus marginalis (Hall)										R																	
Bumastus globosus (Billings)						R					R							F	R	C							
Calliops sp.											R																
Ceraurus hudsoni Raymond						R																					
Ceraurus ? sp.	R					R																					
Eoharpes antiquatus (Billings)		R																	R								
Homotelus obtusus (Hall)																					P						
Illaenus sp.																		P									
Isoteloides ? sp.																								P			
Isotelus beta Raymond										R																	
I. harrisi Raymond						R									R			C									C
I. platymarginatus Raymond		R				R				R	R													R	R		
Isotelus sp.—fragments		P												F	C		F		P	F	P		R	P			
Lonchodomas sp. cf. *L. halli* (Billings)													R														
Pseudosphaerexochus vulcanus (Billings)										R																	
Pseudosphaeroexochus ? sp.											R																
Pterygometopus ? sp.																P									P		
Vogdesia bearsi Raymond		F				R									R												
Trilobite fragments	C				C		F	F			C		F							A		R		C			
Eurychilina latimarginata Raymond	F				F	F		F		C			C	A		A				F							R
Leperditia limatula Raymond							C																				
L. *nana* Jones					F		R	A		F			C	A													
Schimdtella ? sp.														A													

Ostracoda ssp.																	P										
Blastidocrinus carchariaedens Billings											R		R														
Bolboporites americanus Billings													R														
Malocystites ? sp.											F										C						
Pelmatozoan fragments			F		C	A		C	C		C	C	C				P		C	F		A					C
Girvanella sp.					C				C																		
Stromatolites																						A					

CROWN POINT

Locality Number	51	54	66	139	197	220	229	233	234	235	248	252	293	312	368	369	381	420	483
Zittelella varians (Billings)									R										
Stromatocerium rugosum Hall								A											
Stromatocerium sp. cf. *S. rugosum* Hall						P													
Billingsaria parva (Billings)													P						
Nyctopora ? cf. *N. vantulyi* Bassler[1]								C											
Streptelasma sp. aff. *S. expansum* Hall								R											
Rhinidictya fenestrata (Hall)												F							
Rhinidictya sp.							R												
Ateleasma ? multicostum (Hudson)												F		F					
Camarella varians Billings				F															
Dactylogonia incrassata (Hall)				F								F							
Dactylogonia ? sp.																	R		
Hesperorthis ignicula (Raymond)												F		R					
Macrocoelia champlainensis (Raymond)				C												F	F		
Mimella borealis (Billings)														C					
Mimella vulgaris (Raymond)									C			C		F		F	R		
Mimella sp. cf. *M. subquadrata* Cooper												R							
Mimella sp.												R					R		
Multicostella platys (Billings)							F					C				F	F		
Onychoplecia gracilis (Raymond)									R										
Orthambonites acutiplicata (Raymond)														R					
Orthambonites ? exfoliata (Raymond)				C								R		C					
Ptychopleurella porcia (Billings)												R							
Rostricellula pristina (Raymond)								F											
Schizambon ? sp.									R										

Valcourea strophomenoides Raymond				F										F		C			
Maclurites magnus Lesueur	C	F		R	P		P		C	F				F				F	P
Maclurites operculi	F				P	P													
Raphistoma striatum (Emmons)									R										
Trochonema ? sp.										R									
Gastropoda, small, ssp.																		P	
Cameroceras tennuiseptum (Hall)	R								P										
Endoceras sp.									P										
Nanno sp.									P		P								
Stereospyroceras sp.																			
Vaningenoceras sp.									P										
Orthoceracone—large															P				
Orthoceracone—small																		P	
Isotelus harrsi Raymond																R			
Isotelus sp. fragments				C		P													
Remopleurides canadensis Billings							R		R										
Trilobite fragments												C							
Leperditia limatula Raymond	R																		
Leperditia ? sp.												F				R			
Ostracoda ssp.														P					
Pelmatozoan fragments				A										C				C	
Girvanella ocellata (Seely)	A		A																
Girvanella ssp.		C								P								P	
Solenopora compacta (Billings)														P					

[1] Reidentified as *Foerstephyllum wissleri* Welby; see Jour. Paleon., v. 35, p. 391–394, 1961.

VALCOUR

Locality Number	250	305	306	313	329	334	362A	363	463	464	476	478	480	491
Atactoporella sp.						C	A		R					
Dianulites sp.			R											
Rhinidictya fenestrata (Hall)	A												F	
Rhinidictya sp. cf. *R. fenestrata* (Hall)									F	F				
Rhinidictya sp.			F			R	F							
Stromatotrypa ? sp.			R											
Stromatocerium sp.												P		
Ateleasma ? *multicostum* (Hudson)	C													
? *Ateleasma* sp. cf. *A. decorticatum* Cooper							R							
Camarella varians Billings										R				
Christiania sp. cf. *C. subquadrata* (Hall)	R													
Dactylogonia incrassata (Hall)	C		R				F			C			F	F
Dactylogonia sp.			R											
Glyptorthis sp.							R		F					
Hesperorthis ignicula Raymond	R						R			C				
Lingula sp.		F							R					
Macrocoelia champlainensis (Raymond)	C									F				
Macrocoelia ? *distans* (Raymond)													R	
Mimella sp. cf. *M. transversa* Cooper							R				R			
Mimella sp. cf. *M. valcourensis* Cooper											R			
Mimella vulgaris (Raymond)	C		F			F	F			C	C			F
Mimella sp.										F			R	R
Multicostella platys (Billings)							C			C	R		F	
Onychoplecia gracilis (Raymond)										R				
Orthambonites sp. cf. *O. acutiplicatus* (Raymond)										F				

Orthambonites ? exfoliata (Raymond)	C									R				
Platymena sp.	F													
Ptychopleurella porcia (Billings)	C													
Rosticellula plena (Hall)										R			F	
R. pristina (Raymond)													F	
Schizambon ? sp.													R	
Sowerbyella ? sp.	R													
Valcourea strophomenoides Raymond	R						F							
Valcourea cf. *V. strophomenoides* Raymond										F	R			R
Brachiopods not identified, sev. sp.							R							
Bucania sulcatina (Emmons)													R	
Bucania ? sp.							R							
Gyronema sp.							R							R
Lophospira sp.														R
Maclurites magnus Lesueur		F		R	R									
Maclurites sp.							R						R	R
Raphistoma striatum (Emmons)														R
Raphistoma sp.						R							R	
Raphistoma ? sp.						R								
Protogastropoda sp. undet.													R	
Orthoceracones—smooth								P						P
Orthoceracones—annulated							R	P						
Nautilicone								P						
Bumastus globosus (Billings)								R						
Bumastus sp.										R			R	
Calliops ?								R						
Homotelus obtusus (Hall)			F					R						
Illaenus bayfieldi Billings										R			R	

VALCOUR—*Continued*

Locality Number	250	305	306	313	329	334	362A	363	463	464	476	478	480	491
I. punctatus Raymond													R	
Isotelus harrisi Raymond								F		R			F	
I. platymarginatus Raymond													R	F
Isotelus cf. *I. platymarginatus* Raymond	R													
Isotelus sp.			F											
Pliomerops cf. *P. canadensis* (Billings)										R				
Sphaeroxochus sp. cf. *S. parvus* Billings										R				
Trilobite fragments	C		A			F	C							
Trilobite sp. undet.													R	
Eurychilina latimarginata Raymond			C											
Cystoidea undet. calices							C							
Pelmatozoan fragments							C						C	
Solenopora sp.									R					

ORWELL

Locality Number	62	64	65	290A	322	327	339	400	422	477	479
Stromatocerium rugosum Hall		R					F				C
Stromatocerium sp. cf. *S. monliferum* Seely			P								
Stromatocerium ssp.	P						F	P			
Foerstephyllum halli (Nicholson)					R	R			C		
Lambeophylum profundum (Hall)	R	R				F				F	F
Streptelasma corniculum Hall	R										
Batostoma sp.										F	F
Eridotrypa sp.						F			F		
Escharopora sp.										F	R
Rhinidictya sp.						C			A	F	
Campylorthis ? sp.											R
Glyptorthis sp.						R					
Hesperorthis tricenaria (Conrad)										R	
Hesperorthis sp.											R
Opikina ? sp.						R				R	R
Piondema ? sp.						R					
Protorhyncha ? sp.						R					
Rafinesquina trentonensis (Conrad)						F			C	C	A
Rafinesquina sp.	R										
Rhyncotrema sp. cf. *R. increbescens* (Hall)										C	
Rhyncotrema minnesotense Sardeson										C	
Rhyncotrema sp. cf. *R. minnesotense* Sardeson							F				
Rhynchotrema sp.						F					
Strophomena sp.									R		

ORWELL—*Continued*

Locality Number	62	64	65	290A	322	327	339	400	422	477	479
Hormotoma sp.				P		R					
Lophospira sp. cf. *L. oweni* Ulrich & Scofield										R	
Lophospira sp.							R			P	
Maclurites logani (Salter)						F		C		C	F
Maclurites operculi								F			C
Raphistoma sp.									R		
Gastropoda, small ssp.		C				F					C
Murrayoceras ? multicameratum (Emmons)											R
Murrayoceras sp.	R										
Orthoceracones small											P
Bathyurus spiniger (Hall)										R	
Bathyurus sp.											R
Bumastus sp.										R	
Calliops ? sp.											R
Illaenus sp.							R				
Isotelus sp.						R				R	
Asaphidae fragments											R
Trilobite fragments									C		
Ostracoda ssp.									P		P
Pelmatozoan fragments						A	A		A	A	A

GLENS FALLS

Locality Number	28	52	53	182	191	239	253	277	280	316	317	318	320	342	343	344	347	348	356	419	424	425	427	484
Conularia trentonensis Hall													C										P	
Conularia sp.			P																					
Eridotrypa exigua Ulrich																		C	A	C				A
Eridotrypa sp.									R		C	C									R			
Escharopora ? sp.								R																
Hallopora sp.								R					F											
Mesotrypa quebecensis Ami											R							F	R	F				
Mesotrypa sp.																								F
Prasopora orientalis Ulrich								C										C	A					
Rhinidictya sp.								F			C	C	F											F
Bryozoa, ramose, ssp.		F						F			R												C	
Campylorthis ? sp.												R	R						R					
Christiania trentonensis Ruedemann													R											
Dinorthis pectinella (Conrad)												A	R					C	C	R			R	F
Doleroides ottawanus Wilson																							R	
Hesperorthis sp.																		R						
Lingula quadrata (Eichwald)																							R	
Lingula trentonensis (Conrad)															R									
Lingula ssp.	R							R			R							R	R	F				
Oxoplecia ? sp.																			C					
Paucicura rogata (Sardeson)									R	R	F	C	F		R	R			C	C			F	C
Platystrophia cf. *P. trentonesis* McEwan																			F	R				
Platystrophia sp.											R													
Rafinesquina trentonensis (Conrad)											R	F							R				A	C
Reuschella edsoni (Bassler)	F	F	F					C	R		C			R				A	C	A			F	C

Locality Number	28	52	53	182	191	239	253	277	280	316	317	318	320	342	343	344	347	348	356	419	424	425	427	484
Schizotreta sp.																			R	R				
Sowerbyella sericea (Sowerby)	F	R	R					C		R	C	A	A						A	F			C	C
Swoerbyites ? sp.													C											
Strophomena sp. cf. *S. conradi* Hall		R																	R					
S. incurvata (Shepard)		R																					F	
Strophomena sp.								R			R									R				F
Trematis terminalis (Emmons)											R	R	R						R				R	
Zygospira recurvirostris (Hall)											R								F				F	
Modiodesma sp.																							R	
Orthodesma sp.																				R				
Holopea symmetrica Hall																			R	R				
Holopea sp.																			R					
Sinuites cancellatus (Hall)																		R						
Sinuites sp. cf. *S. cancellatus* (Hall)																			C					
Sinuites sp.	R																			R				
Endoceras proteiforme Hall																							P	
Orthoceracone—small								P																
Spyroceras sp.													P											
Bascilicus marginalis (Hall)															R									
Bathyurus sp.								R															P	
Calliops callicephalus (Hall)																			F					
Ceraurus pleurexanthemus Green																			F	R				
Ceraurus sp.								R				R								R				

Cryptolithus tesselatus Green				R				C			C						P	F	A	C			C	
Encrinurus cybeleformis Raymond																							R	
Encrinurus sp.											R													
Flexicalymene senaria (Conrad)	F	C	A						P			R	C					F	R	R	R	F	R	
Flexicalymene thoracic segments					F		C		A															
Isotelus gigas Dekay	F					P		F					F						C				F	
Isotelus sp. fragments			R									C								R				C
Trilobite sp. undet.											R													
Trilobite fragments											F													
Ostracoda ssp.			R								P													
Dendocrinus alternatus (Hall)																	P				R			
Pelmatozoan fragments—chiefly columnals	P	C						C	F				C						C				C	C
Diplograptus amplexicaulis (Hall)																R								
Lasiograptus ? sp.																R								
Pasceolus globosus (Billings)																							P	
Solenopora sp.												R							R					

STONY POINT

Locality Number	261	309	310	335	337	346	505
Rafinesquina ? sp.	R	R					
Resserella ? sp.		R					
Orthoceracone aff. *Orthoceras hudsonicum* Ruedemann							P
Triarthus beckii Green		C					
Amplexograptus ? sp.					R		
Climacograptus typicalis Hall					C		
Climacograptus cf. *C. typicalis* Hall	F			F			
Climacograptus sp.				R		R	
Dicranograptus ? sp.						R	
Diplograptus amplexicaulis (Hall)				C	F		
Diplograptus sp. cf. *D. mohawkensis* Ruedemann				R			
Diplograptus sp.			F				F
Diplograptus ? sp.		R					