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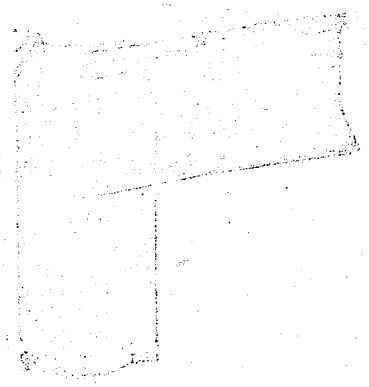

THE EDGE OF THE APPALACHIANS IN SOUTHERN QUEBEC.

T. H. CLARK AND H. V. McGERRIGLE

See Lacoste map area

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THE EDGE OF THE APPALACHIANS IN SOUTHERN QUEBEC

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PREFACE

Since 1927 the senior author has been engaged in mapping a strip of country in Southern Quebec immediately north of the International Boundary. Three map units have been completed, namely the Lacolle, Sutton, and Memphremagog. These maps will be published as the manuscript becomes available. The reports, of which this is the first, will not be confined to map areas, but will treat areas that are definite geological units. This present report deals with the Lacolle quadrangle and part of the Sutton. A contemplated report to follow will deal with the remainder of the Sutton and part of the Memphremagog, leaving the remainder of the Memphremagog for later treatment.

The program of work was conceived as a means of providing a standard of comparison with which the complicated structure and stratigraphy of the Appalachians* elsewhere in Quebec could be compared. Investigations of problems of

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* Throughout this report the term "Appalachian" is used to refer to the folded Paleozoic rocks of eastern North America, and not merely to those folded towards the close of the Paleozoic.

economic importance in this wide area at the present time are hampered by the lack of such a standard, and progress in the understanding and exploration of the hilly country of eastern and southern Quebec has been thereby immeasureably held back. The strip of country along the International Boundary appears to have been useful in tying together work done one hundred miles to the north. ~~Of the scientific importance of this investigation it is scarcely necessary to speak.~~

INTRODUCTION

General Statements

For more than sixty years the geology along the trace of the great frontal fault of the Appalachians in Canada has been neglected. Inherent difficulties abound, but those alone would have served to spur investigation rather than to subdue it. Deposits of economic interest and importance occur throughout, and have stimulated local studies. But on the whole, sixty years after Logan's epochal "Geology of Canada, 1863", little progress had been made towards unravelling the difficult stratigraphical and structural problems involved. First and foremost of the reasons for this lamentable stagnation is the almost complete inability of the earlier workers to realize that they were dealing, along the fault, with two sets of rocks which might be, and usually were, totally different, so that formational names applied to one set would have no meaning when transferred to the other, and the Geological history worked out for the region on one side failed to work when applied to the other, Added to this apparently inexplicable confusion was the comparative lack of fossils in the region to the east of the fault, except at a few localities, such as Levis, and Philipsburg, Que., and the folded and thrusted nature of the rocks. All in all, it was not to be wondered at that

geologists of the last half of the nineteenth century turned their attention to the more attractive fields in the west.

Partly because of this age-long confusion, and partly because numerous scattered areas surveyed in the Appalachian area of Quebec could not be correlated because there was no standard with which their sections and history could be compared, the Geological Survey of Canada decided to work out in considerable detail a cross-strike strip of country starting at the edge of the Appalachians and penetrating the folded rocks eastwards as far as possible. The greatest variety of formations, it seemed, would be found in a strip just north of and adjacent to the International Boundary. In accordance with that view the senior author was directed to survey the Sutton quadrangle in 1927. One summer's work on that yielded abundant results, justifying the selection of that region as a starting point, but also indicated the desirability of not limiting the work to the folded rocks, but beginning some distance to the west, so as to include rocks of the unfolded region. Accordingly, H. W. McGerrigle, field assistant during the 1927 season, was given the adjoining sheet to the west, the Lacolle quadrangle, as a thesis area, completing the mapping of it in 1928 and 1929. Meanwhile further progress had been made on the Sutton sheet, and it became apparent that because the strike of the formations and of the thrusts which cut them have an average direction

of N20°E, publication of two reports on adjacent map areas would involve considerabe repitition. The decision was reached therefore as stated above to publish the maps as completed, whereas the reports should cover logical subdivisions of the area according to structure. To this end the plan adopted is as follows. The present report covers all of the Lacolle quadrangle and as much of the Sutton as is included in the two westernmost thrust blocks, thus giving an opportunity, in one volume, to show the contrast between the "unfolded" and the "folded" rocks. The second report is intended to include the more intensely folded rocks to the east, which culminate in the schists of the Sutton Mountains, partly in the Sutton sheet, partly in the Memphremagog sheet. Following that a third report is contemplated dealing with the rocks to the east of the Sutton Mountains and within the Memphremagog sheet. The eastern half of this sheet was mapped by Dr. F. H. Kerr in 1920, and his report will be incorporated within the third mentioned above.

Thus, this series of three reports will cover an area approximately 18 miles from north to south, and 75 miles from east to west, sixty miles of which will be within the disturbed rocks of the Appalachians. The hope that this extensive strip might serve as a standard appears to be fully justified.

As a supplement to these three geological reports, the details of the paleontological data will be brought together in a Museum Bulletin as soon as possible.

Location, area, and physical features. This report covers all of the Lacolle quadrangle, and approximately one quarter of the Sutton quadrangle, i.e. that part between its western boundary and the so-called Oak Hill Thrust, which separates major thrust blocks. The 500 foot contour level marks the division between the two parts of the Sutton quadrangle nearly accurately, practically all of the county east of the Oak Hill Thrust lying above that elevation.

The so-called St. Lawrence-Champlain fault divides this area into two districts, one of comparatively flat Upper Cambrian and Ordovician rocks to the west and a second of faulted and folded rocks of Cambrian and Ordovician ages belonging to the Appalachian Mountains to the east.

The Lacolle sheet (see fig. 1) lies between the International Boundary Line (a mile or so north of latitude 45°N) on the south and latitude 45°15' on the north. The eastern and western boundaries are respectively 73°W and 73°30'W longitude. The area is approximately 405 square miles and lies within the counties of Laprairie, Napierville, St. Johns, Iberville, and Missisquoi. In addition, the part of the Sutton sheet which is included in this report is bounded on the west by the Lacolle sheet, north and south as in the Lacolle sheet and on the east by an irregular line

cutting the International Boundary a quarter of a mile west of longitude 72°55'W and the northern border at approximately longitude 72°42'30". This eastern border is a thrust fault. The area of that part of the Sutton quadrangle here included is approximately 145 square miles and lies entirely within Brome and Missisquoi Counties. Thus a total of 650 square miles is treated in this report.

A network of railways covers this area. The Canadain National, Delaware and Hudson, Central Vermont and Canadian Pacific afford fairly easy access to all parts of it. In addition, through-going provincial roads and an abundance of rural roads serve to make practically all of the area easily accessible.

Missisquoi Bay, the part of Lake Champlain which extends into Canada, is the largest body of water within the quadrangle, and occupies an area of about 18 square miles. Pike River, flowing into the Bay from the north, and draining a considerable part of the Eastern District, is slowly filling up the northern end with a deposit of sand; and, in Vermont, the Missisquoi River is building its delta northward into the Bay. At the present time, the above-water portion of this delta reaches almost to the International Boundary.

The main drainage channel of the area, the Richelieu River, is separated from Missisquoi Bay and the northeastern

arm of Lake Champlain by Alburg Peninsula. The Richelieu is the outlet of Lake Champlain; from its source near the Boundary it flows northward for 75 miles and empties into the St. Lawrence at Sorel. It is, in general, considerably wider between its source and the city of St. Johns, Quebec, than along the remaining 40 miles below that city. In earlier years this river was of great importance as a trade-route between the farming communities bordering Lake Champlain and the cities of Montreal and Quebec; it also served as a link in the chain of inland waterways connecting these two Canadian cities with New York City, and, as a military route.

The South and Lacolle rivers are tributaries of the Richelieu. The South flows in a northward direction, in the lower part of its course, and joins the Richelieu near Isle Aux Noix. The Lacolle flows eastward through Lacolle Village, and empties into the main stream near Ash Island, about 7 miles south of Isle Aux Noix. A third river, known as either the Little Montreal or L'Acadie River, has its source in swampy land in the northwestern part of the area; flows westward for five miles; then, turning northward, leaves the quadrangle north of the town of Napierville, and continues its northward course to join the Richelieu at Chambly.

The Yamaska river, rising in the Sutton Mountains, meanders across the northeastern part of the area through Cowansville to the St. Lawrence, which it enters at Lake St.

Peter. The most important towns and villages follow:

Napierville
Lacolle
Henryville
Clarenceville
Philipsburg
Bedford
Cowansville
Sweetsburg
Stanbridge East
St. Armand Station

Occupation. Mixed agriculture is the main support of the population. Along the King Edward Highway and the Philipsburg - Henryville - St. Johns highway and the Cowansville - Farnham highway, attempts have been made to attract tourist business, without conspicuous success. Tourists need more encouragement than they get from the dinginess of the wayside farms, to tarry en route to Montreal. Fur-raising occupies a limited number of occupants. Quarrying operations at Philipsburg and near Stanbridge Station are locally of importance. In that part of the area of the Sutton sheet which is more hilly, an increasingly large number of deserted farms can be seen year by year.

Earlier field work. Several geologists have examined the rocks of this area; but all except two confined their observations to matters bearing on special problems - particularly the age and relations of the Philipsburg Series. Inasmuch as the latter does present a special problem, the detailed relation of the previous work on it will be delayed

until that series is directly discussed. In this place only that work which bears on the geology of the area as a whole will be reviewed.

Sir William Logan laid the foundation for all subsequent work in this area. In his Geology of Canada, 1863, he described practically every formation that is now known to occur in the area, and traced their boundaries. He also traced the course of the great fault that has since come to be known as the St. Lawrence and Champlain fault, or, more briefly, Logan's Line; and he realized that the rocks east of the fault were older than those immediately to the west, and had been thrust over them. East of the fault he described and mapped in some detail the Philipsburg Series, and noted the fact that a dolomite formation was thrust over this series from the east. This formation, now known to be Lower Cambrian age, he mistakenly termed the "Potsdam", and traced it southward into the "Red Sandrock Series" of Vermont.

The mass of crumpled slates, immediately west of the fault, Logan thought to be of Trenton or Utica age. Westward, between Missisquoi Bay and the Richelieu River, were black "Utica" slates. West of the river these slates again appeared, but within a few miles the Chazy, and then the "Calciferous" came to the surface.

Logan's descriptions were so complete, and his formation boundaries so exactly mapped that, in 1896, Ells added little except a more extensive collection of fossils from the various formations. He did, however, map two new formations, the true Potsdam, and the Quebec City. The sandstones of the former are to be seen in the southwestern corner of the quadrangle, and what he erroneously identified as the Quebec City formation lay between Clarenceville and the Richelieu River and extended southward to the International Boundary. The Philipsburg Series was reviewed, and many fossils were collected, but the resulting conclusions varied little from those of Logan; Ells was merely more definite than was Logan when he stated that the series belonged to the "Calciferous" and Chazy horizons. As a result of Walcott's discovery of Lower Cambrian fossils in the Red Sandrock Series of Vermont, Ells correctly assigned the dolomite formation east of the Philipsburg Series, which Logan had called the Potsdam, to the Lower Cambrian.

Since 1896, no geological study of the rocks of the area as a whole was made until the present work was undertaken.

Present Field Work. Field work was begun on this area in 1927 by both authors. Subsequently the junior author spent the summers of 1928 and 1929 on the Lacolle sheet,

being assisted in 1929 by Mr. Joseph Morin. He also spent a few weeks at Philipsburg in 1930 for the purpose of closer correlation of some of the stratigraphic units. Complications arising from the study of some of the fossils of the eastern district have been responsible for some delay, and indeed are not sufficiently resolved yet for publication. The 1 inch to 1 mile maps prepared by the Department of Militia and Defense served well as a base for field work, which was accomplished by pace and compass methods.

Acknowledgments. Numerous experts have at various times contributed advice and suggestions in the field. Among these may be mentioned E. O. Ulrich, R. Ruedemann, P. E. Raymond, C. Schuchert, G. A. Cooper, and M. P. Billings. Both authors feel very deeply their indebtedness to these men for their helpful analysis of the problems of stratigraphy and structure and for fertile suggestions regarding critical points.

We are also indebted to Maurice Black of Trinity College, Cambridge, England for a voluntary study of the thin sections of the rocks of the Philipsburg and Pigeon Hill Series. This was done while Black was Commonwealth Fellow at Princeton University. His report is included here practically verbatim as an appendix. The photomicrographs accompanying it were all made by Black.

General Geology.

The rocks of this area are divided into two distinct provinces by the St. Lawrence and Champlain fault. The present trace of this fault follows closely the east shore of Missisquoi Bay from the International Boundary to Philipsburg; there it leaves the Bay with a trend of about 20°E to a point one half mile west of Morgan's Corners; at this place it swings sharply to 50°E and follows that course for one mile; then, turning back toward the north, it crosses the Bedford-Stanbridge Station road about midway between these two villages; it then follows a strike of about 10°E until it crosses the Lacolle - Sutton line, northwest of Mystic Village, after which its course is less certain, but it certainly passes in a northeasterly direction for one mile and then by an irregular course northwards till it crosses the northern boundary of the area at approximately the same place where the Central Vermont R. R. crosses it. Throughout the last four or five miles of its course, outcrops are scarce, fossils absent and topography fairly uniformly flat. In this report the area east of the fault will be described as the "Eastern District", and the area to the west as the "Western District".

The division of the area into two districts is necessitated by structure, stratigraphy, lithology, and topography. The Eastern District embraces an overthrust

block, or rather a series of two or more such blocks which have been pushed westward over the rocks of the western district.. Along the western limit of this district the approximate trace of the fault is marked for some miles in the southern part by a pronounced escarpment, where the strata, predominantly limestones, are in every case older than the slates which, at the present time, they overlie. These limestones, part of the Philipsburg Series, are folded and faulted. Along the northern part of the fault, that is, from Morgan's Corners northwards, there is no escarpment at all, and where there are no limestones which from their fossils can be allocated to either the Eastern or Western district extreme difficulty is experienced in locating or postulating the position of the fault. The overriding and overridden rocks are here both slates which cannot be differentiated on account of the amount of contortion, and which in the absence of fossils are practically identical.

THE WESTERN DISTRICT

General Statement

Physiographically and geologically the Western District of this area may be said to belong equally to the St. Lawrence Lowlands province or to the Champlain Valley province, for the boundary between these two provinces has to be drawn arbitrarily in this region. The larger portion of the District is underlain by shales and slates, formerly thought to be Utica age, but now believed to be mostly Upper Trenton. The considerable breadth of outcrop of these shales makes them appear thicker than is actually the case, for they are repreated again and again by shallow folds, especially within a few miles of the St. Lawrence and Champlain fault.

The succession of formations in the Western District is, in descending order,

Iberville shales (possibly Utica)

Stony Point shales (Upper Trenton)

Lacolle conglomerate (Trenton, but definite horizon unknown)

Chazy limestone (Probably Upper Chazy)

Beauharnois dolomite (Middle Beekmantown)

Potsdam sandstone (Upper Cambrian)

The Potsdam is found in the southwestern corner of the area, and is succeeded to the north and east by the Chazy. Along the eastern side of the Chazy lies a band of conglomerate that is Trenton in age. All of the above formations occur between the Richelieu River and the western border of the quadrangle. Trenton slates also outcrop west of the river, but they have their greatest development to the eastward, and, with the Utica (?), underlie the entire area between the river and the frontal thrust fault. Approaching the fault from the west, the slates, nearly flat or gently folded in the neighborhood of the Richelieu, are thrown into a series of folds, until, within two miles of the present trace of the fault, thay become so badly smashed that their structure cannot be determined at all definitely.

Stratigraphy

Potsdam Sandstone. No prior description of the Potsdam Sandstone as it occurs in the Western District has appeared in the literature, and no notice of it has been given save on the map accompanying Ells' report of 1896, where a small area in the southwestern corner of the quadrangle was mapped as Potsdam.

Distribution and Structure. The Potsdam Sandstone ~~is exposed only~~ in the southwest corner of this area, ~~where~~ it occupies 15 square miles. In only one outcrop is there a contact between it and the next overlying formation, so that its boundary line is drawn between outcrops. It is characteristically flat, dips of 5° being exceptional. Bordered on W., N. and E. by younger strata it would appear to occupy the center of a low northward plunging anticline, the same gentle fold to which, further north, Logan gave the name Chambly anticline.

Thickness. No estimate of the ~~true~~ thickness ~~of this sandstone~~ can be given; the base is not exposed, there are no deeply-cut sections, and the strata are flat or nearly so. The thickness of the exposed strata is no more than 50 feet, even when the interstratified series of sandy and calcareous strata at the top of the sandstone is included. It may be possible, however, to obtain a closer approximation of the true thickness by referring to adjacent sections. At Hemmingford Mountain, about five miles west of the Lacolle quadrangle and near the International Boundary Line, Logan (1863, p. 88) reported the Potsdam to be 540 feet thick at least, the base of the section not being exposed. In the region immediately south of the Boundary Line, in Clinton County, New York State, the thickness of the Potsdam was believed by Cushing (1895, p. 512) to be in the neighborhood of 2,000 feet, while, in

the vicinity of Plattsburg, about twenty miles south of the Line, the thickness estimated by Van Ingen (1901, p. 533) was 1,150 feet, with the base not seen. Thus, obviously, only the uppermost beds of the Potsdam are exposed here.

Lithology. About 500 feet beyond the western boundary of the Lacolle ~~Quadrangle~~, on the east-west road three-quarters of a mile north of the International Boundary ~~Line~~, an outcrop occurs in which beds of compact sandstone or quartzite are common and are interstratified with dolomitic sandstones. In places these beds are stained with iron. The quartz grains are small, on the whole, averaging about .3 mm., although larger grains are present. Cross-bedding on a small scale occurs. Similar strata are exposed four miles northnorthwest, on the road running westward from Belle Vallée. These particular strata are close to the top of the sandstones, for a short distance west and east ~~of the outcrops in which they occur~~ the Beauharnois dolomite ~~comes in~~.

East of the first outcrop referred to above, other exposures of arenaceous strata occur. Some of these are ~~made up of beds~~ all of which are either relatively pure sandstones, weathering to a light gray color, or are sandstones with a calcareous cement, weathering light brown. Both types are gray in color on fresh surfaces, and in many places ~~frequently~~ cross-bedded.

In the purer sandstones the grains are very uniform in size - about .5 mm. and the percentage of rounded and angular grains appears to be about the same. In the sandstones with a calcareous cement rounded grains predominate greatly over the angular, and frosting is common; in these, also, the grains are not uniform in size, for although diameters of .5 mm. are most common, there are many grains as small as .3 mm., while grains as large as 1.0 mm. are abundant. In the cross-bedded deposits grains of 1.0 mm. diameter are very rare, the average size being less than .5mm. No pitted grains were observed.

Besides the exposures mentioned above there are others in which relatively pure sandstone beds are interstratified with sandstones having a calcareous cement and also with dolomite beds containing very few sand grains. Apart from the occurrence of sand grains in the last mentioned beds, they are quite typical of the dolomite referred to the Beauharnois formation.

Stratigraphical Relations and Correlation. It has already been indicated that the stratigraphic boundary between the Potsdam and the Beauharnois is indefinite, not only because the beds at or near the contact are not exposed, but because there seems to be a gradation between the two formations; or, if not gradation, an interbedding of the upper beds of one with the lower beds of the other. This sandstone is in

direct continuation with the Potsdam in the northern part of New York State and with that strip of Potsdam which extends from the New York-Quebec Line through the counties of Chateauguay and Beauharnois to Lake St. Louis, and thence northward, across the St. Lawrence River, to the Lake of Two Mountains. Throughout this area, wherever the sandstones are overlaid by other strata, the latter are of Beekmantown age, and there has never been reported any sign of a break between the two formations, and the passage from one to the other has almost invariably been described as a gradational one (vide, Emmons, Logan, Ells, Cushing, Van Ingen, and others). Such relations would indicate that the upper part of the Potsdam Sandstone in this region is nearer to the age of the Beauharnois than to the Lower Ozarkian* (part of the Upper Cambrian) where, however, on the basis of fossils from the upper few hundred feet, it has been placed by Ulrich. The natural inference from this latter correlation, therefore, would be that a break exists somewhere between the Potsdam (Lower Ozarkian) and the Beauharnois (Middle Canadian). This break, indicated by paleontological evidence, is in reality substantiated by the stratigraphy. The apparent

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* For comments upon the use of the terms Ozarkian and Canadian see page . See also Correlation Table, page .

gradation from sandstone (Potsdam) to dolomite (Beauharnois) has always been considered prima facie evidence of continuity of formation. However, the abundance at the top of the Potsdam of wind-blown sand grains impels us to place at least a disconformity between the two formations (representing Middle and Upper Ozarkian and Lower Canadian time). Moreover, as shown by Raymond (1912, p. 352), there intervenes in eastern Ontario between the Potsdam and Beauharnois the Theresa formation.

If we read the history correctly the Potsdam sandstone hereabouts was deposited under marine conditions during Upper Cambrian (Lower Ozarkian) time and subsequently exposed by a withdrawal of the sea, allowing a rearrangement of the top few feet by winds, and consequent rounding and frosting of the grains before being re-submerged in Beekmantown (Middle Canadian) time when the Beauharnois dolomite was deposited. Calcareous or dolomitic material in solution seeping downwards from the dolomite, or its parental limestone, would obviously account for the calcareous cement of the "transitional" beds. These wind-blown sands then, belong to neither the Potsdam nor the Beauharnois, but their exposures within this area are not sufficiently clear to warrant attaching a new formational name to them. In the table of formations they are referred to as the "Potsdam-Beauharnois

passage beds", (and may lie anywhere between the Lower Ozarkian and the Middle Canadian, or of course that entire interval may have been taken for their formation).

Fauna. No direct fossils occur in the Potsdam sandstone in this area. Indirect evidences in the form of trails of a few different kinds, some resembling Scolithus somewhat, some not identifiable, are common in one outcrop only. These are of no stratigraphic significance.

Beauharnois Dolomite. The term "Beauharnois" was suggested by Raymond (1912, p. 352) as a formation name for the massive dolomites and limestones of Beekmantown age which are well developed in the counties surrounding Montreal. The name itself is derived from "the classic exposures along the Beauharnois canal between Valleyfield and Beauharnois", on the south side of the St. Lawrence River. The Beauharnois is part of Logan's "Calciferous formation", as described in the Geology of Canada, 1863.

Distribution and Structure. In New York State the Beekmantown extends along the western side of Lake Champlain as a band rarely exceeding two miles in width to the Quebec-New York Line, "but here the dip probably diminishes considerably, as the formation in Canada spreads out on the east side of the Beauharnois anticlinal to a breadth of six

I, this M. Chadly article. [illegible] ?

miles, and in some places more. With this breadth, a little to the east of the Richelieu River it folds over an anticlinal, the axis of which runs northward under Chambly. On the west side of this the formation sweeps around the extremity of a synclinal in its progress to Lake St. Louis" (Logan, 1863, p. 114). This wide and irregularly outlined band of the Beauharnois is the eastern band of that formation in southwestern Quebec, and is separated from the formation as exposed in Beauharnois County by Potsdam sandstone, the interval between the two bands being upward of 40 miles on the International Boundary line, and about 8 miles on the south shore of the St. Lawrence (Lake St. Louis). The eastern band of the Beauharnois dolomite, whose southeastern part is in the Lacolle quadrangle, has a general southeast trend, and is underlain on the west and south by the Potsdam, and overlain on the east and north by the Chazy.

The eastern Beauharnois band is bounded on the west & south in the Lacolle quadrangle by the Potsdam sandstone. Its northern and eastern boundary, shown on the map accompanying Ells' report, 1896, is substantially correct, except that instead of passing two miles west of the Lacolle Village it should be drawn passing through that place.

Throughout the area underlain by the Beauharnois

the strata are prevailingly flat, but have occasional northeasterly dips at angles less than 5°. Exceptional conditions were recorded to the east of the King Edward highway, at the eastern edge of the Beauharnois exposures. Here the beds strike due north and dip to the east at about 10°. A short distance farther eastward beds which closely resemble the Beauharnois and presumably belong to that formation, strike due north and dip to the east at angles of 8° to 15°. These comparatively high dips are probably due to drag along the line of the Tracy Brook fault, which is believed to reach the Boundary Line somewhere in this neighborhood, and has been located by Cushing (1895, p. 573) about two miles west of Rouses Point, in Champlain township, N. Y.

Lithology. Although dark gray dolomite predominates in this formation, buff colored beds are common. Both types occur in beds varying between one and two feet in thickness, and are finely crystalline. The former usually weathers to brownish colors, the latter to buff.

In practically every outcrop these dolomites are interstratified with beds that have a high content of quartz grains, a feature that is particularly evident on the weathered surfaces, where the quartz grains are coated with iron oxide. The grains are small, less than .5 mm. in diameter, and angular.

Relatively pure limestone beds can be seen in but two exposures of the Beauharnois. One of these is east of the road leading south from St. Bernard-Sud, on the west side of the Lacolle River. The major part of the outcrop is made up of brownish-weathering, dark gray, crystalline dolomite, interstratified with arenaceous dolomite, in beds one foot or more thick. On the eastern side, in a ten-foot cut made by the Lacolle River, the dolomites are interstratified with limestone beds, which vary in thickness up to one foot. Some of the limestone is compact and very fine-grained, while some is more coarsely crystalline than the dolomite. The color is dark gray on fresh surfaces, weathering to a light gray. Throughout the limestone beds there are thin seams of shaly material which reticulate over their surfaces, giving the rock a nodular appearance when weathered. The limestones contain fragments of gastropods.

Thickness. No accurate measurement of the thickness of the Beauharnois formation has been published, nor of the Beekmantown of Clinton County, N. Y., which is the continuation southward of the Beauharnois. It has been supposed to be between 300 and 400 feet thick in the vicinity of Montreal. Where the Beauharnois formation crosses the International Boundary ~~line~~, in the Lacolle quadrangle, we estimate its thickness at 275 - 300 feet, from the dips of the strata concerned.

Stratigraphical Relations. The stratigraphic relations of the Beauharnois to the underlying Potsdam have been given above. The relations of the Beauharnois to the overlying Chazy are indefinite, because of the absence of exposures at the contact. In certain places, however, the Beauharnois occurs in unconformable relation (actual contacts visible) to an overlying conglomerate which is correlated with the Lacolle conglomerate of Trenton age, the Chazy being absent. These relations are observable at three localities in the southern part of the area, between Lacolle Village and the International Boundary Line.

Fauna and Correlation. As far as the Lacolle quadrangle is concerned, the fauna of the Beauharnois is poor in quantity and quality. The following forms were collected and identified by the junior author:

Brachiopods:

1. Orthoids
2. Linguloids

Echinoderms:

3. Cystid calyx

Gastropods:

4. Hormotoma cf. artemesia (Billings)
5. Hormotoma cf. gracilens (Whitfield)
6. Ophileta cf. levata Vanuxem

7. Lecanospira conferta Ulrich (Figured in Geology of Alabama, Special Report 14, Plate 16, 1926)

8. Liospira sp. undt.

Cephalopods:

9. Fragments of two Orthoceratite forms

Trilobites:

10. Fragments, unidentified.

These fossils add little to what is already known concerning the fauna of the Beauharnois formation. However, they serve to show definitely that the Beekmantown dolomite in the lower Ottawa Valley and along the St. Lawrence River between Brockville and Montreal belongs to the same horizon within the Beekmantown as does the dolomite of the Lacolle quadrangle. The dolomite of the latter area is in direct continuation geographically with the Beekmantown dolomite at Beekmantown, New York, where the fauna contains important elements in common with that of the Beauharnois, although, on the whole, it is more varied than the Beauharnois fauna. Also, the dolomite on the west side of the Beauharnois anticlinal, in the St. Lawrence and Ottawa Valleys, is practically continuous with the Beekmantown of northern New York known as the Ogdensburg formation. It is probable that these three formations are contemporaneous, and the fossils collected from the dolomite of the Lacolle area serve, to some extent, to confirm this view.

A more sweeping correlation is made by Butts (1926,

pp. 94 - 95) who says: "By far the most significant of these fossils of the Longview formation are the species of Lecanospira figured on Plate 16. These forms mark constantly a zone extending without a break from Alabama to Canada. They occur abundantly in the lower part of the Beekmantown limestone at Beekmantown, in northwestern New York. The same species of Lecanospira have been collected in Alabama, Tennessee, Virginia, Maryland, Pennsylvania, New York and Canada and also in the Roubidoux formation of Missouri and in the middle of the Arbuckle limestone of Oklahoma.....The lower part of the Beekmantown of Canada and northeastern New York, the Nittany dolomite of central Pennsylvania, an intermediate part of the Knox dolomite of Virginia and Tennessee, the Longview limestone of Alabama, the Roubidoux formation of Missouri, and the middle part of the Arbuckle limestone of Oklahoma were all laid down upon the same continuous sea floor during the same geologically short period of time."

Bridge (1930, p. 124), in his discussion of the correlation of the Roubidoux formation of Missouri, states that "The Lecanospira fauna of the Roubidoux is well developed throughout the length of the Appalachian trough, occurring in the Longview limestone of Alabama and in the Nittany limestone of Pennsylvania and Tennessee and in the lower part of Division C of the New York Beekmantown. It continues northeastward and is again found in the northern portion of Scotland and

Scandinavia."

Thus the upper part of the New York and Vermont Beekmantown is wanting in the Lacolle area and northwards. Whether this is because of non-deposition or of subsequent erosion we have no means of telling, for nowhere do the Beauharnois and the succeeding formation, the Chazy limestone, come together in outcrops. In either case an interval of non-deposition of greater or less duration intervened between the Beauharnois and the Chazy.

Chazy Limestone. The first definite reference to Chazy rocks in the area to the south and southeast of Montreal was made by Logan in Report of Progress for the years 1851-52. At that time the Chazy on the south shore of the St. Lawrence River, at Caughnawaga, was mentioned. Later, (1863, p. 131) he described the distribution of the formation in a general way, from the International Boundary ~~line~~ (Lacolle quadrangle) to Montreal, but without any description of the rocks or mention of the fossils in the Lacolle area. Ells (1896, p. 48) gave a very brief and general description of the Chazy rocks in the Lacolle area, as well as lists of fossils identified by Ami. Raymond (1906, p. 554) modernized the list of Grande Ligne fossils given by Ami. Parks (1914) and Goudge (1927), while discussing the Chazy and other formations chiefly from the economic point of view, gave excellent and detailed descriptions of the lithological characters of the Chazy

strata in the Lacolle quadrangle and elsewhere.

Distribution. The Chazy formation is well developed in New York along the west side of Lake Champlain. Taking Keeseville on the Ausable River as a arbitrary strating point, Logan (1863, p. 131) stated that the Chazy "follows the Calciferous along the margin of Lake Champlain.....to the province line, passing in its course the town of Chazy, from which it takes its name. Beyond this, folding over the axis of the Chambly anticlinal and under the corresponding synclinal to the west, the formation attains Lake St. Louis, the summit of it reaching some distance below Caughnawaga.". On the map accompanying Ells' report, 1896, the Chazy is shown as occupying a wide area in the northwestern part of the quadrangle, but contacting towards the south and reaching the International Boundary ~~Line~~ as a band between one-half and one mile wide. However, no outcrops of Chazy limestone occur between the International Boundary ~~Line~~ and Lacolle Village, nor north of that village until the "Legeault quarry" locality of Ells (1896, p. 48) is reached. This quarry is four and a half miles N.15°E. of Lacolle Village and one and a half miles N.50°W. of St. Valentin (Stottsville).

Structure and Lithology. The southernmost exposure of Chazy limestone is at the Legeault quarry. In this neighborhood are three small quarries, all within a few

hundred feet of one another. The most northern and second largest is apparently the one described by Parks (1914, pp. 72 - 74), who gives the locality as "Lot 14, Parish of St. Blaise, St. Johns County". His description follows: "The quarry is about 100 feet long by 40 feet wide and has been opened to a depth of eight feet. The beds dip to the north at a low angle and are cut by a major series of vertical joints striking northwest. These joints are as much as 10 feet apart: they do not appear to be crossed by a second defined set although irregular fractures occur.....Three beds have been worked as below:--

Upper bed, 22 inches thick, crystalline in character and variable in grain and colour. At the western end the stone is grey but towards the east it is speckled with red.....

Second bed, 18 inches thick, uniform, grey crystalline.....

Third bed, 11 inches thick, blue and less crystalline....."

In some of the samples of these rocks many of the calcite crystals have been stained red by oxide of iron. The rock is both coarse and fine in grain, and is semi-crystalline. Some of the samples are mainly composed of little globular bodies. These are "distinctly dark in colour and are cemented in a somewhat lighter matrix. Larger crystals of calcite are scattered throughout the mass. The little spheres appear to

be made of a single crystal of calcite and do not show concretionary structure. They are probably to be ascribed to an organic (encrinal) origin." The massive character of the limestone in this quarry is shown in Plate .

Two and a half miles N.25°E. of this locality there is a comparatively large outcrop of the Chazy. Plate is a view of the western side of the outcrop, where the rocks have been quarried to some extent. The beds are dipping about 5° to the southeast. In this quarry, and in a smaller one about 100 yards to the east, the beds are massive, gray, coarsely crystalline limestones, often spotted with reddish-colored calcite crystals and with iron stains. They are abundantly fossiliferous, in some parts being almost entirely made up of fragmentary fossils. On the surface of the highest bed in this exposure, and in the outcrop a short distance to the east, there are several irregularly outlined and limited areas resembling reef structures (Plate) and composed largely of corals and Stromatocerla.

Four and a quarter miles N.20°E. of this locality are the Grande Ligne quarries. These are situated a mile north of Grand Ligne School and half a mile west of the Canadian National Railway. The Otis quarry, the largest, is described by Parks (1914, p. 74) as follows: "The main

opening is about 300 feet long and 150 feet wide; it is said to extend to a depth of 40 feet..... [no more than 10 feet of the rock is now exposed, the rest being under water].

"The beds dip a little to the east of north at an angle of about 15^{0}. Strong vertical joints divide the formation due northwest and southeast at intervals which do not prohibit the obtaining of large blocks. A second, less defined set of joints runs due east and west and consequently cuts the major set at an angle of 45^{0}. The beds are somewhat irregular, but on the whole, they are thick, with a probable maximum of about 3 feet. As far as could be judged from the layers now exposed there seems to be a considerable variation in the character of the stone even within the same bed. The upper layer, at the southwest side, is blue in colour and is largely made up of broken shells, ...towards the northeast this bed is less uniform, with smooth argillaceous bands, wavy veinlets of calcite parallel to the major jointing, and large scattered crystals of pink calcite.....Some of the lower beds are of different character and yield a grey uniform crystalline stone.... ." Two smaller quarries are close to the Otis, on its western and eastern sides; these are known as the Perron and Poirier quarries. They are shallow, and the rocks exposed are identical with layers in the Otis quarry.

Ells (1896, p. 48J) stated that from the Legeault quarry the Chazy "can be traced northward by a somewhat well-defined escarpment to the vicinity of Grande Ligne. The contact here between the Chazy and the Utica of the Richelieu plain, is well marked by a ridge, which is about one mile north-west of the Grande Ligne station. Here some quarries occur in the Chazy limestone about one mile west of the contact.....A short distance north....., the Chazy sinks again to the level of the plain and the country is presumably occupied by the Trenton and more recent formations." What Ells meant by "escarpment" is not clear from the topography, but the "ridge" exists, and there is little doubt that this is one of the beaches that mark the contraction of a once more widespread Lake Champlain.

A mile west of the Otis and adjacent quarries, on the northern side of the road from Grande Ligne, there is exposed in another quarry quite a different type of limestone from those described above. This rock is not as coarsely crystalline as some of the Chazy, its color is a darker shade of gray, and it contains enough magnesium to give it an appearance more or less typical of the dolomites of the area. Fossils were not common here, but the few brachiopods and one bryozoan collected were identical with forms found in the Chazy exposures.

The only other Chazy outcrops seen are almost directly south of the last mentioned quarry, on the eastern side of the Grand Ligne road. Here the presence of numerous Stromatocerıa and forms which superficially resemble Eospongia, but which are probably corals, and the occurrence of other fossils in rather restricted patches, give the impression of a reef formation. A somewhat similar rock was mentioned above as occurring in the outcrop between the Legeault and Grande Ligne quarries, but the two exposures are too far apart to refer them definitely to the same zone. In the outcrop one-half mile distant from the road, the typical gray, crystalline rock is interbedded with a few layers of extremely dense or fine-grained, dove-colored limestone.

Among the "Analyses of Chazy limestones" Goudge (1927, p. 12) gives the following for the rocks of two exposures in the Western District of the Lacolle Quadrange:

	Otis Quarry	Outcrop on land of A. Fortin, 1 mile SW. of Napierville.
Insoluble mineral matter...	2.72	3.76
Ferric oxide.....	0.71	0.14
Alumina.....	0.17	0.06
Calcium carbonate.....	85.35	91.60
Magnesium carbonate.....	10.24	3.44

Thickness and Stratigraphic Relations. The thickness of the Chazy in the Western District can only be inferred from its thickness in other areas. In this District the exposures are few, and the structure varies from one exposure to the next. All that is known is that the formation has been quarried to a depth of about 40 feet near Grand Ligne.

Most of the published data regarding the Chazy formation in the Champlain Valley, Quebec, and the Ottawa Valley is brought together by Raymond (1906) in his paper "The Chazy Formation and Its Fauna". Following Brainerd and Seely, the thickness of the Chazy at the type section, Chazy, New York, is given at 732 feet. About 19 miles south of Chazy Village, at Valcour Island, the thickness is 890 feet. About 50 miles still farther south, at Crown Point, the thickness has decreased to 306 feet, and apparently it is only the middle division of the Chazy and Valcour sections that is here represented. The most southern exposure of the Chazy in the Champlain Valley is at Orwell, Vermont, five or six miles east of the Lake, where the thickness is reported to be 60 feet. North of Chazy Village the thickness is not definitely known, but Raymond remarks that "From Ells' statement it is probable that the thickness does not decrease north of the Canadian line. At Montreal, Ami estimates the thickness of all formations from the Potsdam to the Lorraine, at only

1,275 feet, thus allowing only 300 feet for the Chazy, and about the same for the Beekmantown, but he states that a well boring reached the Potsdam at a depth of 2,500 feet which, if the strata were horizontal, would allow 600 feet for the Chazy and 1,200 for the Beekmantown. The writer is inclined to believe that Dr. Ami has greatly underestimated the thickness of both these formations" (1906, p. 507). In this connection it must be remembered that, as pointed out by Ami, the sediments around Montreal are cut and intruded by dikes and sills which, if not discounted, would give an erroneous impression of the thicknesses of the various formations. Certainly there is no evidence in the undisturbed strata surrounding Montreal that the thickness of the Chazy greatly exceeds 300 feet.

For the Ottawa Valley region Raymond states that the Chazy is not more than 200 feet in thickness and this is considered to be equivalent to the upper part of the Chazy in the Champlain Valley. At the Mingan Islands, 600 miles to the northwest of Montreal, in the St. Lawrence River, the Chazy is estimated to be 500 feet. Here the Chazy is apparently as young, at least, as the youngest Chazy of the Champlain Valley (Schuchert and Twenhofel, 1910, p. 693).

From the above, it would seem that the deepest part of the Chazy basin of New York and Quebec lay approximately

in the area between Chazy Village and Valcour Island. Although not very far removed from this area, the Crown Point region first received deposits at a distinctly later period in the Chazy. Such would seem to be true also of the Montreal and Ottawa Valley regions, from which no Chazy save-Upper has been reported. The Chazy limestones of the Western District of the Lacolle quadrangle also belong to the upper part of that formation.

Hence the conclusions seem warranted that the thickness of the Chazy does not decrease northward from Chazy Village, and that in the northwestern part of the Lacolle quadrangle the thickness can not be much more than 300 feet, since only the Upper Chazy outcrops. If the Lower and Middle Chazy were deposited in this area they lie to the east of the exposures now observable and are masked by younger Ordovician deposits.

In the Lacolle quadrangle the next younger formation to the Chazy is the Lacolle conglomerate of Trenton age. The Lowville and Black River formations are missing here. Whether their absence is due to non-deposition, or to their having been eroded during the interval immediately preceding the formation of the Lacolle conglomerate is not known. Inasmuch as the Lacolle conglomerate is known to lie upon an unconformity that truncates both Beauharnois and Upper

Chazy, thus eliminating the latter in the southern part of the sheet, it is by no means impossible, except for the limitations expressed in the preceding paragraphs, that this unconformity may also account for the absence of Middle and Upper Chazy, Lowville, and Black River. The significance of this is discussed more fully under the Lacolle conglomerate.

Fauna and Correlation. The following is the list of fossils from the Grande Ligne quarries given by Ami in the Appendix to Ells report (1896), and revised by Raymond (1906, p. 554 and later):

Stromatocerium sp.
Blastoidocrinus carchariodens Billings
Palaeocystites tenuiradiatus (Hall)
Palaeocystites sp.
Cystidean Fragments, undetermined
Stictopora cf. glomerata Hall
Amplexopora (?) sp.
Dicranopora sp.
Solenopora sp.
Rafinesquina sp.
Hebertella borealis (Billings)
Dinorthis (Plaesomys) platys (Billings)
Clitambonites porcia (Billings)
Dalmanella perveta [This must be a species of Hebertella"--Raymond]
Camarotoechia plena (Hall)
Zygospira acutirostris (Hall)
Triplesia sp.
Metoptoma sp.
Raphistoma staminoun (Hall)
Hyolithes (?) sp.
Cameroceras velox (Billings)

Bathyurus spiniger (Hall)
Isotelus canalis (Hall) /"Probably Isotelus harrisi" -- Raymond/

Thaleops ovatus Conrad
Bumastus globosus (Billings)
Illaenus bayfieldi Billings
Leperditia canadensis Jones

The following as a list of fossils so far identified by the junior author from the Legeault quarry, one and a half miles N.50°W. of St. Valentin (Stottsville):

Palaeocystites tenuiradiatus (Hall)
Cystid plates and fragments of stems very abundant
Bryozoa -- varied and abundant
Orthis sp.
Hebertella vulgaris Raymond
Hebertella borealis (Billings)
Hebertella sp.
Rafinesquina distans Raymond
Rafinesquina sp.
Leptaena? sp.
Camarotoechia major Raymond
Camarotoechia pristina Raymond
Camarotoechia plena (Hall)
Camarotoechia sp.
Camarella sp.
Zygospira? sp.
Archinacella? propria Raymond
Palaeacmea? sp.
Gyronema sp.
Trochonema hudsoni? Raymond
Raphistoma striatum (Emmons)
Raphistoma stamineum Hall
Raphistoma n. sp.
Cephalopods -- a few straight forms
Eoharpes sp.

Isotelus beta Raymond
Illaenus tumidifrons Billings
Illaenus sp.
Leperditia sp.

Although much work remains to be done on the fauna of the Chazy formation in this and surrounding areas, the evidence at hand is sufficient to make its correlation with the upper 200 feet of the Chazy at Valcour Island, where the formation is at its thickest, fairly probable. Most of the species in the above lists range from the base, or nearly so, to the top of the Valcour Island Chazy, but the following forms common to both regions, have not been found below the upper 200 feet on Valcour Island and are considered to be diagnostic of the Upper Chazy, sometimes referred to as the "Valcour formation".

Camarotoechia plena
Camarotoechia major
Rafinesquina distans

On the other hand, the following forms from the Chazy of the Western District have not been reported from the upper 200 feet of the New York Chazy, although they do occur at lower horizons. In no case however are they considered of as great stratigraphic value as the three species listed above.

Camarotoechia pristina
Hebertella borealis
Archinacella? propria
Trochonema hudsoni?
Raphistoma striatum
Isotelus beta

And finally, the following species occur in the Chazy of the Western District and in the localities indicated below, but not in the New York Chazy:

Cameroceras velox (Mingan, Montreal and Bizard Islands)
Clitambonites porcia (2 miles south of Montreal)
Illaenus fratemus (Div's L, N, and P, Newfoundland)
Illaenus tumidifrons (Div. P, Newfoundland)
Illaenus bayfieldi (Mingan Islands).

Raymond's conclusion (1906, p. 568) regarding the stratigraphy of the Chazy beds was that "it would seem that in this region there was a shallow sea invading south and west on a slowly sinking land. Since the Chazy fauna seems to be developed less directly from the Beekmantown fauna of the Lake Champlain region than from that of Newfoundland, and since new European types are added to the American fauna during Chazy time, it seems probable that the sea was more constant and open toward the east or the northeast."

This carries implications of considerable importance. The Lacolle Chazy lies approximately on the strike of the Chazy and Valcour Island exposures. An invading sea from Newfoundland

would then have passed over Lacolle before reaching Valcour Island, and yet the latter place has a complete section whereas only Upper Chazy occurs near Lacolle. Two possibilities suggest themselves. First, there was at Valcour Island, the debouchure of an eastern trough whose waters spilled westwards throughout Chazy time, not reaching Lacolle until about the beginning of the Upper Chazy and ultimately spreading north to Montreal, Jolliette, and west to Ottawa before the epoch closed. Or, secondly, perhaps Lower and Middle Chazy were deposited near Lacolle but in a restricted basin, and were covered by Upper Chazy when those deposits were spread widely over the area north and west. These Lower and Middle Chazy then would only be obtainable in drillings east of Lacolle. Of the two, the former seems to be the preferable, especially as we are now fairly certain that a European invasion of a trough further east actually took place, bringing with it the Telephus bearing fauna noted by Ulrich (1929). This fauna is as yet largely unknown, but a large collection in the possession of the Canadian Survey awaits identification. More exact stratigraphical correlation between the Lacolle and Lake Champlain Chazy and these Telephus-bearing beds of European origin must wait upon the working of the Telephus fauna.

Nowhere within this district can there be seen

the lowest of the local development of the Chazy beds. However, elsewhere in New York and the Ottawa Valley the Chazy begins with a basal sandstone which doubtless represents the primal deposit of an advancing sea over an unconformity developed upon the Beekmantown strata. This is particularly true in the Ottawa Valley where the Aylmer sandstone lies upon the Beekmantown and is succeeded by the Aylmer Limestone, both types containing practically the same fossils. At Orwell, N.Y., and on Valcour Island, N.Y., basal sandstones occur, but these are not, of course, of the same age. At Valcour Island, where the section is most complete, it is basal Lower Chazy, at Orwell, Vt. it is basal Middle Chazy, and in the Ottawa Valley it is basal Upper Chazy.

Also, in the Champlain region the Chazy closed with emergence, the succeeding formation, the Lowville, lying upon the Chazy unconformably, usually with a basal sandstone, and sometimes with obvious irregularities in the contact. In the Lacolle area the next formation is the Lacolle conglomerate but inasmuch as this contains boulders of Trenton (lower) limestone it is of little help as evidence of the events of the Chazy-Trenton interval. Information regarding the top of the Chazy is lacking in the Montreal region.

Enough however, has been said to indicate the writers' opinion that the Chazy rocks were deposited in a

small local basin shaped somewhat as in the accompanying sketch. Chazyan waters first spilled westwards from the main Appalachian geosyncline to form the Lower Chazy basin around Valcour Island and Chazy, N.Y. Later, in Middle Chazy time, invasion to the south occurred, the waters attaining Orwell, Vt. and probably further, but not making any progress to the north of the Valcour-Chazy basin where Middle Chazy sediments covered the Lower Chazy; and at last a reverse tilt sent the Upper Chazy sea far northwards over the Lacolle area, to and beyond the St. Lawrence, and westwards to Ottawa. Meanwhile the Valcour-Chazy area continued submerged so that there, and there alone, are to be found Lower, Middle, and Upper Chazy deposits. Finally the Chazy sea withdrew whence it came and left the region emergent.

Lacolle Conglomerate. The Lacolle conglomerate formation has not received previous notice in the literature, a circumstance that is rather strange considering its conspicuous and easily accessible exposures, which occur from the International Boundary almost to the northern limit of the quadrangle. The formation is of considerable interest, resting as it does upon the Beauharnois dolomite in some places, the Upper Chazy in others, and being Trenton in age.

Distribution and Lithology. Almost all of the exposures of this formation south of Lacolle Village show a predominance of unfossiliferous dolomite phenoclasts, with a few limestone phenoclasts that occasionally carry fossils, all apparently derived from the Beauharnois formation. On the other hand, to the north of the village, though dolomite phenoclasts predominate there also, they are mixed with fossiliferous limestone phenoclasts which came from the Chazy as well as from some low horizon in the Trenton.

What is this?

In the outcrop at the International Boundary, all of the phenoclasts that can be seen are dolomitic, indistinguishable from the dolomite of the Beauharnois formation, sub-angular to angular, and vary in diameter to six feet. What little matrix there is is made up of small fragments of dolomite in a calcareous cement. Tw-thirds of a mile north of this locality, another exposure shows a small patch of conglomerate directly overlying a ten-foot development of the Beauharnois. The phenoclasts here are of two types; one is relatively pure,

No member of the Survey staff knows this term now in I find its definition in the library. Suggest deletion WC

dark gray, brownish-weathering dolomite; and the other is gray, highly arenaceous dolomite. Both types are identical with the interbedded dolomite and arenaceous dolomite below. The actual contact of the conglomerate with the beds below is obscure, but the respective positions of the two formations gives the impression that the conglomerate fills hollows or depressions in the stratified layers.

Two and a half miles north of the latter outcrop, on the north-south road branching from the King Edward highway near Odelltown, this conglomerate again occurs. At this place the conglomerate is not entirely made up of dolomite and arenaceous dolomite phenoclasts, there being a few phenoclasts of limestone as well. The latter are gray on fresh surfaces, and light gray or dove in color when weathered. For the most part they are crystalline, but two or three are non-crystalline and very dense or fine-grained. Lithologically these limestone phenoclasts have a closer resemblance to the limestone beds occurring in the Beauharnois formation than to any other limestone found in place in the Western District. They are comparatively small, varying in diameter from six inches up to one and a half feet. The dolomite phenoclasts, again being either relatively pure or sandy, vary in size from small "pebbles" to blocks with a length of twnety-five feet and a thickness of four feet. These large masses are confined

to the west side of the conglomerate outcrop, and overlie, but cannot be seen in actual contact with, horizontal beds of arenaceous dolomite of the Beauharnois formation.

The jumbled nature of the conglomerate, the large size and angularity of many of the phenoclasts, and the con confinement of these large phenoclasts to one side (the west) of the outcrop, suggests that much of the material of the conglomerate was not transported any great distance, the agencies that broke up the beds being heavy seas and solution.

One of the crystalline limestone phenoclasts in this conglomerate contains a few fragments of trilobites, mainly free cheeks and genal spines. One of the fairly well preserved cranidium was found and an almost entire pygidium. The latter resembles a minute Bathyurellus or Dolichometopus, while the cephalon is similar to that of a Leiostegium. The genus Bathyurellus has been reported from Ozarkian, Canadian, and Chazyan formations; Dolichometopus seems to be confined to the Canadian or Beekmantown in America and the genus Leiostegium has never been reported from the Chazy basin. Thus, although fossils are found in the phenoclasts of this exposure, they are by themselves, of little use in determining the age of the conglomerate.

Immediately underlying the conglomerate described above, on the western side, there is exposed a small amount

of flat-lying, arenaceous, dolomite carrying "Ophiletas" -- listed above as Lecanospira conferta Ulrich.

Five-eighths of a mile northeast of this outcrop, or one and a quarter miles south of Lacolle, are two exposures of conglomerate, one on either side of the King Edward highway. In the eastern part of the conglomerate on the west side of the highway, there are more than the usual number of limestone phenoclasts. The outcrop measures about 300 feet across the strike, but even in that distance the limestone phenoclasts decrease in number going westward, until, at the western side of the outcrop, they are very rare, and the conglomerate is made up almost exclusively of dolomite and arenaceous dolomite phenoclasts. Here again, as in the outcrop last described, the phenoclasts on the western side are extremely angular, and many of them are large, although never as large as in the outcrop to the southwest. Also, on the western side of the outcrop, the conglomerate overlies flat beds of arenaceous dolomite. The contact shows little sign of erosion in the dolomite beds.

On the eastern side of the highway in this locality there are two outcrops, the northern one being conglomeratic, and the southern consisting of massive, dark gray, somewhat areaceous, crystalline, dolomite, in flat-lying beds. The relative positions of these outcrops indicated that the

conglomerate overlies the dolomite which is here an inlier within the Lacolle formation. No fossils were found in either the dolomite or the conglomerate, although the latter contained several limestone phenoclasts.

One-half mile north of these outcrops, and about the same distance south of Lacolle Village, conglomerate outcrops in two knolls which are separated from each other by about 400 feet of drift, in a north-south direction. The more northern of these contains more dolomite than limestone phenoclasts, the latter being abundantly fossiliferous, with faunas ranging above the Chazy. On the eastern side of the southern conglomerate outcrop there are more limestone than dolomite phenoclasts, with many of the limestones containing fossils in abundance, some of which are not known to range below the Trenton. A few feet to the west and north after a drift-covered interval, flat-lying dolomite occurs, with a border of conglomerate on its western and northern sides. The dolomite is arenaceous, and is identical with dolomite seen in the Beauharnois formation, being apparently an erosion remnant of that formation. In the conglomerate on the western side of the dolomite, limestone phenoclasts are conspicuously rare, but are more common around the northern end.

One half mile north of the outcrops mentioned above, on the eastern side of the highway in Lacolle Village, conglomerate again occurs. There are at least six varieties of phenoclasts, half of them being arenaceous dolomites, relatively pure dolomites, and limestones, which can not be distinguished from beds in the Beauharnois formation. The remaining varieties are limestones, often very fossiliferous; some of these are finely crystalline to compact and fine-grained, but most are conspicuously crystalline. The phenoclasts vary in size from minute fragments in the matrix to blocks measuring twelve feet in length and one foot or more in thickness. Some of the phenoclasts are themselves conglomeratic, being composed of angular fragments of dark and grayish shales in a calcareous matrix or cement; the fragments or phenoclasts averaging less than two inches in length. Very rarely are any of the phenoclasts rounded. Most of them are at best sub-angular, and many do not show any sign of attrition (Plate). The northern part of the exposure is made up mainly of dolomite phenoclasts, and about 500 feet N.20°E., in the bed of the Lacolle River, another and smaller outcrop has this same peculiarity.

Slightly west of north of the larger conglomerate outcrop, five-eighths of a mile distant, and on the eastern side of the highway, conglomerate is met with again. The eastern side of this outcrop is massive, dark-gray, brownish-

weathering, dolomite, apparently in flat beds. Only a small amount of this rock is exposed, but it is thought to be in place and not a phenoclast. Conglomerate occurs on the western side of it, and at a slightly lower altitude, as if surrounding an erosion remnant or "island" of the Beauharnois dolomite. On the western side of the outcrop are strata which again appear to be beds in place; they are dove-weathering, gray, crystalline, limestones, in beds varying from one inch to six inches in thickness. Some of the layers are conglomeratic carrying small pebbles of limestone up to an inch or more in length which occur in a matrix of much the same type of limestone. The "beds" have a strike of E.30°S., and dip to the north at 60°. Because of this abnormal structure, and because of the position of the limestones relative to the dolomite mentioned above, they are believed to constitute one large, slab-like, fossiliferous phenoclast of the Chazy in the Lacolle conglomerate. This belief is strengthened by the occurrence above the limestone layers of a conglomerate which contains phenoclasts carrying fossils of Chazyan and younger age. The conglomerate is not in contact with either the dolomite beds "above" or the limestone layers below. Most of the phenoclasts here are grayish, semi-crystalline to crystalline, dove-weathering limestones.

Conglomerate is again exposed one half mile N.30°E.

of this outcrop. Here the great majority of the phenoclasts are gray, crystalline, brownish-weathering dolomites. Although limestone phenoclasts occur throughout, they are more or less confined to the eastern side and middle of the outcrop, which is about 250 feet long and 75 feet wide. The limestone phenoclasts are much the same as those described from the outcrop in Lacolle Village, and they carry similar faunas. Conglomerate within conglomerate was also noted. Some of the limestone phenoclasts are fairly well rounded, but most are angular, or, at best, sub-angular. The dolomite phenoclasts show little sign of wear. There is no particular allignment of the phenoclasts, and no size uniformity. They vary from small "pebbles" to blocks measuring six to eight feet in length.

One quarter mile due north of this outcrop conglomerate is meagrely exposed, the phenoclasts are mainly dolomitic, and smaller than those of the above outcrop. This is the most northern observed exposure of conglomerate on the general N.10°E. line of conglomerate outcrops that extends from the Boundary Line through the village of Lacolle.

One other conglomerate exposure remains to be mentioned, although it is off the general N.10°E. line of strike of the Lacolle formation. This outcrop is about nine miles north of the last outcrop mentioned above, and

about three and a half miles northnorthwest of Napierville Village. The phenoclasts are of two main types: first, a grayish, crystalline limestone, weathering to a light grayish-blue; and second, a very fine-grained, light gray, "marbly" limestone. Of considerable significance is the fact that no dolomite phenoclasts were noticed. Fossils are present in some of the phenoclasts, but are not abundant, and are usually fragmentary. However, this conglomerate is definitely younger than the local exposures of the Chazy, for one phenoclasts contained brachiopods identical with forms found in the Chazy quarries of Grande Ligne and elsewhere. The phenoclasts vary in size from small fragments up to blocks three feet in length and one and a half feet across. Many of the smaller phenoclasts are very sharply angular, while the larger phenoclasts are sub-angular to angular.

Fauna and Correlation. No fossils have as yet been found in the matrix of this formation. Many of the phenoclasts are very fossiliferous, however, and from their study as well as from the apparent stratigraphic position of the formation, its age may be approximated.

The conglomerate contains phenoclasts of at least three older formations, the Beauharnois, Chazy, and Trenton. The Beauharnois phenoclasts are referred to that age on lithological evidence alone. In all of the conglomerate

exposures except one these predominate greatly over phenoclasts of other ages. The exception is the most northern exposure of the formation, three and a half miles north-northeast of Napierville, just described, where the phenoclasts are either all of Chazy age or are mainly Chazy, with a few belonging to a somewhat younger horizon. Whether or not the Lowville and Black River formations are represented among the phenoclasts is not known as yet, but the Trenton has a relatively large representation. Phenoclasts of Trenton age are common in the exposures at Lacolle Village, and also one-half mile south of the village on the eastern side of the King Edward highway. Preliminary study of the faunas has been confined mainly to the Trenton phenoclasts, since they are apparently the youngest in the formation.

From the outcrop in Lacolle Village the following forms have been identified (Field locality 4E-1 Lacolle)

Phenoclast 5--

Hormotoma gracilis Hall (numerous, with varieties)
Lophospira cf. perforata Ulrich and Scofield
Schizolopha cf. moorei? Ulrich
Fusispira sp.
Tetranota? sp.

Phenoclast 6--

Hormotoma gracilis Hall
Fusispira? sp.
Leperditia sp., or Isochilina sp.

The exposure one half mile south of Lacolle Village (Field Locality 4E-7 Lacolle) contains:

Phenoclast 1--

Isotelus sp.
Plectambonites sericeus (Sowerby)
Rafinesquina alternata (Emmons)

Phenoclast 3--

Pterygometopus sp.

Phenoclast 4--

Cryptolithus sp.
Cryptolithus tesselatus Green (abundant)
Encrinurus? sp.
Homotelus sp.
Platystrophia lynx (Eichwald)

Phenoclast 5--

Platystrophia lynx (common)

Phenoclast 6--

Cryptolithus tesselatus Green
Pterygometopus sp.
Plectambonites sericeus (Sowerby) (abundant)

Phenoclast 7--

Rafinesquina alternata (common)

The brachiopods in the above list are of little value in determining the age of the formation, all three being long lived forms. Plectambonites sericeus would indicate, however, that the conglomerate is not older than Black River.

The gastropods are also indefinite, although Lophospira perforata has been found so far only in the Trenton.

The ostracod and trilobite genera given are also long lived. But the species Cryptolithus tesselatus, although possibly ranging above the Trenton, is not known to go below that group (Ruedemann, 1926, pp. 109 - 113).

The stratigraphic relations of the Lacolle conglomerate in the quadrangle itself give little clue to its age. The youngest formation exposed to the west, and underlying the conglomerate, is the Upper Chazy, while to the east there are shales of Upper Trenton or Utica age, but a normal fault separates the shales from the conglomerate. However, strata of Trenton age have been reported from a locality a few miles to the north of the quadrangle, in the neighborhood of St. Johns. In the general region west of the Tracy Brook Fault, the strata are near the axis of the low fold, termed by Logan the "Chambly anticlinal", and are dipping gently to the north. Thus, the Trenton in the vicinity of St. Johns would overlie the Lacolle conglomerate.

The faunal evidence indicates that the Lacolle cannot be older than Trenton, and the stratigraphic evidence indicates that it cannot be younger. It is not basal Trenton in age,

for it contains Cryptolithus tesselatus, a species that first comes in "40 to 80 feet above the base of the Trenton" (Stetson, 1927, p. 91) in the St. Lawrence and Champlain valleys. Inasmuch as there is a considerable development of Trenton shales (Stony Point) east of the Tracy Brook Fault it seems as if the Lacolle conglomerate should be low in the Trenton. For the present we shall provicionally refer it to the Lower Trenton.

Origin and Significance. Inasmuch as conglomerate of the nature of the Lacolle has not been reported from the Trenton in other areas, it is concluded that it owed its origin to local conditions. From the absence of signs of attrition in many of the phenoclasts it is judged that they had not been transported any great distance. The predominance of dolomite phenoclasts over those of any other type, even over all other types taken collectively, is important, for their most probable source is the Beauharnois formation, which, as now exposed, occurs but a short distance to the west of the main outcrops of conglomerate. In the most northern exposure of the Lacolle formation there are no dolomite phenoclasts, and it is assumed from this fact that erosion did not there get down to the Beekmantown, not so much because the erosional and conglomerate-forming agencies were less effective in the northern than in the southern

part of the area as because of a tilt given to the strata before the formation of the conglomerate, bringing the Beauharnois dolomite to the surface in the southern part.

It would seem, therefore, that the condition which initiated the formation of the Lacolle conglomerate was a local tilting of the strata, after an indefinite but small amount of the Trenton had been deposited -- a tilting which was more pronounced in the southern part of the area, where the Beekmantown was brought up to the level of erosion, and which, in the northern part, brought only the Chazy and younger formations up to that level.

The Shales of the Western District (Stony Point and Iberville). The shaly strata described below have generally been considered to be of Utica age. Recent work by Ruedemann (1921) and others has shown, however, that much, if not all, of the so-called Utica shale in the Champlain Valley should be referred to the Trenton; and it is possible that this applies also to the shales of the Western District here described.

The first mention of these strata appeared in the Report of Progress for 1847-48, where Logan stated that the "Utica shale" follows the Trenton limestone from Montreal to St. Johns, and along "the east side of the Richelieu, with a

width, extending beyond Henrysville, it constitutes all that point on Lake Champlain lying between the exit of the Lake and Missisquoi Bay". Later Logan (1863, p. 208) noted the occurrence of Triarthrus becki near Henrysville.

In 1892, Ami (1892, p. 22) listed the fossils found by Ells at three localities in the Western District. These fossils, are relisted by Ami in the Appendix to Ells' report.

In 1896, Ells (1896, p. 21) reported on the "Utica" of the area to the south and east of Montreal, which includes the Lacolle Quadrangle, as follows; "To the south and east of Montreal the Utica appears but rarely. Black shales with characteristic fossils show in the bed of the Little Montreal River at L'Acadie, west of St. Johns, and, further south, they are well exposed in the Lacolle River, half a mile east of Lacolle Village. On the east side of the Richelieu, west of Clarenceville, on the road from Lacolle, black graphitic shales are exposed which contain graptolites and other fossils of a lower horizon. These are probably the equivalents of the Quebec City rocks, overlain by the Utica on either side. The typical Utica occurs again at Clarenceville and for some distance east towards Missisquoi Bay". Presumably the strata west of and beneath the Bay were considered by Ells to be Trenton; those of the western shore, immediately underlying

the St. Lawrence and Champlain Fault, were stated to be "probably lower" Trenton (1896, p. 32J).

Distribution, Lithology, and Structure. The "Shales of the Western District" occupy about half of the Lacolle quadrangle, i.e. the area between the "St. Lawrence and Champlain fault" on the east, and the Tracy Brook fault on the west, and extending beyond the northern and southern limits of the area. On the western side of the Richelieu River, only three questionable exposures were found, and as nothing was found indubitably in place, the structure could not be determined. On the eastern side of the Richelieu outcrops are extremely rare north of a line drawn between Henryville and Notre Dame de Stanbridge; in an area of about 130 square miles there are less than a dozen outcrops, in which the shaly strata are meagrely exposed, considerably sheared, thin-cleaving, and unfossiliferous. The observable dips were commonly to the east and northeast at angles of less than 20°.

South of the line between the two towns mentioned above, outcrops are more frequent. The road from Henryville to Clarenceville follows an outcrop ridge, with low land on either side, and with a general N.20°-30°E. strike. This ridge is anticlinal, with the dips to the west steeper on the whole

than those to the east; it continues to the south of Clarenceville for one mile, when it gives place to low swampy land. The strata of the ridge are strongly calcareous, dark-colored shales, weathering gray or buff, and interstratified with occasional black, fine-grained, argillaceous limestones in thin beds; graptolites and Triarthrus becki are common throughout. Between this ridge, if continued southward to the boundary line from Clarenceville, and the Richelieu River, there are several exposures of the same calcareous shale, with graptolites and Triarthrus becki. Limestone bands again occur here, interstratified with the shale and occasional small exposures are composed almost entirely of limestone in beds from less than one inch to two inches thick. No fossils were found in the limestone.

The area described by Ells as Quebec City (mapped as D3A, Farnham slates, on the map accompanying his report) extends from the road running due west from Henryville, where it is about half a mile wide, southward past Clarenceville to the boundary line, and apparently continues across the line into Alburg township, Vermont. On the boundary line, this area is about a mile and a half wide, and it has the same width between Noyan and Clarenceville, where its eastern limit is about a quarter of a mile west of the latter village. In this area there are no outcrops at all north of the Clarenceville-Noyan road and south of this road all of the

rocks observed are identical lithologically and faunally with those of the ridge running between Henryville and Clarenceville. The occurrence of Triarthrus becki in these rocks is sufficient evidence on which to state that they can not be Quebec City, for that formation belongs to the so-called "Levis channel" and is not known elsewhere on the western side of the St. Lawrence and Champlain fault. Ruedemann has stated that the fossils listed above as Quebec City indicate a Normanskill age.

Eastward from Henryville and Clarenceville toward Missisquoi Bay only a few scattered exposures of shaly strata occur. These shales are less calcareous than those previously described, and are more thin-cleaving and brittle. Traces of graptolites were seen in them.

On the western shore of Peel Head Bay are good exposures of dark gray to black calcareous shales and argillaceous limestones, weathering to buff and brownish colors, all considerably sheared, and crossed by joints which cut the strata at right angles to the strike (Plate). About one mile south of Martin (almost directly opposite Philipsburg) is a small exposure on the lake shore of the same type of rock. And, about two miles farther south, at Province Point, on the boundary line, is a third exposure. The general lithological character of these rocks places

them with the rocks of the Clarenceville-Henryville ridge, and this was supported by finding Triarthus becki in quantity about one mile south of the boundary line, on the lake shore near Alburg Springs. At this place the rocks are less sheared than those along the lake shore north of the boundary line, and are identical in appearance with those of Clarenceville. Rocks of the same general character were observed along the eastern shore of Alburg peninsula as well as at Stony Point, about one mile south of Rouses Point, in New York. At the latter place, Triarthus becki again occurs associated with graptolites. There is little doubt that the shales lying between Missisquoi Bay and the Tracy Brook fault, in the Lacolle quadrangle, are but the northward continuation of the shales of Alburg peninsula and Stony Point.

The flat, drift-covered peninsula known as Jameson Point is bordered along its western side by slaty strata, some of which break into very thin plates, others are less fissile, and break into blocks of half-an-inch in thickness. Many of the strata are uniformly black in color, but some have very thin, light-colored bands one to two inches apart. On the eastern side of the Point, near its southern end, rocks of the same character are interstratified with calcareous, or calcareo-magnesian, brownish-weathering beds.

The rocks of Jameson Point differ from those along

the western shore of Peel Head Bay and from those of Clarenceville - Henryville in that they include brownish-weathering strata. And, although superficially the shales of the two areas resemble each other, an important difference is that the shales of Jameson Point are not calcareous; also a common feature in these shales, not observed in those to the west, is a pseudo-concretionary structure, which induces the rock to break, so as to produce rounded or nodular fragments.

Along the western shore of the Point the dips are constantly vertical, varying from 80°E. through the vertical to 80°W., while on the eastern side the dips are to the west at angles varying between 15° and 30°. The strike varies between due north and N.30°E. These structures may indicate an asymmetrical synclinal fold, with the steeper dips on the western side.

North of Missisquoi Bay and west of Pike River there are a few meagre exposures of dark gray to black, non-calcareous, thin-cleaving slate, which resembles the rock of Jameson Point only in its display of pseudo-concretionary phenomena. In the bed of Pike River, one-half mile south of the village of that name, there are shaly strata consisting of dark gray to black, argillaceous thin-cleaving shales, calcareous and more compact shales, and black, fine-grained limestones, which occasionally weather brownish -- all interstratified. The

beds strike N.20°E. and dip to the east at 25°. The same type of rock occurs in the bed of the river as far north as the crossroads north of Malmaison, a distance of three miles. In this distance the strike varies between N.8°W. and N.50°E., and the dip is even more inconstant.

The rocks exposed in the few outcrops within a mile or so to the west of Pike River are thin-cleaving, brittle, dark gray to black argillaceous slates. The same type of rock occurs eastward from the river to the St. Lawrence and Champlain fault, but is there interstratified with occasional calcareous and siliceous strata, usually in beds of about one inch in thickness. It seems practically impossible to harmonize the structures of the individual exposures, but the impressions received have been those of sharp synclinal and anticlinal folds plunging to the north , and in a few outcrops small northward-plunging folds can actually be demonstrated.

Along the eastern shore of Missisquoi Bay, from a point about one mile north of Philipsburg southward to the boundary line and beyond, strata quite comparable lithologically to those in the bed of Pike River, and in a lesser degree to those of Jameson Point, are occasionally exposed. Here again the structure is variable; the strike averages about N.25°E., and the dip, while varying several degrees, is constantly to the east. These rocks were well described by Gordon (1923,

p. 177) who wrote: "Just south of the little bay at the village of Philipsburg.....the shore is formed of black, slaty rocks carrying graptolites.....Except for their greater alteration and more pronounced cleavage and disturbance these rocks are much like those of Alburgh and North Hero. They carry firm, siliceous bands, weathering rusty brown, which from their fragmented condition and scattered arrangement among the more shaly layers bear testimony to the severe crushing which these rocks have suffered. In their deformational features these rocks are much like those which will be described for the lake shore south of St. Albans Bay".

Some of the deformation which these rocks have suffered is shown in Plates . It should be noted that although "siliceous" beds do occur in the shaly strata along the lake shore, they are subordinate in numbers to magnesian limestone beds which also weather "rusty brown".

In regard to these shales of the Western District, it does not seem practicable at the present time to distinguish more than two horizons on the basis of lithology. Over the greater part of the area fossils either have not been found or are too poorly preserved to be of assistance in separating the horizons. Supplementing the lithology, and even giving the most definite clue to the shale problem, is the structure, a general statement which would be that between the "St. Lawrence and Champlain fault" on the east and the Tracy Brook

fault on the west the shales are thrown into a series of folds plunging northerly and with northnortheasterly trending axes. It would be expected, therefore, that the older shaly strata would be exposed at the boundary line and younger strata to the north. The observable facts fit this expectation, for, between the boundary line and the road connecting Henryville and Pike River villages, the country is almost entirely underlain by the "Triarthrus beds" of Clarenceville and Henryville or what seem to be their lithological equivalents. (For the purpose of description these rocks will hereafter be termed the "Triarthus beds", Stony Point formation, Upper Trenton to distinguish them from the thin-cleaving argillaceous slates commonly found to the north of the Henryville-Notre Dame de Stanbridge line. These thin cleaving slates, Iberville formation, Utica, occasionally come down from the north into this area but in no case do they pass southward beyond the latitude of Clarenceville.) Near the crossing of the Philipsburg Morgan Corners road with the Wallace Sandstone Quarry railroad the thin cleaving slates are again seen, and the "Triarthrus beds" are exposed to the west-southwest on the shore of the bay.

The ~~reference of~~ slaty rocks on the eastern shore of Missisquoi Bay and those of Jameson Point are referred to the "Triarthrus beds" rather than to the thin-cleaving slates. It must be remembered that the strata of these localities, and notably those along

the eastern shore of the bay, have been subjected to considerably more stress than those to the west, and such lithological dissimilarities as do exist between the typical "Triarthrus beds" and those on the eastern shore of the bay may be due to alteration under pressure more than to any other cause. This correlation is supported by Gordon's conclusion, quoted above, that the shaly strata on the eastern shore of Missisquoi Bay [illegible] in Vermont are very much like those of Alburg and North Hero (Stony Point formation), except for their greater alteration and more pronounced cleavage and disturbance.

Although the thickness of the two horizons can not be determined their succession is considered to be as follows;

1. Upper horizon -- Dark gray, thin-cleaving, argillaceous slates, much sheared, with occasional siliceous and calcareous beds interstratified. The name Iberville shales is suggested for them because of their wide development in that portion of Iberville County ~~occurring~~ in ~~the~~ Lacolle Quadrangle.
2. Lower horizon -- Dark gray to black, calcareous shales, more compact than the above, interstratified with numerous limestone and occasional siliceous strata (Triarthrus beds" of the preceding description). Considered to be the northward extension of the Stony Point shales.

On the map of the Lacolle sheet the boundary between these two formations should be understood to be necessarily approximate as to position. Also, although four synclines of the Iberville are shown, the folding is probably far more complicated than that would signify. In all probability the correct boundary, if observable, would show hundreds of minor complications of the boundary line, which for lack of evidence cannot even be indicated.

Age and Correlation. Of the two horizons in the "Shales of the Western District" only the lower has furnished recognizable species. A composite list of the fossils collected by Ells (1896, appendix) from this horizon is given below.

Might be Collingwood

- ? Cyathodictya reticulata (Walcott)
- Glossograptus quadrimucronatus (Hall)
- Lasiograptus mucronatus (Hall)
- Climacograptus sp. (prob. C. bicornis Hall)
- Plectambonites sericeus (Sowerby)
- Endoceras proteiforma Hall
- Triarthrus sp. cf. T. glaber Billings
- T. becki Green

eatoni?

To this list may be added from the present collections Climacograptus typicalis Hall and a form which Ruedemann referred to the group originally identified as "Climacograptus putillus", but which is now subdivided; the exact species was not determined, but it more closely resembles the Canajoharie forms than any others.

Canajoharie
Onondaga
Utica

The age of determination and correlation of this fauna are very unsatisfactory. The most that can be said at first glance is that it can not be as young as the Frankfort shale which, in New York, has its "basal limit defined by the top of the true Utica" (Ruedemann, 1912, p. 37), nor can it represent any horizon older than the Canajoharie. The Frankfort shale contains Climacograptus typicalis and Glossograptus quadrimucronatus, but has no other forms in common with the shale of the Lacolle quadrangle. On the other hand, the Canajoharie shale carries Climacograptus typicalis, "C. putillus", Glossograptus quadrimucronatus, Plectambonites sericeus, and Triarthrus becki. But the closest faunal resemblance is found between the Utica and the "Triarthrus beds", the only forms which occur in the Lacolle area and not in the Utica of New York are Lasiograptus mucronatus, Triarthrus glaber, and Triarthrus becki. Lasiograptus mucronatus is not reported elsewhere than in the "Chazy channel" shales and is considered to be a Normanskill species. Triarthrus glaber, although not known from the typical Utica of New York, occurs in the Gloucester shale of Quebec and Ontario, a formation which is considered to be equivalent to the typical Utica or younger. "Triarthrus becki" occurs in both the Trenton and the Utica, but Ruedemann (1925, p. 67) has shown that Triarthrus eatoni, originally separated from T. becki by Hall but later referred back to that species by the same author, is, in reality,

distinct from T. becki, and that the latter is confined to the Trenton, while T. eatoni does not go below the Utica.

Of the other fossils of these shales, Cyathodictya reticulata, whose identification was questioned by Ami, is known in New York only in the "upper Utica shale at Holland Patent, Oneida County" (Ruedemann, 1925a, p. 18). Climacograptus typicalis "is the most abundant graptolite of the Utica shale, but it appears already in the Trenton and passes into the Eden (ibid). It "is absent in the Snake Hill beds and likewise in the Canajoharie shale, except the very last stage at Dolgeville (Dolgeville beds), but is very common in parts of the Schenectady beds, probably the later stages. It thus does not seem to have reached New York in Trenton time. In the Utica it is the dominant fossil in the lowest division, but continues through all three divisions distinguished in the paper.

Climacograptus typicalis still occurs in the Frankfort..." (ibid, p. 59).

The Glossograptus quadrimucronatus listed by Ami may be the typical form of the species, or may be a mutation. Concerning the typical form, Ruedemann (ibid, p. 64) writes that it was "originally described from the black "Utica" shale from Lake St. John in Quebec. It is there, according to Raymond (Dresser, 1916, p. 39) associated with Leptobolus

(Gallmgrd.)

insignis, Endoceras proteiforme and Triarthrus glaber. This black shale, now termed the Gloucester formation by Raymond (1916, p. 255) overlies the Collingwood of Ontario and is probably younger than the Utica of New York, which at least in part is of Upper Cobourg age.....

"The typical form is now...known from Atwater creek shale, a Frankfort facies which in the Black River valley follows upon the Deer River black shale, which we believe to be equivalent to the Collingwood shale".

This review of the species found in the shales of the Western District shows that with the exception of Triarthrus becki and the form or forms of "Climacograptus putillus", the evidence favors a Utica, rather than a Trenton, age for the shales.

In writing on Grand Isle, Vermont, Ruedemann (1921, pp. 96-99) discusses not only the shales of Grand Isle, but their general occurrence throughout the Champlain valley. He stated (p.96) that the "black calcareous shale" at Ticonderoga and the "black shale" at Willsboro Point are referable to the Canajoharie, the fauna at the latter locality indicating the uppermost division of the Canajoharie. Ruedemann then stated that "There is but one outcrop of shale on the New York side of the lake between Willsboro Point and the Canadian boundary line, that at Stony Point, 1 1/2 miles south

of Rouses Point, and thus close to the international boundary. Here were found in hard, splintery, dark bluish-gray calcareous shale:

Climacograptus spiniferus Ruedemann c.
Glossograptus quadrimucronatus Hall c.
Lasiograptus eucharis (Hall) r.
Leptobilus insignis Hall r.
Triarthrus becki Green

"....Climacograptus spiniferus and Triarthrus becki point unmistakeably to the eastern shale belt and a northern continuation of the Martinsburg, Snake Hill and Canajoharie shales of Pennsylvania and New York into this northern Champlain region. As to the age of the rock we infer from these two fossils that it is still older than Utica and probably homotaxial to late Trenton, a conclusion that is not contradicted by the other graptolites because they also occur in the Snake Hill and Canajoharie shales, though ranging considerably higher up".

One and a half miles east of the Windmill Point exposures, along the lake shore at Alburg, Vermont, a fauna consisting of brachiopods, trilobites, and ostracods was found, ten species in all, none of which occurs in the shales of Stony Point, Windmill Point, or the Lacolle quadrangle. It is to be inferred from Dr. Ruedemann's discussion of the fauna of the shale at Alburg that it indicates a middle Trenton age, and he states (p. 98) that the Alburg shale

"forms a connecting link between the Canajoharie shale and the northern Trenton"; the Stony Point-Willsboro Point shale being the "northern Trenton".

On page 99 Ruedemann states: "The 'Utica' shale forms a broad belt in Vermont from the Canadian boundary line southward over the islands of the lake, especially North Hero and Grand Isle (see Perkins, 1904, p. 103) and attains a considerable thickness. This shale is described by the Vermont geologists as being remarkably barren of fossils, Triarthrus becki and "Diplograptus" being the only fossils mentioned as common in places. This combination of Triarthrus becki and Glossograptus quadrimucronatus (the "Diplograptus pristis" of earlier authors), as well as Climacograptus typicalis which the writer has collected on Grand Isle, indicates that the Stony Poin shale reaches, on the Vermont side, in pretty strong development, to the middle of the Champlain basin.

"There is, however, little doubt that the Canajoharie shale which reaches such great thickness along the Panton shore, only 30 miles south of South Hero, is still represented in the lower part of the black shale of the island and its fauna is still recognizable in the shaly limestone at Alburg, close to the Canadian boundary.....

"The black Ordovician, so-called 'Utica' shales of the Champlain basin consist then in the south entirely of Canajoharie shale; in the north prevailingly of the Stony Point shale. In the middle they may meet, the Stony Point shale resting upon the Canajoharie shales on Grand Isle and in the Vermont portion of the northern part of the basin; while on the New York side the Canajoharie shale is replaced by the peculiar facies of the Cumberland Head shale, the latter placing itself between the lower division of the true Trenton limestone and the black Stony Point shale".

Thus, in that part of the Champlain Valley lying between the boundary line and Grand Isle, the older shales are to the south and the younger to the north, as in the Lacolle quadrangle.

From the above discussion we conclude that there is no more logical correlative for the lower horizon of the Shales of the Western District of the Lacolle quadrangle than the Stony Point shale, in view of like fauna and geographic contiguity. Whether or not the Stony Point shale be considered as the uppermost Trenton of the Champlain Valley or as Utica is apparently a matter of individual preference, most of the fossils indicating, but not proving, the Utica age of the beds. However no man may be declared wrong unless it be agreed that Triarthrus becki is diagnostic of the Trenton,

and such has been urged by Ruedemann, in which case the Stony Point shale is Trenton. In this report it is considered to be Upper Trenton, and the Iberville shales Utica in age.

Structure.

Although described as "unfolded" rocks west of the Appalachian region, that description is only partly adequate. East of the Richelieu River folds are common, with dips between 0° and 90°, but dips of high angles are of very local importance and are not indicative of deep seated folds. In general the formations dip eastwards. The oldest rock in the district is the Potsdam sandstone, which outcrops in the southwestern corner of the area. This is practically flat, with dips never higher than 5°. The Beauharnois dolomite, covering the Potsdam, is also flat, 10° being the maximum dip observed, and that exceptionally high. The same may be said of the Chazy limestone. Thus, these three competent members of the area together with the Lacolle conglomerate, have all withstood the deformative effects of the Appalachian orogeny, which shows itself in them only in inconsiderable structural disturbances such as slight dips. The Tracy Brook fault separates these competent strata from the relatively incompetent strata to the east, comprising two formations, the Stony Point and Iberville shales. Both of these suffered tremendously in the overthrusting.

Close to and therefore below the frontal Appalachian thrust they have been smashed beyond recognition, shearing, sharp folding, and minor faulting contributing. In regard to the structure of these shales of the Western District, a general statement would be that between the St. Lawrence and Champlain fault on the east and the Tracy Brook fault on the west the shales are thrown into a series of folds plunging northerly, and with north-northwesterly trending axes, the intensity of the folding being greatest on the east and diminishing westwards. It would be expected, therefore, that the older shaly strata would be exposed at the boundary line.

In general then, the structure of the Western District is relatively simple. Near the course of the Champlain thrust the shales, with their interbedded limestones and occasional sandstones, are greatly deformed by shearing, sharp folding, and minor faulting. Going westward, away from the thrust, the folds broaden and flatten out, until, when the more competent strata of the western part of the District are reached, the folding is so gentle as to be more easily recognized by the distribution of the formations than by actual structures observed. On the western side of the Richelieu River the Potsdam, Beekmantown, Chazy and Trenton formations are affected by the low northward-plunging fold that was termed by Logan the "Chambly anticlinal". The sharper folds to the east of the River, in the Stony

Point and Iberville shales, also plunge to the north.

Faults are uncommon in the western district. Only one, the Tracy Brook fault, is mappable. This fault named by Cushing (1905, p. 570) with the down-throw on the eastern side, has brought the Stony Point shales against the older strata to the west -- the Lacolle conglomerate, the Upper Chazy and the Beauharnois. The age of this fault is uncertain. Keith (1923, p. 137) argues for a Triassic age. Schuchert (1930, p. 718) more recently, is convinced that they may more properly be referable to the Acadian Disturbance.

A second fault mapped by Cushing (ibid., p. 571) map, p. 572) cannot be identified north of the International Border. Cushing projected it to the border, but it probably dies out before the line is reached.

A discussion of the relationship between the rocks of this district and those of the eastern district as displayed along the course of the St. Lawrence - Champlain fault is deferred to the treatment of the Philipsburg fault block (see forward p.).

THE EASTERN DISTRICT

General Statement

The rocks of this district belong to the Appalachian physiographic and structural Province. They are all folded, and faulted, ~~and thrusted~~ to a greater or less degree. The ~~competent beds have remained~~ limestone, dolomite, limestone conglomerate, etc., whereas the shales have yielded to the folding and have become slates, ~~whose structure is well-nigh inexpricable~~. Lying beside, and in contact with, ~~the strata of the St. Lawrence lowlands, heretofore described as the~~ rocks of the Western District, these Appalachian strata show by their fossils that they were deposited in a different basin of accumulation which lay to the east of their present position.

The Eastern District is composed of the rocks of three thrust slices. The lowest, here called the Granby block, is only barely represented in this area. The intermediate one lies directly upon the rocks of the Western District along the frontal thrust, except for the northernmost mile, where the Granby block underlies it and rests upon the Western District. It is in turn covered by the rocks of the upper slice. These two latter rock units have their own distinctive stratigraphic succession which, in the intermediate or

Philipsburg block, is called the Philipsburg series, and in the eastern, uppermost, or Pigeon Hill block is called the Pigeon Hill series. These both consist of folded limestones, dolomites and slates, with an almost negligible amount of sandstone, but nowhere is the folding sufficiently complex to obscure the normal succession. The stratigraphic succession of these three series is shown in the correlation table opposite page .

Stratigraphy of the Pigeon Hill Series.

The Pigeon Hill block consists of a relatively minor amount of dolomite and limestone of Lower Cambrian age and a much greater, but actually indefinite, amount of younger slates of Upper Cambrian and possible Ordovician age. The component formations are discussed below.

Mallet Dolomite (Lower Cambrian). This formation which takes its name from Mallett Bay in Vermont, is well exposed in that state, but occurs in only one small outcrop in Canada. Discussion of its relations to the overlying formations will be included in the discussion of the Milton dolomite.

Milton dolomite (Lower Cambrian). What appears to be a single dolomite formation, crossing the International Boundary between the eastern and western valleys of Rock

River, is considered to be the continuation northward from Vermont of two formations, the Mallett and the Milton. These were named and their occurrence in Vermont described by Keith (1923). The distribution of these two dolomites and contiguous formations in Vermont, immediately south of the border has been mapped and published by the junior author (McGerrigle, 1930). In Quebec, the presence of two formations rather than one is postulated on their distribution in the contiguous parts of Vermont. No positive criteria for separation, such as lithological or faunal differences, have been noted as yet; therefore the two formations will be described, for the moment as one.

These Lower Cambrian dolomites have a breadth of outcrop on the boundary line of one and a half miles, gradually diminishing northwards to Rosenberg, a distance of three and three-quarter miles.

Lithology. Logan's description (1863, p. 283) of the lithology of this dolomite which he referred to the "Potsdam", is fairly complete, although based largely on the study of but one section, that along the boundary. His description follows:--- "Buff and whitish, brown-weathering sandy dolomite, holding a great amount of black and grey chert in angular fragments of various sizes up to a foot in length and six inches wide. The chert occasionally forms layers of a few inches, in which different shades of colour

coincide with the stratification. In some beds the fragments of chert make up the chief part of the rock, while in others it lies in scattered pieces. It is often associated with masses of white quartz, which occasionally appear as if filling geodes or druses."

Not all of the dolomite is sandy, for there are some large outcrops in which no sand grains were seen, and the rock is a rather pure, crystalline dolomite. The buff-weathering dolomite is more finely crystalline than that which weathers to darker colors. In the northern part of the exposure three beds of white quartzite occur. No quartzite was noticed elsewhere in beds. In other places it appears in patches which, in some cases, are clearly erosion remnants, but in others seem to be broken fragments of former beds, probably broken by movements within the formation. Most of the visible sand grains in the quartzite and sandy dolomite are well rounded, and are larger than the grains seen in the limestones of the Philipsburg series. As a rule the grains are clear, but one layer of quartzite is composed almost entirely of clouded (whitish) grains. For a description of the micropetrography of this rock see the Appendix by Maurice Black. [illegible]

Logan (1863, p. 851) described the lower strata of this Cambrian formation, near the northern end of its exposure

as a "mixture of pure limestone and dolomite, somewhat like that of division B [of the Philipsburg series], but interstratified with layers of slate, and many beds of white sandstone, all without observed fossils". Higher strata were said by him to show "extensive surfaces of white sandstone and of brown-weathering magnesian limestone, interstratified with one another and dipping at a very low angle eastward of north."

Logan's "mixture of pure limestone and dolomite" is the brecciated zone at the base of the overthrusting Cambrian block, and the layers of slate, which Logan supposed to be interstratified with the dolomite, are [illegible] of slaty limestone belonging to the Philipsburg series. No slates are to be seen in this Lower Cambrian dolomite.

Structure. The dips and strikes of the dolomite can be stated in only one general way, for bedding planes are only occasionally determinable. As quoted above, Logan described the strata near the northern end of the exposure as dipping "at a very low angle eastward of north." Judging from the topography and the slope of the individual outcrops, the dolomite dips to the east at an angle of about 10°. These dips, which are the rule all over the outcrop, suggest that the dolomite is a gently tilted block; this is borne out by the section along the International Boundary. The four formations, Mallett, Milton, Highgate, and Georgia are exposed

from west to east, and all dip to the east. However near the northern end of the exposure the strike on the sandstone beds is about ~~N. 20° E.~~ N. 80° W., and the dip is ~~northeasterly~~ at a low angle, about 5°. This northward dip suggests one explanation for the disappearance of the Cambrian at Rosenberg, that is, the strata here are in the form of a very low anticline the axis of which, except possibly along the boundary line, lies outside the limits of the Pigeon Hill Block. The trend of the Highgate formation to the east and north of these anomalous dips too, suggests an anticlinal. The thrust faults which are apparent in Vermont cannot be identified in Quebec, though doubtless they cut the dolomite, which is thereby repeated to some extent. The probable traces of these faults is indicated on the Lacolle map. The only authority for them is McGerrigle's map (1930, p. 4) of the formation in Vermont.

Thickness. The indefiniteness of the structure prohibits a definite estimate of the thickness. Logan (1866, p. 283) estimated the thickness at 790 feet, basing his estimate on a 12° dip and a breadth of outcrop of a "little more than a mile." This measurement was made at the International Boundary. For the same section recent measurements yield a thickness of about 1,300 feet, based on a 10° dip and a breadth of outcrop a few hundred feet less

than a mile and a half (about 7,600 feet). This thickness, however, is perhaps double the true thickness, for the Milton has been repeated by overthrusting. 700 feet seems to be a reasonable estimate. Keith states that the Milton is about 800 feet thick in Northern Vermont.

Age and Correlation. This dolomite appears to be barren of fossils in Canada, and its stratigraphic position relative to older formations (except the Mallett) is not shown, as it composes one of the many overthrust blocks of the region, resting against or on top of the younger Philipsburg series. Lower Cambrian fossils have, however, been found a short distance south of the boundary line in beds which conformably underlie the dolomite. The trilobite, "Conocephalites arenosus", referred to Ptychoparia adamsi by Walcott (1886, p. 195), was reported by Logan (1863, p. 282) from "Bluish thin-bedded, argillaceous, dolomitic flagstones", which were associated with slates. Billings (1865, p. 15) described this fossil, referring it to the "Potsdam", and stated that the locality was "about one mile south of the Province line", on the Swanton-St. Armand road, east of Rock River. Gordon (1923, p. 184) recorded the trilobite, Olenoides marcoui, from "gray, rusty-weathering, impure quartzite, east of the St. Armand road and about 100 rods northeast" of Saxe monument.

There is no doubt of the conformability of the

quartsite and the dolomite at the second locality mentioned, for the former passes upward into the latter through a zone of interstratified and alternating beds. The stratigraphic relationships at the locality mentioned by Logan and Billings are not so definite, but there is no evidence of any break between the beds reported to carry Ptychoparia adamsi and the dolomites above them.

Fossiliferous rocks underlie the dolomite at a third locality -- on the Swanton-St. Armand road, east of Rock River, about two miles south of the boundary line. These rocks were examined by Logan, who recorded the presence of "Conocephalites adamsi" and "Conocephalites Vulcanus" in red beds "in the cliff opposite the residence of Mr. Church". (1863, p. 281). This locality was reexamined in the summer of 1929, and numerous specimens of Ptychoparia adamsi were collected in fine-grained, reddish-brown sandstone layers. In all probability the two species recorded by Logan are to be referred to a single one, Ptychoparia adamsi (Billings). The contact between the dolomite and the brown sandstone is obscure, but, although it can not be stated that one grades into the other, there is nothing that would indicate that the sandstone does not underlie the dolomite conformably.

Thus, in the continuation of the dolomite south of the boundary line, it is interbedded at the base with, and underlain by, rocks carrying Lower Cambrian fossils,

and a key to its age is thus given. On comparative lithological grounds there is no reason for supposing that the dolomite is anything but Lower Cambrian in age, for, immediately south of the line, in the township of Highgate, Vermont, the only formations that may be compared with it, lithologically, are the Mallet and the Milton, the former certainly, and the latter probably, being Lower Cambrian in age (Howell, 1929). The Mallett and the Milton are lithologically very much alike, and both resemble the dolomite of the Lacolle quadrangle. Resolution of this difficulty would have been almost impossible except for further work on the rocks of Keith's "Central Sequence" during the summer of 1930, the results of which have already been published by the junior author (1930). This led to the conclusion that much the greater part of the dolomite in question was Milton, and that the Mallett barely succeeded in being represented north of the boundary line. The unusual thickness of the Milton and the absence of the Colchester shale (normally to be found between the Mallett and the Milton) are accounted for by thrusting movements -- the Milton cutting across the Colchester to rest on the Mallett.

Contact should be mapped as a fault in places

Highgate Formation.

Distribution. Immediately east of the Milton dolomite, and overlying it, is a series of interstratified shales and shaly limestones that is correlatable with the

Highgate formation of Vermont. This series extends northward from the boundary line to the east branch of Rock River, a distance of about one-half mile; northward from Rock River no rocks that may be referred to the Highgate outcrop except at Rosenberg, where a small development of strata follows around the extreme northern limit of the Milton dolomite (Plate). Southward from the boundary line the series may be traced to localities where the Highgate has been definitely recognized by Keith, notably at the Oliver Grange farm, one-half mile south of the boundary, and at Highgate Falls.

Thickness. The thickness of the Highgate varies greatly in the five miles between the ~~Canada line~~ International Boundary and Highgate Falls, Vermont. At the latter place the formation is stated (Keith, 1923, p. 115) to be at least 300 feet thick, whereas near the boundary line it is no more than 100 feet thick. This variation is largely due to the varying amounts of erosion which the Highgate formation suffered ~~from one locality to another~~ prior to the deposition of the succeeding Swanton and Georgia sediments. Near the boundary line the Highgate is in unconformable contact with the Georgia above it, and, in some places is separated from the Milton (below) by only a few feet of drift. At Highgate Falls "the top of the formation is cut off by a thrust fault" and, in consequence "the original thickness of the formation is not known" (ibid).

Lithology. The principal development of the Highgate formation is in the township of Highgate, Vermont, where, according to Keith (1923, p. 114): "The formation consists mainly of dark slate, in places black, and usually banded. The banding is in most places regular, sharp, and clear, and strongly resembles the seasonal banding of glacial deposits. The dark and light layers are evenly spaced and from one-eighth to one-fourth of an inch in thickness.... Interbedded with the slates are numerous thin seams of blue limestone an inch or two in thickness. These are very evenly spaced between layers of slate of about the same thickness and constitute a very marked horizon. One-third of a mile northwest of Highgate Center these layers thicken and and outcrop in the railroad-cut as a strongly banded limestone mass 35 feet thick. These are probably the highest beds in the formation near Highgate."

Within a mile of the boundary line and northward it is apparently the upper part of the Highgate that is represented. Here the strata are mainly dark-colored, fine-grained limestones in beds up to six inches in thickness, separated by relatively thin layers of dark brown to black shale.

Stratigraphical Relations. From the meagre exposures of the Highgate in Canada the contactual relations of the formation could not be determined. The nearest

exposure to the south of the line where these relations may be studied is one-half mile from the boundary, on the "Oliver Grange farm", at the eastern end of the road which crosses the Lower Cambrian dolomites north of Proper Pond. In 1923, Keith separated the strata ~~that outcrop~~ there into three formations, the Highgate, Swanton, and Georgia. This separation was based on the discovery of a small patch of conglomerate, overlain by siliceous rock, and underlain by the shaly banded limestones of the Highgate; the conglomerate was assigned to the Swanton, and the siliceous rock, composed of sandstone and arenaceous slate, was considered to be the basal portion of the Georgia slate formation. The Highgate at this place is, then, overlain unconformably by the Swanton and Georgia; these relations are clearly shown, although the contact extends but a few yards and the amount of Swanton conglomerate represented is very slight; "The grey, slightly sandy slate of the Georgia cuts out 2 feet of the Highgate slabby limestones, the two formations dipping easterly from 10 to 15 degrees" (Keith, 1923, p. 125) (Plates).

Although a presumably nearly complete section of this formation outcrops in Northern Vermont, in Canada only the upper part occurs. Thus the time interval represented by the Milton - Highgate unconformity must be lengthened to include the earlier and middle part of the Highgate time too; and, moreover, this probably indicates a northward

invading sea of Highgate time in Southern Quebec.

Age and Correlation. In 1924 Raymond listed all the species of trilobites identified by him from the Highgate, as follows (1924, p. 462)

Agnostus sp. ind.
Hypagnostus sp. ind.
Leptopilus declivis Raymond
Cholopilus vermontanus Raymond
Leiostegium puteatum Raymond
L. cingulosum Raymond
Maryvillia sp. ind.
Lloydia seelyi (Walcott)
L. saffordi (Billings)
Hemigyraspis sp. ind.
Pilekia extenuata Raymond

Raymond then stated that "This fauna contains only one species found in the Milton [later called the "Missisquoi" which name, like the Milton, is also preoccupied] namely, Lloydia seelyi, although the presence of Maryvillia is suggestive of Upper Cambrian. On the other hand, the most common species, Leiostegium puteatum and Pilekia extenuata, belong to the genera which are characteristic of the Lower Ordovician, as does Hemigyraspis. The specimens of Lloydia saffordi are large and closely comparable to those found in the Beekmantown at Philipsburg, Quebec, and Cholopilus vermontanus as well as Lloydia saffordi occur in the next higher formation, the Georgia.

"So far as can be judged from the trilobites as known at the present writing, the Highgate would be termed Ordovician rather than Cambrian but would be placed about on the border between the two. Pilekia and Hemigyraspis are the only genera which belong to the Ceratopyge fauna."

In the summer of 1928, Raymond accompanied the present writers to the locality one-half mile south of the boundary line, described above. At that time fossils were found in a bed of dark limestone in the Highgate, less than ten feet below the unconformity separating that formation from the Swanton and Georgia formations. Early in 1929, Raymond identified the genera collected, as follows: Agnostus, Harpides (sp. prob. nov.), Shumardia, Triarthrus, Holometopus, Lloydia, Leiostegium, Pilekia, Plumulites and Isoteloides. Of these genera three species were identified -- Leiostegium puteatum, Leiostegium cingulosum, and Plumulites mobergi Clark.

Raymond considered that this fauna was proof that the Highgate is Beekmantown and not Upper Cambrian. "The most significant things are probably Shumardia, Holometopus, and Plumulites mobergi, all of which occur in the Levis" (Letter, March 11, 1929). In the same communication Raymond stated that the fossils listed above, which he believes to have come from the lower Highgate than with the Georgia fossils listed in his 1924 paper (see page).

In the summer of 1930 E. O. Ulrich was shown this same locality. His conclusions communicated personally are summed up as follows. Of the fossils collected from the Highgate -- "not less than 12 species of trilobites -- are identifiable with the species described by Raymond from what he called the Milton", later called the Missisquoi, and are "probably lower Ozarkian" in age.

In summary, the determinations respecting the age of the Highgate are: regarded as of Upper Cambrian age in Keith's paper of 1923; tentatively referred to the basal Ordovician by Raymond in 1924, and definitely referred to the Beekmantown by him in 1929; "probably" lower Ozarkian in age, according to Ulrich, 1930. Inasmuch as the formation in Canada has not yet yielded fossils we have nothing more to contribute to this knotty problem. Certainly more collecting should be done at the critical locality above described. In the meantime, because of a considerable unconformity above it, coupled with the correlation of the next succeeding formation with the Upper Ozarkian, it seems justifiable at present tentatively to adopt Ulrich's correlation of the Highgate with the Lower Ozarkian (Upper Cambrian), making it approximately the equivalent of the Rock River dolomite in the Philipsburg series, and of the Potsdam of the unfolded rocks to the west. If this correlation stands, then the Appalachian trough at that time had a low shore line on the west along which the

Potsdam sands were accumulated (there is in this no indication of high or rising shore lines), whereas rising or high shore lines on the east were responsible for the deposition of the relatively great amount of shale in the Highgate. In the central, or possibly west of the central, part of the trough clear waters prevailed in which the Milton dolomite accumualted.

Swanton Formation. Between the Highgate and Georgia three formations occur in Vermont, namely the Shelburne marble, Williston limestone, and the Swanton conglomerate. ~~The first two of these do not concern us here, for they are~~ but locally developed in Vermont, and do not approach the Canadian line. ~~Although~~ The Swanton does not outcrop in Canada, the nearest exposure being one-half mile south of the line; but the former ~~it~~ plays such an important part in the discussions of the Highgate and Georgia and their relations to each other that it is advisable to review some of the features of the formation, drawing from Keith's report (1923, pp. 118 - 122).

The beds of the Swanton "begin about eight miles south of St. Albans and appear at many localities northward to and across the Canada border. ....The formation is not continuous but forms disconnected lenses at the base of the Georgia slate.....The formation consists largely of coarse limestone conglomerate.....Closely associated with the limestone conglomerates are beds of gray, sandy limestone

and calcareous sandstone. These are from a few inches up to eight or ten feet thick and show occasional passages into quartzite.....As a rule the sandstones are above the conglomerates, but in some places they are interbedded or even at the base of the conglomerate....A few layers of calcareous and argillaceous slate are found interbedded with the sandstones and conglomerates."

Although the Swanton has been separated as a distinct formation, it is considered by Keith to be essentially the basal part of the Georgia slate and conformable with that slate, and to be separated from the Highgate by an erosional unconformity.

Georgia Formation. As determined by Keith in 1923, the Georgia, predominantly a slate formation, unconformably overlies the Highgate, and, because of overthrusting from the east, is covered by the lowest formations (Cambrian) of his so-called "Eastern Sequence". With these generalities we are in agreement, for the same relations exist in the boundary line section and for some miles into Canada. However, whether the wide exposure of slate rock assigned to the Georgia (see map on page) contains but one formation or more than one is uncertain until the exceedingly scanty faunal evidence is more conclusive.

Distribution and Structure. Within a half mile on

either side of the boundary line, the Highgate is separated by a few feet of drift from the Georgia above, the contact being seen in only one place. The maximum thickness of the exposed Georgia close to the Highgate in this distance is 75 feet, a measurement rendered unreliable by the sharp folding which some of the Georgia has suffered as well as by a thrust fault paralleling the strike and traceable for one mile. Physical evidence of the thrust is fairly clear. On the Canadian side of the boundary line the strata are considerably contorted and broken. This applies more particularly to the eastern part of the outcrop, where the dips are steeper than in the western part. At the most northern exposure, in the bed of Rock River, strata of the "eastern part", dipping about 50°E., but broken, contorted, and sheared, are in contact with those of the "western part", where the dips are 12°E. or less. The eastern rocks form a twenty-foot escarpment in the bed of the river. When tracing the series southward to the boundary line, no actual contacts between the overthrust and underthrust sections were observed; but the general characteristics of the two remained the same as those seen in the bed of Rock River. One-half mile south of the boundary line the same conditions held. At this place the natural section of the Highgate, Swanton, and Georgia formations is separated from the overthrust portion of the Georgia, to the east, by a narrow valley, floored with glacial

drift. The lowest beds of the Georgia here resemble the Highgate in lithological character and appearance, but the faunal evidence shows them to be separate. Because the thrust is of little importance, and everywhere lies within the Georgia formation, it is not recorded on the map.

In the slates themselves, the bedding planes commonly have been obliterated by shearing, and although numerous calcareous beds are interstratified with the slates, they have been either closely folded or locally, but frequently, faulted, so that they were of no use in determining mappable structures. All of the dips observed were eastward, but at angles varying between 25° and 90°. The general strike is northeast, but varies between N.15°E. and N.75°E.

The distribution of the Georgia formation eastwards of the Highgate is a puzzling problem. Between the Highgate and the Oak Hill Thrust there are outcrops of nothing but slate of the Georgia type with limestone and dolomite bands, rarely a sandstone band, and occasional limestone conglomerate beds. From Rosenberg north the easternmost competent bed of the Philipsburg Series is the Stanbridge conglomerate, between which and the Oak Hill Thrust are similar slates, with limestone beds, sandstones and limestone conglomerates. It might appear that between the northern and southern boundaries of this area this slate belt includes but one

formation. This cannot be, for the slates in contact with and adjacent to the Highgate to the south, and the Stanbridge to the north must be of two different ages, and also belong to two different thrust slices. Therefore, there must be a boundary between them which begins in the vicinity of Rosenberg and runs in a northerly, easterly or southerly direction. In other words any conceivable division of the slate belt, limited only by those parts in contact with either the Highgate or the Stanbridge, might possibly represent the true distribution.

Fossils are of little help. The Highgate is called, for the present Upper Cambrian (Lower Ozarkian of Ulrich). The Stanbridge is Trenton and possibly younger, so that any shales which could be proved by their fossils to be intermediate in age between these two must perforce belong to the Pigeon Hill block. Only in the close vicinity of Mitchell Corners, near St. Armand, have such diagnostic fossils been found. All other fossils in the slates indicate an age younger than the Chazy, and might therefore as well belong to the Philipsburg block as the Pigeon Hill. We are therefore driven back on lithology and physiography, and even with these two aids it is only possible to force the issue. A line running east from Rosenberg for a mile or so and then swinging north and around the hill between Guthrie and East Stanbridge, and meeting the Oak Hill thrust west of Hunter Mills accomplishes

the object. All the slates south and west of this line are much more calcareous than those beyond it, and far less sheared and metamorphosed. Although the calcareous layers weather buff, there is nothing comparable to the "rusting" of the more crumpled slates to the north. This boundary, too, includes within it all the fossils so far discovered in the slates whose age is Chazy or younger. Thus, it is possible to draw a boundary which has physiographic, petrographic, and paleontological backing, but whose position is not fixed by any direct evidence.

Lithology. These slates are dark gray to black in color. They are occasionally banded, the result of the interstratification of thin siliceous lamellae with the dark-gray slate. The lamellae are usually not more than 3 mms. thick, and not readily observable on fresh surfaces, but are easily seen on surfaces exposed to the weather. Occasionally the bands are very evenly spaced, in alternating thick and thin layers, and there may be as many as fourteen bands in the space of one inch. Between zones, in which the bands are thus closely spaced, there frequently occur unbanded beds an inch or more thick. Most of the slates are uniformly dark gray to black in color, occasionally somewhat siliceous, but mainly argillaceous, and non-banded.

Interstratified with the slates are many beds of

limestone, dolomitic limestone, and conglomerate. In the Sutton quadrangle, there are occasional beds of sandstone or quartzite also, usually about one foot thick, interstratified with the slate. Of the non-argillaceous members limestones predominate, particularly towards the base of the formation; these are usually dark gray to black in color, weathering light-gray or dove, and fine-grained. The beds average about one inch in thickness. Frequently they have been broken, and are now represented by undulating "pebble zones" in the slate. Less common are the heavier beds of gray, crystalline limestone, and dark gray, crystalline dolomitic limestone. The dolomitic beds vary in thickness from two inches to one foot or more. Although fossils occur in these beds, they are commonly distorted or represented only by fragments and thus practically useless. Some of the conglomerates may have been true beds originally, like the "pebble zones" mentioned above. Most of them, however, are in lens-shaped masses, which, as a rule, can not be traced along the strike for more than fifty feet. Three-quarters of a mile southeast of Mitchell Corners, conglomerate occurs in a large slate outcrop and can be traced for about 700 feet along its strike. Patches of similar conglomerate again occur in slate about half a mile north of this exposure, and may belong to the same horizon, although not in the same line of strike. The conglomerate varies in thickness from zero to twenty feet. It is made up of angular and sub-angular fragments of limestone and

dolomitic limestone in a shaly and shaly-dolomitic matrix. The phenoclasts vary in size from diameters of one-half inch to eight inches or more.

A somewhat different conglomerate occurs just north of the boundary line, on the road running south from Mitchell Corners. This exposure is about a half mile east of the line of strike of the one just described, and may be at a higher horizon within the slate formation. At least two types of conglomerate occur at this locality. One is an edgewise conglomerate, and the beds from which the slabby phenoclasts were derived are seen associated with them. The other type forms a heavier bed, twenty feet thick or more, and is made up largely of angular and elongated laths of limestone in a limestone matrix. Angular blocks of brown weathering dolomite also occur. These are arranged with their longer axes parallel to the strike, and all occur at about the same distance above the base of the conglomerate. They are separated from one another, underlain, and overlain, by non-conglomeratic, dove-colored limestone. The fact that the edgewise conglomerate has obviously suffered a minimum of transportation suggests a similar origin for the more unassorted type. In fact it is highly probable that in none of the conglomerates in this area has long transportation been a factor.

The Georgia i

The Georgia in Vermont. According to Keith (1923, pp. 122 - 124) the Georgia slate formation "lies in a belt 34 miles long whose southern end is in Colchester and northern end in Highgate. North of the main belt there are several narrow strips of the formation extending to Canada....The formation consists almost entirely of slate, as a rule of a dark gray color. Much of it is banded, a character which is easily seen on the weathered outcrops, which are apt to show a whitish surface. At the base of the formation lie several specialized and very important beds, chief of which is the Swanton conglomerate, which has been separated as a distinct formation. It is possible that there are other and higher conglomerates, but all now known are explainable as basal beds.....Only two exposures of the Georgia-Swanton contact are yet known, although in many places the two formations are separated by only a few feet, and are conformable in dip."

Age and Correlation. Recent estimates of the age of the Georgia vary even more radically than they do for the Highgate. In brief, the Georgia has been said to be (1) Middle Ordovician (Keith and Schuchert), (2) Beekmantown (Raymond), and (3) Upper Ozarkian (Ulrich). The reasons for these estimates follow:--

According to Keith (1923, pp. 123 - 126), "The fossils found in 1921 in the Swanton conglomerate underlying

the Georgia slate showed it [the Georgia] to be of post-Potsdam age instead of Lower Cambrian, as long supposed. How much younger than Potsdam the slate was could not be determined then, as in the few contacts known the slate appeared to lie conformably on the conglomerate. Its precise age was not determined until September, 1922, when two localities were found in Highgate which settled the matter. At the Oliver Grange farm, 4.5 miles N.10°E. of Highgate Center and .5 mile from the Canada border, the slate was found by the author.....lying unconformably on the Highgate slate and separated from it by only a little lens of Swanton conglomerate.....In the Georgia slate, 30 feet above the Highgate, Upper Cambrian fossils were found in several small masses resembling squeezed boulders of oolitic limestone. The fossils were fragments of trilobites, brachiopods, tiny gastropods and cystid columnals." Later "fossils were found by Schuchert in gray slate of the Georgia formation that rested immediately on the banded limestone and slate of the Highgate." A mile S.20°E. of the above another locality was found "where suhstantially the same fauna but of other species was more plentiful, especially the trilobites, in arenaceous limestone layers in gray slate. The fossils from these localities, according to the field determination by Schuchert, were at least as young as Black River and possibly as young as Trenton."

In the following year Raymond (1924, pp. 462, 463) discussed briefly the Georgia formation, listed the identical fossils, and suggested a tentative correlation with the Beekmantown:- "The Georgia formation is best exposed directly north of Highgate Center and within a mile or two of the Canadian border. Like the Highgate it consists chiefly of shale, but has some limestone in the lower portion. At one locality the fossils are numerous, but badly preserved; at another, where the Georgia and Highgate are in contact, the fossils are well preserved, but the quantity of material to be had is very limited.

"The following species have so far been determined, all from the lower part of the formation:

Agnostid, gen. et sp. ind.
Cholopilus vermontanus Raymond
Petigurus cybele (Billings)
Gignopeltis rara (Billings)
Hystricura mammatus Raymond
Lloydia saffordi (Billings)
Lloydia, sp. ind.
Asaphellus obtectus Raymond
Asaphellus, sp. ind.
Pilekia eryx (Billings)
Pliomerops, sp. ind.

"The presence of Petigurus cybele, Gignopeltis rara, Lloydia saffordi, and Lloydia sp. ind., which is an undescribed species known at Philipsburg, Quebec, indicates that this is

a Beekmantown fauna, but so little is known of the range of trilobites in the Beekmantown that it would not be safe to make a definite correlation with any particular division. The genera Asaphellus and Pilekia would indicate a horizon very low in the Lower Ordovician; there is nothing to indicate a correlation with any member near the top of the Beekmantown, nothing, at least, higher than the Fort Cassin."

Ulrich's determination of the age of the Georgia is much more nearly in agreement with that of Raymond than with that of Keith and Schuchert; for, what Raymond would call Lower or Middle Beekmantown quite possibly would be called, in Ulrich's terminology, Upper Ozarkian. Ulrich's determination of the Upper Ozarkian age of the Georgia is based on collections of fossils from two localities and, apparently, three horizons in the Georgia slate formation. One of these localities is the same as that from which Schuchert and Raymond made their collections, namely, the Oliver Grandge farm. One horizon at this place, in which fossils were found, was at the very base of the Georgia, in the "contact" material overlying the small patch of Swanton conglomerate; the second horizon at this same locality appeared to be from 40 to 50 feet above the contact, but if this is in an overthrust part of the Georgia (see above) it is impossible to state definitely how far above the contact this second horizon may be stratigraphically.

A second locality, and presumably a higher horizon, from which fossils were collected by Ulrich and the junior author lies to the east of the line of strike of the strata at the locality just mentioned. According to Ulrich (personal communications) the faunal evidence indicates that these three zones or horizons belong to the same formation, that they carry the Leiostegium fauna and are, therefore, of Upper Ozarkian age, and that they might be correlated with the lower part of Division B (Hastings Creek and Luke Hill formations, particularly the latter) of the Philipsburg series.

Allotting the fossiliferous beds to the Upper Ozarkian does not however indicate that the entire formation belongs there. As shown above, between the Highgate and the Georgia there are three formations in Vermont, the Shelburne, Williston, and Swanton. Hence, if the Highgate be called Lower Ozarkian as seems reasonable and if three formations intervene between it and the Georgia there does not seem to be much chance of any of the Georgia being older than the upper limits. Evidence is presented above for a Black River and possibly Trenton age for some of the shales. It is not inconsistent with the general geological history to suppose that these shales were being continuously formed throughout Beekmantown, Chazy, and Trenton times.

The higher beds of the Georgia formation should be met with further and further east, but as the extension of the formation in that direction is limited by the Oak Hill Thrust and its superjacent Lower Cambrian strata, in all probability only the lower part of the Georgia outcrops in this area.

This, then, is the uppermost formation of the Pigeon Hill Block. Its northern extension, as hypothetically mapped, is limited by erosion which has brought the Stanbridge and Georgia slates together, increasing the difficulties of delineating the bounding thrust, as described above.

Stratigraphy of the Philipsburg Series.

General Statement. The term "Phillipsburg series" was first used by Logan, in 1863. It included a belt of limestone outcrops which lay, roughly speaking, between Missisquoi Bay and and the western valley of Rock River, and which extended northward from the International Boundary to the village of Mystic.

For eighty years and more the strata of this series have been studied by many geologists, and various solutions of their problems have been proposed. The structural and stratigraphic difficulties have been considered so great that since Logan's time little attempt has been made to study it

in detail. The general belief seems to have been that the fossiliferous formations of the series, particularly those of "Division B", have suffered more or less extensive repetition by faulting. Neither of these notions is true. The structure is, in reality, simple, and what repetition has occurred has been confined to the lower members of the of the series (those in Division A) and to members considerably higher than those in the Philipsburg-St. Armand section (Division B).

However, it is not the structure that has been of primary interest, but the age and correlation of the strata. These have been assigned to ages ranging from "far below the Potsdam sandstone" to the "Trenton or Montreal limestone".

Historical Summary. The first detailed report of the Philipsburg series was that given by Logan, in the Geology of Canada, 1863. Prior to that time, during the formative years of the Canadian Survey, rapid surveys were being made by Logan and his assistants of extensive areas in what was then known as Canada West and Canada East. But it was not until 1849 that any mention of the rocks in the southeastern part of the Lacolle quadrangle appeared in the literature. In that year the Report of Progress for the years 1847-49 was published, and a general summary of the Survey's knowledge of most of the area on the southeastern side of the St. Lawrence River was given. Logan stated in this report that

he had traced a band of interbedded limestones and slates from St. Dominique, a town about twenty miles north-northeast of the Lacolle quadrangle, through the township of Farnham East to Bedford Village and thence to Philipsburg. Logan correlated this band with the "Trenton or Montreal limestone"; as far as that part of the "band" which outcropped between St. Dominique and Bedford was concerned, Logan was certain that his correlation was correct, but there were too many lithological dissimilarities between the rocks at Philipsburg and those at St. Dominique and Farnham for him to be certain that the former belonged to the same Trenton band.

Although Logan had previously recognized that there were at Quebec and Levis rocks belonging to two different troughs (1845, p. 12) it was not until 1855 that he had the evidence on which to base his theory that these troughs extended southwestward. In their Esquisse Geologique, 1855, Logan and Hunt announced that an anticlinal axis separated the area southeast of the St. Lawrence into two provinces or troughs, and that this axis extended from Quebec City to Missisquoi Bay, and thence southward through the valley of Lake Champlain and along the Hudson River. On the west side were the Trenton and Utica formations, and in the eastern trough lay the Sillery and Levis divisions of the "Quebec Group", a term first used in 1855. It was not known at this time in what part of the Quebec Group the rocks

at Philipsburg should be placed, or even if they belonged in that Group at all.

About 1860, Logan again visited the Philipsburg region, in company with Billings, and their observations were published by the latter in 1861. The series was then divided into two groups:

2. Blue, thin-bedded, nodular limestones; 400 feet thick or more. Forty species of fossils were found, "which show that this part of this series of limestones is the equivalent of the upper part of the Calciferous sandrock."

1. Magnesian limestone with interbedded limestone and occasional sandstone beds make up "the lower half" of the series. No fossils were found in this part. 400 feet thick.

In this paper also, a table showing the fossils common to Levis and Philipsburg was given, and it was concluded that "the upper limestones of Phillipsburg must lie on the same geological horizon, very nearly, as that of limestone No. 2 at Point Levis."

In 1862, Marcou published the results of his work in northern Vermont and adjacent Canada. He regarded the "Calciferous sandrock", displayed at Philipsburg, as the base of the "Lower Silurian". But in the same year, in a letter

to Barrande, he stated that the rocks at Philipsburg were "far below the Potsdam sandstone, and in the middle of the Upper Taconic."

In the year 1866, Logan's "Geology of Canada, 1863" was published in its final form. There, the Philipsburg region was described on pages 273 to 287 and again in greater detail with the section given below on pages 844 to 860. In that report the Philipsburg series was referred to the "Calciferous sandrock"; the latter was considered by Logan to be a part of a "great series of strata" corresponding to the Quebec Group and represented in Eastern Canada by the Levis limestones. A detailed description of the lithology, stratigraphic succession, and structure of the Philipsburg Series was also given. A summary of his divisions follows, in descending order:

D 3. gray and black striped slates.....1,500'

D 2. black and greenish, argillaceous slates.....1,000'

D 1. limestone conglomerates, at least two bands, separated by slates..... 300'

C 2. black slates, or, thin-bedded black limestones..... 170'

C 1. black, massive, pure limestones..... 150'

B 5. black limestones, magnesian beds at the base. 350'

B 4. Black, slaty, thin-bedded, nodular limestones 300'

~~B 3. black, slaty, thin-bedded, nodular~~

B 3. dark, bluish-grey, thin-bedded nodular limestones..... 150'

B 2. dark limestones, some magnesian beds..... 120'

B 1. white and dove-grey, pure limestones, some magnesian bands..... 120'

A 3. reddish-grey and black dolomites, some thin-bedded black limestones..... 200'

A 2. white and dove-grey, pure, compact limestones 100'

A 1. dark-grey and yellowish-white dolomites..... 400'

Logan recognized that the Lower Cambrian dolomites (Mallett-Milton) were faulted against the Philipsburg series, and that the latter rested by thrust (the word he used was "overlap") on the slates along the eastern shore of Missisquoi Bay. The Point Levis rocks were believed to be younger than the "lower divisions of Phillipsburg". The Philipsburg series was, however, considered a part of the Levis division of the Quebec Group, and to belong to the summit of the "Calciferous formation."

The next report in which the Philipsburg series was mentioned was also written by Logan (Geology of Canada, 1866a, p. 4). His ideas regarding the series had changed but little, and when, as a result of Richardson's work, he divided the Quebec Group into three divisions the Philipsburg series was assigned to the basal part of the Levis. The following is an outline of his divisions of the Quebec Group, in descending

order:

Sillery

Lauzon

Levis.....The Levis included the Philipsburg limestones, the black shales above them, and that part of the Levis shales and magnesian conglomerates which is included in the members 1-9 of the Orleans section.

In the same report Richardson (1866, p. 31) reported to Logan as follows: "The greatest development of the Levis division occurs at Phillipsburg, where you have shown a thickness of 4,860 feet, and this being supposed to be in addition to the lower members of the Orleans section, measuring 1,285 feet, the whole volume of the division would be 6,145 feet, and perhaps more--since the base of the Phillipsburg section comes against the great dislocation which limits the Quebec group on the northwest."

Then followed a period of twenty-three years, during which no mention of any interest was made of the Philipsburg Series in the literature; nor was there much progress made in the study of the Quebec group as a whole, save a recognition that Logan's order of superposition was reversed. During this time, Selwyn, who succeeded Logan as

Director of the Canadian Survey, made several contributions to the study of the Quebec Group, but the only real advance that he made in this connection was in 1879, when he removed the crystalline rocks of the Eastern Townships from the Quebec Group and assigned them to the Pre-Cambrian.

In 1889, Marcou, with opinions as positive as they had been twenty-seven years previously, had accepted Logan's correlation of the Philipsburg Series with the lower part of the Levis formation, but he considered that both were to be assigned to the lower part of the "Upper Taconic".

In the following year one of the most important contributions to the study of the deposits surrounding Lake Champlain appeared. Writing on the "Calciferous Formation in the Champlain Valley", Brainerd and Seeley (1890, pp. 501 - 516) described, in particular, the now famous East Shoreham section, and suggested correlations between the Lake Champlain Calciferous divisions and certain subdivisions of the Philipsburg Series. The suggested correlations are briefly tabulated below;

Lake Champlain Calciferous	Philipsburg Series
E	B 5(lower part)
D	B 1--B 4
A, B, C	A

These authors then stated that "The higher beds of B 5 at Phillipsburg, and the beds of C 1 seem to be represented

in western Vermont, but by the lower beds of the Chazy." And they added that "A similar comparison might be made between the Calciferous of Lake Champlain and the 1,830 feet of strata on the northwest coast of Newfoundland (divisions D to L of the Geology of Canada)".

Thus, for the first time, with the exception of Logan's suggested age relationship between the Philipsburg and Levis beds, the subdivisions of the Philipsburg Series were definitely correlated with formations elsewhere. Subsequent investigations, with few exceptions, have resulted in correlations which are essentially the same as those of Brainerd and Seeley.

Appended to the report of Brainerd and Seeley is a general discussion of the Calciferous, by Walcott. Referring to the Philipsburg Series, Walcott reported that he found, on the shore of Missisquoi Bay, "a small outcrop of Potsdam sandstone, with characteristic fossils, subjacent to the limestone of the Calciferous terrane." Also, he stated that the Calciferous fauna ranged through 1,400 feet of the section and then passed into the Chazy without any definite break. In other words, Walcott's Calciferous at Philipsburg included all of Logan's subdivisions between the base of "A 1" and the top of "B 4". The higher beds, from "B 5" upward, Walcott called Chazyan.

In the same year Walcott (1890, p. 111) reported that he had found thrue Beekmantwon fossils

In the same year Walcott (1890, p. 111) reported that he had found true Beekmantown fossils in the matrix of the conglomerate band 3 at Levis, and correlated that band with the central part of the Philipsburg section "where an identical fauna occurs 1,000 to 1,100 feet above the recognized Potsdam sandstone."

The next year, Brainerd cut about 300 feet from the top of the Calciferous at Philipsburg and added this portion to the Chazy. He stated that the lower part, about 1,100 feet, of the Philipsburg section, "corresponds well in fossils and in lithological features to the Calciferous of the southern part of Lake Champlain." That is, Logan's subdivisions B 4, B 5, and C 1 were considered to be Chazy in age and equivalent to the Chazy of western Vermont; B 4 was thought to be lower Chazy; and the upper 50 feet of B 5 was said to belong to the Middle Chazy, because it contained numerous specimens of Maclurea magna, a species also found in subdivision C 1.

In 1896, Ells remarked on the difference between the Philipsburg rocks and those of the typical Calciferous and Chazy of other areas, especially of the Ottawa Valley. However, he referred Logan's Division A, and all of his Division B except the "upper portion", to the Calciferous. The upper beds of B, and all of Divisions C and D, he called

Chazyan. In the appendix to Ells' report, Ami placed the Philipsburg Series above the Chazy, between that group and the Quebec City formation, but he considered the Series to be equivalent in age to the Fort Cassin rocks.

Two brief references have been made to the Philipsburg Series by Raymond. In 1905, he (1905, p. 327) reported the presence of the Fort Cassin fauna "at Stanbridge"--that is, in the conglomerates of Division D; and, later, he stated (1916, p. 327) that "the so-called Chazy in the section between Philipsburg and St. Armand contains no Chazy fossils, and belongs to the Beekmantown. The 'Chazy slates' of Ells at Mystic and vicinity are the shales and conglomerates of the Levis formation."

In 1923, Foyles reported that the Fort Cassin rocks formerly believed to be comprised in one formation and to be of Beekmantown age, consisted of two formations, one of which was Chazy and the other Trenton in age. Also, the Philipsburg Series was said to be older than the Fort Cassin formations.

In the same year a brief discussion of the rocks between the shore of Missisquoi Bay and St. Armand Station was published by Gordon. It was suggested that some of the strata (probably at about the horizon of Logan's subdivision B 4) were of Chazyan age. This opinion was based largely on lithological resemblances with Chazy rocks in Vermont.

In 1923, Bradley made known some new facts in respect to the lithology and structure of the rocks in question, and referred the entire Series to the Beekmantown. The three subdivisions of Logan's Division A were correlated with the A, B, and C divisions of East Shoreham, and all were assigned to the Lower Beekmantown. Bradley's Middle Beekmantown included the East Shoreham divisions D and E, and it was said that these could be correlated with the Middle Beekmantown at Philipsburg. The latter included the five subdivisions of Division B as well as C 1. Thus the Fort Cassin fauna was placed in the Middle Beekmantown, and Bradley stated that a faunal assemblage in subdivisions B 5 and C 1 at Philipsburg was very similar to the Fort Cassin fauna. In the Upper Beekmantown were included "an unknown thickness of closely folded slate with intercalated lenses of limestone conglomerate", --in other words, Logan's subdivision C 2 and all of Division D. This was believed to be the only occurrence of the Upper Beekmantown in the Champlain Valley.

The senior author's discussion of the fauna of the Beekmantown boulders and the matrix of the limestone conglomerates of the Levis formation, in 1924, contained the following statement---"Of the sixty species in the list ten are common to Levis and Phillipsburg.....In addition.....there are a great many forms at the two localities which are very closely related, and there are but a very few genera which are not

found at both localities. All the evidence points to a connection between the two places, and in fact, there was probably a continuous belt of limestone from one to the other." (1924, pp. 37-38). Remarking on the correlation of Walcott (1890) that band 3 of Point Levis could be correlated with the central part of the Philipsburg section, the senior author wrote that "This correlation, though sound enough, is unsatisfactory in one respect. We are by no means certain of the exact stratigraphic position of the Philipsburg section. Now that I have been able to demonstrate the exact position of the limestone bands with respect to the graptolitic shale series, the tables are turned, and we may use the Levis formation to reassign the Phillipsburg rocks to their correct position.....If, now, we can definitely correlate band 3 at Levis with division B 3 at Phillipsburg we may be on the road to a much fuller understanding of the Beekmantown series in North America".

From the above summary of the previous work on the Philipsburg Series, it will be noted that opinion in regard to the general age of the Series has varied but little since 1861, when Billings assigned the higher of his two divisions at Philipsburg to the upper part of the Calciferous. Subsequently, the lower 1,400 feet or so were considered to be Calciferous, or Beekmantown, and the higher beds of the Series Chazyan. These age assignments were generally

accepted until, in 1916, Raymond denied the presence of any rocks of Chazyan age in the Series, and placed the entire group in the Beekmantown, as Bradley did later, in 1923.

In regard to correlation, attempts have been made to link the Philipsburg Series, or parts of it, with certain of the conglomerate bands at Levis and with the Beekmantown of the Champlain Valley. The central part of the Philipsburg and St. Armand section was provisionally correlated with band 2 of Levis by Billings in 1861, and definitely correlated with band 3 of Levis by Walcott in 1890 and the senior author in 1924. In 1890, the major part of the Philipsburg series -- that is, up to and including Logan's subdivision C 1-- was correlated by Brainerd and Seeley with the divisions of the East Shoreham section, their correlations being essentially the same as those made by Bradley in 1923.

Occasional suggested correlations of the Philipsburg Series with strata in Newfoundland have been made by Logan, in 1863, by Brainerd and Seeley and by Walcott, in 1890 and by the senior author in 1924.

In the last few years ~~the backing of~~ the present field work has resulted in a paper by the junior author, who, in 1930, published the results of his mapping of the Philipsburg and Pigeon Hill Series in Vermont, and although he then adduced little evidence for the ages of the beds concerned he demonstrated

the structure of the region lying between the border and that described by Keith in his 1923 paper. Thus the junior author's report will prove a very valuable liason between our present field and well-known sections further south. In this paper the junior author proposed new names for several of Logan's subdivisions bringing the nomenclature into harmony with modern tendencies. The structure as worked out for northern Vermont has proved to be of incalculable value in understanding the structure and succession of the Philipsburg rocks. In 1931 both the junior author and E. O. Ulrich published abstracts of papers concerned with the stratigraphic position of the Naylor Ledge formation, notice of which will be given later.

Hitherto, except for the junior author's paper just referred to, all refernces to the subdivisions of the Philipsburg beds have been by letter and number. Similar designations have been proposed for the Beekmantown of Shoreham, Vermont, for the Levis Beekmantown, and for similar rocks at Newfoundland. Though admirably simple for an unrelated group of beds, this system soon becomes unwieldy and confusing especially where a new classification by letter is substituted for an older. We are therefore compelled to drop the present designations, and in conformity with modern procedure substitute geographical names. This, however, has its drawbacks, for the area is small and the formations are many, so many that there are not enough location names on standard maps to go around.

Logan's subdivisions and the corresponding names used in this report are given below.

D 3 D 2	.....Stanbridge slate
D 1	.....Mystic conglomerate
C 2	.....Basswood Creek slate
C 1	.....Corey limestone
B 5	.....St. Armand limestone
B 4	.....Solomons Corners limestone
B 3	.....Luke Hill limestone
B 2 (summit bed of)	.....Naylor Ledge limestone
B 2 (except as above) B 1	....Hastings Creek limestone
A 3	.....Morgan Corners dolomite Wallace Creek limestone
A 2	.....Strites Pond limestone
A 1	.....Rock River dolomite

Use of the Terms Ozarkian and Canadian. Although it is not the Canadian Survey's practice to adopt the names Ozarkian and Canadian, both may well be employed as satisfactory subdivisions of the Cambrian and Ordovician respectively. So much confusion has reigned regarding the stratigraphy of the Upper Cambrian, the passage beds to the Ordovician, and the Beekmantown, that little good can result from refusing to use modern detailed elaborations of those groups. We refer, of course to Ulrich's classification as expressed all too sketchily in publications of the last two decades. For such

elaborations as he attempts we can have nothing but respect. There is, however, a very widespread opinion that his terms Ozarkian and Canadian are not worthy of systemic rank, but should quite properly be reduced to a lower category equivalent to, say, Chazy or Trenton. Because the evidence Ulrich has been accumulating for a quarter of a century or so is largely unpublished, scepticism must yet prevail. When his evidence, stratigraphic and paleontologic, is finally published, as happily seems to be in sight, geology will either accept or reject the proposed new systems. This, after all, is a minor detail of nomenclature. The all important factor in today's unravelling of the beds concerned is the publication of as much detailed stratigraphy and paleontology as possible. In this Ulrich has taken the lead.

Rock River Formation. (A 1 of Logan)

Distribution. The Rock River formation is well exposed from Morgan Corners southward to the boundary line, a distance of five miles, and thence southward for about two miles near the mouth of the Rock River, from which the formation name is derived. Its outcrop, from Philipsburg south, follows closely the shore of Missisquoi Bay, being separated from it in some places by a narrow band of slates, which are referred to the Trenton, and over which the Philipsburg Series has been thrust westward. North of

Philipsburg the Rock River formation leaves the Bay and continues, as a prominent ridge with a pronounced western escarpment, to a line west of the crossroads at Morgan Corners. There it is cut off by a fault.

Thickness. The breadth of the outcrop of the Rock River across the strike varies from three-eighths to three-sixteenths of a mile. A section, measured where an accurate dip could be taken on beds of quartzite interstratified with the dolomite, and where there did not appear to be any notable disturbance of the strata, showed exactly a quarter of a mile of outcrop, with a nearly uniform dip of 25°, indicating a thickness of the formation of about 500 feet. This is probably more nearly the true thickness than the 400 feet given by Logan.

Lithology.= The formation, as mapped by Logan and by ourselves, contains three distinct divisions, which will be designated here as the Rock River sandstone, the Rock River limestone, and the Rock River dolomite.

Rock River Sandstone. About a mile north of the boundary line, at the base of the Rock River formation, there is exposed on the shore of Missisquoi Bay a series of thin-bedded sandstones. These are made up of rounded quartz grains bound together by a calcareous (dolomitic) cement, and contain a large number of small chert fragments. A few thin beds of

slate also occur, interstratified with the sandstones. The total thickness of this series, as exposed, is twenty feet, and the individual layers of sandstone are two to three inches thick, on the average. At the top of the series are two beds of quartzite, separated from each other by a layer of shale which varies in thickness from a very thin line to eight inches.

Throughout most of this exposure the evidence favors conformable relations between this series and the overlying Rock River dolomite. The upper quartzite bed is followed by a dolomitic sandstone which grades into a crystalline, sandless dolomite bed. Also, the strike and dip of the two divisions are the same. One contact, however, may be seen where the quartzite underlies the dolomite unconformably -- the contact was sharp and irregular and there was no gradation from one type of rock to the other.

Bradley (1923, p. 7) reported that he found a "marked unconformity....between the massive overlying limestones of A l and the narrow layers of sandstone which overlie the Champlain fault.....The overlying limestones, in this place apparently thin-bedded, meet the underlying sandstones almost at right angles, and then after bending into a small anticline, resume their easterly dip parallel to that of the sandstones." But he stated that it was his

opinion "that this local difference in the attitude of the strata is due purely to differential folding rather than to causes implying uplift and erosion".

Although Bradley's explanation may be correct for the particular structure observed by him, the rapid change in the character of the rock plus the unconformable contact mentioned provide sufficient evidence on which to state that an unconformity exists between the Rock River sandstones and the overlying Rock River dolomite.

Within the sandstone series there has been much brecciation, particularly in the lower ten feet; the upper beds, although irregular, are not broken to any great extent.

The Rock River sandstones correspond to those mentioned by Walcott (in Brainerd and Seeley, 1890, p. 512) who stated that a "small outcrop of Potsdam sandstone, with characteristic fossils subjacent to the limestone of the Calciferous" occurs on the lake shore south of Philipsburg. Later, Walcott (1912, p. 548) reported the presence of Lingulella (Lingulepis) acuminata "in sandstone on the east shore of Missisquoi Bay, 1.5 miles south of Phillipsburg."

Fragments of brachiopods, collected from these beds during the present field work, are doubtfully referred to Lingulella (Lingulepis) acuminata. This species is common

in the Potsdam, and ranges through the Theresa and Hoyt formations into the Little Falls, so that, on the strength of this evidence alone, there is little justification for referring the Rock River sandstone to the Potsdam. But, like the Potsdam of the Mohawk Valley and that of East Shoreham these sandstones are overlain by a considerable thickness of dolomite, which, in the Mohawk Valley, is definitely called the Little Falls, but which at East Shoreham and Philipsburg is only referred to the Little Falls. If this reference is correct, it becomes more probable that the Rock Rivers sandstones are at about the horizon of the Potsdam.

Rock River Limestone. Beds of fine-grained, dove-colored limestone, with a maximum thickness of 30 feet, are exposed on the lake shore at the International Boundary. These are entirely different from the Rock River dolomites which overlie them, differing on color and composition, and in the absence of sand grains and chert. The limestone beds strike N.10°-15°E. and dip to the east at a very high angle -- almost vertically; a short distance to the east the Rock River dolomites dip about 25°E.; but these structures do not necessarily mean that the original relations of the limestone to the dolomite were disconformable, for folding and faulting are common in the limestone, and possibly in the dolomite also, at the boundary line and southward (Plate ; see also Plate). The Rock River limestone was traced south along

the shore for about two miles to its last exposure on the small point bounding the north end of Rock River Bay. At no place in this two miles did its thickness appear to exceed 75 feet, but the exposures were not carefully examined, and, as the rocks are considerably faulted and folded, the true thickness may be much more or less than 75 feet. The limestone occurs discontinuously north of the boundary line, and is probably present in thrust contact with the Trenton slates 200 feet south of Gallagher's Hotel at Philipsburg.

Shearing has destroyed any fossils that may have existed, and it is only possible, therefore, to state that this limestone appears to be a local, calcareous phase at or near the base of the Rock River dolomite. It is impossible to state with certainty whether the Rock River limestones or the Rock River sandstones are the younger of the two sub-formations, for they have not been found together, and both are followed directly by the Rock River dolomite. However, the unconformity noted above between the sandstone and the dolomite, coupled with an apparent thinning of the limestone northwards, indicate that it may well belong between the sandstone and the dolomite. It would not be surprising if further work elsewhere justified the assigning of each of these three divisions to a separate formation.

Rock River Dolomite. Logan did not mention, in 1863, the beds that are here described as "Rock River sandstone" and "Rock River limestone". His description of A 1 applied only to the higher beds, the Rock River dolomites, and these he described as "dark-grey and yellowish-white dolomites, weathering grey and yellowish-brown, and divided into massive beds. Some of these hold geodes of Calcspar, and others, geodes of quartz, which also occur in patches and nodular portions; while at the top are beds similarly marked with black and grey chert, which sometimes occur in angular masses". (1863, pp. 276 - 277).

Lithologically the Rock River dolomite very closely resembles the Lower Cambrian (Mallett-Milton) dolomite east of the valley of Rock River; there does not, in fact, seem to be any criterion which can be used to distinguish hand specimens of the two formations. Both are light to dark gray dolomites, with crystals varying in size from less than 1 mm. to 3 mm.. Chert, which weathers to a very dark gray or black, is present in both formations, and is widely scattered throughout the Rock River dolomite in patches which are smaller and somewhat lighter in color on fresh surfaces than those of the Lower Cambrian. These chert patches were searched for fossils without success.

Sand grains are common in the Rock River dolomite, and in places form layers of dolomitic sandstone and quartzite.

These grains, like those of the Lower Cambrian, are rounded and rather coarse, up to .75 mm. in diameter. Dolomitic sandstones are not uncommon. Occasionally heavy beds of quartzite, with a maximum thickness of four feet, occur. The most massive and extensive of these is to be seen about two miles north of Philipsburg.

At three localities the dolomite brecciated zones were observed. One of these crosses the International Boundary about 600 feet east of the lake shore, and can be traced for about 200 feet on either side of the Boundary. Another occurs one and a half miles north of Philipsburg, and the third about two miles farther north. All three are at a horizon near the middle of the formation. The fragments are angular, are composed of dolomite and dolomitic sandstone and vary in size up to blocks with a diameter of one and a half feet.

There is practically no notable difference between the upper and lower beds of the Rock River dolomite, except that in the lower beds the dolomite seemed to be on the average darker in color and finer in grain than in those above. For details and description see the Appendix.

Structure. The structure within the Rock River dolomite is not easy to determine, but the average dip was found to be about 25°E., which is more than double the average

dip as determined by Logan. Most observers have described these rocks as dipping to the east at a "low angle". Bradley (1923, pp. 6 - 8) has reported folding and faulting in this formation south of the boundary line, but north of the line, the strikes and dips seem to be fairly uniform, exceptional dips can be seen at only two localities. One of these is on the lake shore at the boundary line where dips on the Rock River limestone vary between 65°E. and the vertical, and the other is three-quarters of a mile north of the line, on the lake shore, where the Rock River sandstone and the lower beds of the Rock River dolomite have been broken and stand on end.

The Upper Limit of the Rock River Dolomite. The division plane between the upper beds of the Rock River dolomite and the lower beds of the Strites Pond formation (A 2) was chosen arbitrarily, and, although a definite line is shown on the on the map it must not be interpreted as necessarily the correct dividing line between the two formations, because at a few places along the contact there is, as Bradley indicated, an interbedding of the Rock River dolomite with the dove-colored limestones of the Strites Pond. Moreover, at most localities the transition beds are composed of limestone and dolomite patches, arranged in such a way as to give the beds a conglomeratic or brecciated appearance. In the upper part of the transition zone the

dolomite appears merely as stringers within the limestone. The thickness of the zone, from the base of the beds containing limestone to the top of the beds containing dolomite patches and stringers in abundance, is about 50 feet.

The conglomeratic aspect of the transition zone is explainable by the process of selective dolomitization of the limestone -- a process that decreased in effectiveness upward. From a study of the field relationships and polished specimens it is evident that the dolomitization took place along cracks that had developed in the limestone, and there is no evidence that the process was diagenetic, and little that it was effective after the limestone had become completely lithified.

Correlation. The first attempt to correlate Logan's subdivision A 1 with a formation in another area was made by Brainerd and Seeley, who considered it to be at least "lithologically identical" with Division A of the East Shoreham section. The latter is described (1890, p. 2) as follows: "Dark iron-grey magnesian limestone, usually in beds one or two feet in thickness, more or less siliceous, in some beds even approaching a sandstone. Nodules of white quartz are frequently seen in the upper layers, and near the top large irregular masses of impure black chert, which.... often appears fibrous or scoriaceous. Thickness 310 feet".

Further evidence in favor of this correlation is

afforded by the stratigraphic position of the two formations. At East Shoreham Division A follows directly the Potsdam sandstone, and is succeeded by a "dove-coloured limestone, intermingled with light grey dolomite in massive beds". At Philipsburg the Rock River dolomite overlies a thin series of sandstones which may be about the horizon of the Potsdam, and it is succeeded by the massive dove-colored limestones of Strites Pond (A 2).

After 1890 no direct correlation of the Rock River dolomite with formations of other areas was made until 1923, when Bradley again correlated "A 1" with Brainerd and Seeley's Division A (1923, p. 17). But there has been no correlation by inference, if Brainerd and Seeley and Bradley are correct.

In 1908, Cushing considered the Little Falls formation of the Mohawk Valley, the Theresa of the Watertown District, and the Division A of the East Shoreham section to be practically contemporaneous, and placed them in the lowest division of the Beekmantown. However, he doubted that his reference of these formations to the Beekmantown was correct (in view of Ulrich's discovery of an unconformity between Divisions A and B of the so-called Beekmantown of the Champlain Valley), and he suggested the possibility that the Little Falls formation, as well as the Theresa and Division A, might not be Beekmantown, but older.

Ulrich and Cushing (1910, p. 102) argued that in the Champlain Valley "Division A of the Beekmantown more properly belongs with the underlying passage beds and the Potsdam than with the purer limestones of the remainder of the Beekmantown"; and they stated further that the Little Falls dolomite was the equivalent of Division A and the lower part of Division B of East Shoreham.

Thus, if Division A of the East Shoreham section is the equivalent of the Rock River dolomite formation, Ulrich and Cushing have indirectly correlated the Little Falls with that formation. The presence of Lingulella (Lingulepis)acuminata at the base of, or immediately below the base of the Rock River, together with the lithological resemblance between the Little Falls and the Rock River, make this correlation seem logical.

As it appears today, the chief obstruction to the unqualified acceptance of this correlation is the absence of certainty of unconformity at Philipsburg (and apparently at East Shoreham) between the correlatives of the Little Falls and the overlying limestones. According to Ulrich (1910 and later) an unconformity separates the Little Falls from the true Beekmantown everywhere else in New York. There does not seem to be good reason to expect that the so-called transition beds between the Rock River and the

Strites Pond will lend themselves readily to the hypothesis of either conformability or unconformability. Until inimical evidence is adduced the Rock River dolomite and the Little Falls may well be considered correlatives

Strites Pond Limestone. (Logan's A 2). The Strites Pond formation has practically the same linear distribution as the Rock River dolomite, and it parallels the latter in discontinuous outcrops from south of the boundary line to Morgan Corners. At this place it is cut out by the same fault as the one which eliminates the Rock River. The beds of this formation are in no place exposed in their entirety across the strike, but outcrop on the east and west sides of a narrow valley. The valley is occupied by swamp land and by streams, and, about a mile south of Philipsburg, by the pond from which the formation takes its name.

Thickness. The average width of the formation is slightly less than that of the Rock River, and, with the dip averaging about 20°E., the thickness is estimated to be about 400 feet. The thickness given by Logan was 100 feet, a measurement which has not hitherto been questioned. Judging from Logan's description of the Philipsburg series as a whole, the section that he actually measured was that between Philipsburg and St. Armand Station, and it is probable, therefore, that his measurements were made on some outcrop

near the former town. As a matter of fact, no exposures of the formation within one-half mile of Philipsburg, either to the north or south, would give the true thickness. They would, however, show just such a thickness as Logan estimated. At a locality one mile north of Philipsburg, however, there are two outcrops exposed on an east-west line, separated by 200 feet of drift, which measure 580 feet and 520 feet respectively across their strike. The total of these measurements, with the 20° dip, gives a thickness of somewhat more than 400 feet. There is no evidence to support a view that these beds (outcrops) have been repeated and that, because of such repetition, more than the true thickness has been estimated.

Lithology. The transition zone between the Rock River dolomite and the Strites Pond limestone has already been described. Above this zone there is a considerable, but unestimated, thickness of beds, whose weathered surfaces are marked "by a multitude of thin raised reticulating lines of crystalline dolomite, more numerous in the lower than in the upper beds". (Logan, 1866, -. 277). These beds, like the higher ones of the formation, are dense, compact, massive limestones, varying in color from gray and dove-gray to grayish-white. The limestone is much prized as a building and decorative stone because it takes an excellent polish; in consequence it is locally and commercially known as marble.

But in the hand specimen and in thin sections much of the rock appears as a very fine-grained limestone, with recrystallization developed only locally.

Impurities are present in the form of wavy, stylolite-like lines, which seem to correspond fairly closely to the direction of stratification planes. These are found throughout the formation. Large (.75mm.) sand grains are common in the upper layers. At one place, immediately west of the quarry in this formation at Philipsburg, sand grains were seen on the surface of what appears to have been originally a thin shaly band in the limestone. This is now altered to a green chloritic substance, and some of the sand grains on it appear under the microscope to have been broken by shearing and to have been recemented by calcite. Three-eighths of a mile south of Morgan Corners, west of the road leading to St. Armand, sand grains are conspicuous over the surfaces of the limestone. In the same outcrop a few thin shaly layers were seen, as well as some fragments of black chert. The larger sand grains are usually well rounded, angularity being almost confined to the grains under .6 mm. in size.

The summit beds of the formation are, in many places, true intraformational conglomerates*, made up of angular and

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* Except where otherwise indicated the term "intraformational conglomerate" is here used in its original meaning, that is, as defined by Walcott (1894).

sub-angular pebbles of limestone, enclosed in a calcareous matrix or cement. Unlike the underlying beds of the formation, these carry fossils, which are contained in the matrix. Interstratified with the interformational conglomerates are a few beds of dolomite, very finely crystalline, dark gray in color on fresh surfaces, but weathering brown; they average about one foot in thickness. Pseudo-conglomeratic structures (Plate) occur in beds near the top of the formation, immediately north of the boundary line; these structures are probably due to selective dolomitization, leaving boulder-like patches or areas unaffected by the process.

One of the most interesting phases of the local dolomitization processes may be seen in basal beds particularly along the road one mile south of Philipsburg. The rock there is quite obviously half way between a limestone and a dolomite, and the process, frozen as it were, can be seen to great advantage. Throughout the outcrop dolomite appears mostly as thin veinlets or stringers of medium size crystals penetrating the limestone and surrounding residua of it so as to give a fleeting impression of a breccia. Some beds have been completely replaced, some nearly so, but all are more or less affected. Black (see Appendix, p. and pl.) states that this type of dolomitization took place appreciably later than lithification, but also states that it was probably contemporaneous with the dolomitization of the upper beds of

the upper beds of the Rock River. With this latter statement it is easy to disagree, although the stratigraphic relations between the Rock River and the Strites Pond are not sufficiently clear cut to be of great service to any view. Certainly the bulk of the Rock River dolomite was due to diagenetic change.

Stratigraphic Relations. As stated above, there is no observable break between the Rock River dolomite and the Strites Pond limestone. The upper limit of the Strites Pond is more definite; a sharp lithological change occurs at this horizon, and contacts with the overlying formation are exposed at a few places along the strike. A contact is well displayed about two miles north of Philipsburg, one-quarter of a mile west of the Morgan Corners - St. Armand road. At this place the relations are distinctly unconformable and the rocks above the contact differ markedly in appearance from those below (Plate). In other places, for example south of Philipsburg, on the road to St. Armand, the contact is less definite, and there is little evidence of unconformability between the two formations. Lithologically the Strites Pond and the overlying formation, the Wallace Creek, are in striking contrast, for the massive, light-colored Strites Pond limestone gives place at the contact to thin-bedded, dark, somewhat argillaceous limestones, interstratified with thin seams of black shale. Also there is a marked change in the fauna -- from the gastropod-cephalopod fauna of the

upper beds of the Strites Pond to an assemblage composed predominantly of brachiopods, with a few trilobites, in the Wallace Creek formation.

Fauna. The only fossils that have hitherto been reported from the Strites Pond formation are the "Pleurotomaria" and "Holopea" mentioned by Logan (1866, p. 278), and Cryptozoon steeli mentioned by Brainerd and Seeley (1890, p. 508). Additional discoveries were made in the course of this work in the matrix of an intraformational conglomerate near the summit of the formation. These consist of gastropods and cephalopods in a poor state of preservation. The cephalopods were identified by Ulrich as of the Eremoceras type. The gastropods included the genera Sinuopea and a form which very closely resembles Rhachopea. As yet unidentified forms are a low-spired gastropod with at least three whorls, a higher-spired type with four and possibly five whorls, and a relatively very high-spired type with three whorls.

Age and Correlation. Brainerd and Seeley (1890, p. 508) evidently considered that Division B of the Champlain Valley "Calciferous" was the equivalent of the Strites Pond formation, for they stated that "Logan's division A, with its three subdivisions.....is lithologically identical with our divisions A, B, and C respectively of the Calciferous".

Cushing (1908, p. 171) placed the Champlain Valley

Bradley (1923, pp. 16 - 18) also believed that "Divisions A, B, and C at East Shoreham" could be correlated with "Logan's Divisions A 1, A 2, and A 3 at Philipsburg".

Cushing (1908, p. 171) placed the Champlain Valley Division B in the lowest part of the Beekmantown. Although not definitely stated, it was probably implied that the Strites Pond formation belonged in the same horizon.

Ulrich and Cushing (1910) did not correlate the pure limestone facies of B, East Shoreham, with any formation, but they considered it to be the lowest Ordovician division in the Champlain Valley, as Cushing had done in 1908. They did, however, remove the dolomite facies from B and place it in the Ozarkian as an upward continuation of Division A, East Shoreham. They also separated the "fucoidal beds", a more calcareous and more fossiliferous upper portion of the Little Falls, from the Little Falls, and called it the Tribes Hill formation.

Ulrich (1911, p. 609) placed A and portion of B of East Shoreham in the Ozarkian, along with the Little Falls.

Foyles (1923, p. 74) correlates Division B, East Shoreham, apparently unrestricted, with the Tribes Hill.

The above discussion may be summarized briefly: there has been a tendency on the part of most writers to

correlate Division B of East Shoreham, and inferentially subdivision A 2 or the Strites Pond formation of Philipsburg, with the Tribes Hill; Ulrich, however, places the Tribes Hill well above these formations, with which latter view we are in accord.

On the basis of lithological similarity and stratigraphic position with reference to underlying beds the Strites Pond could be correlated with Division B of East Shoreham. But as far as the overlying beds are concerned there is no similarity either lithologically or faunally between the Philipsburg and East Shoreham sections, and, as will be shown later, there is little evidence in favor of the correlation of Division C, East Shoreham, with Logan's subdivision A 3 at Philipsburg. Furthermore, if Division B of East Shoreham is Tribes Hill in age, its correlation with the Strites Pond can not be accepted, for the latter is considerably older.

From further afield comes another thought. "There is, however, a suggestion of the Van Buren fauna at Philispburg, Quebec, in division A 2 of Billings section" (Bridge, 1930, p. 108). The Van Buren contains genera, at least, that Ulrich recognized in the Strites Pond fauna -- Sinuopea, Rhachopea, and Eremoceras, as well as two other genera -- Levisoceras and Sphenoceras -- which have not been found in the Strites Pond.

Of considerable significance in this connection that it is in the Van Buren that cephalopods "which are sparingly represented in the older formations, as to be almost negligible, but appear in abundance in this formation" (ibid., p. 107). In the Champlain Valley their first known appearance is in the upper part of the Strites Pond formation and in Division B of Brainerd and Seeley's Calciferous.

Wallace Creek Limestone (Logan's A 3 in part). Two of Logan's Division A formations occur above the Strites Pond (A 2). The lower of these has already been mentioned as that formation which, in places, overlies the Strites Pond unconformably; it will be described below as the Wallace Creek formation, the name being taken from the small stream flowing southward through Philipsburg to Strites Pond. The formation immediately overlying the Wallace Creek practically corresponds to Logan's subdivision A 3, and is herein named the Morgan Corners formation.

Subdivision A 3 as defined by Logan (1866, p. 844) consisted of "reddish-grey brown-weathering dolomites, and black dolomites with some thin bedded black limestones". These were said by Logan to follow the A 2 (Strites Pond) limestone, and to be the highest beds in Division A of the Philipsburg series. It was also stated (p. 278) that in contact with the dolomites there were "in two or three places,

some thin-bedded black limestones, which resemble beds much higher in the series, and may here be brought into place by some complicated structure not yet understood".

Bradley (1923, pp. 8 - 9) made two formations out of this set of rocks, calling them A 3a and A 3b, but it is not clear just what rocks he placed in these sub-subdivisions. Bradley's description follows: "A 3 follows A 2 first with reddish grey granular beds of limestone and these in turn by black limestone. In an unpublished letter, Dr. G. A. Young, of the Geological Survey of Canada, has recognized these two quite distinct phases of Logan's A 3. He named these members A 3a and A 3b. Since the integrity of these divisions is maintained in the faulted zone at Morgan's Corners, it is important to distinguish which part of A 3 is being dealt with. The lithology of the two members is well described by Logan". If, now, when Bradley referred the "black limestones" to A 3b, he had in mind the "thin-bedded black limestones" mentioned by Logan, he produced a reverse sequence. On the other hand, if "black limestones" refers to any part of the dolomite of Logan's A 3, then a formation of considerable importance, the Wallace Creek of this paper, was entirely omitted.

Distribution and Structure. The general strike of this formation is N.20°E., and its average dip is 20°E..

It is traceable northward from the boundary line to the valley south of the Philipsburg - St. Armand road, where there is a break in the exposures of about one-eighth mile. Where the St. Armand road turns northward to Philipsburg the three formations above the Rock River (A 1) are shown in their normal succession. There the Wallace Creek is exposed for 500 feet along the strike, and has a width of 350 feet. A narrow band of this formation can be seen faulted in with the dolomite of the Morgan Corners (the next higher formation) in the hill east of Philipsburg, this latter structure probably being responsible for Logan's misapprehension of the inferior age of the Wallace Creek.

North of Philipsburg there is a continuous exposure for a mile and a half of Wallace Creek beds. The south end of this exposure is very close to the "black marble", or smaller of the two quarries belonging to the Wallace Sandstone Co., and marks the line of a transverse fault, as does the northern end of the exposure. Northward to Morgan Corners there are discontinuous outcrops which show that in that direction the strata have in many cases been faulted, but on a rather small scale. These faults are treated more fully under Structural Geology. Just south of Morgan Corners the formation begins to swing more sharply to the east, and, crossing the road leading east from the Corners, may be traced for one-half mile, having gained its position on the

north side of this road by folding over an anticlinal axis. The formation has not been recognized north of this locality.

Thickness. The average width of the Wallace Creek exposures is about 700 feet, and, with the average dip at 20°, the thickness is estimated to be close to 225 feet.

Lithology. The strata of this formation are predominantly thin-bedded, black to grayish limestones, weathering light gray; they are interstratified with numerous thin bands of sheared black shale (Plate). The average thickness of the limestone beds is six to eight inches, with occasional beds reaching one foot or more. At several horizons within the formation beds of intraformational limestone conglomerate occur. In these the pebbles are in nearly every instance angular, and vary in size up to three inches long and one inch across. At the base of the formation a few of the beds contain infrequent pebbles of the Strites Pond limestone. These pebbles are usually not more than one inch in length, and, although much longer than wide, are not angular. The matrix in which they are imbedded is a grayish, granular limestone. Sand grains and chert, so common in the members underlying the Wallace Creek, are not in evidence in that formation.

The rock of this formation makes a very attractive black "marble" and is quarried and marketed at Philipsburg as

described in the chapter on Economic Geology.

Stratigraphic Relations. There is not the slightest doubt that the Wallace Creek immediately overlies the Strites Pond, in spite of the confusion in some earlier reports. The contact between the two formations is unconformable in some localities, while in others there is little physical evidence of unconformability. The relations of the Wallace Creek to the dolomite formation above it are not so definite, no actual contacts being exposed, but the black limestone at the top of the Wallace Creek seem to pass upward into a zone of interstratified limestone and dolomite, and this into a series if beds composed entirely of dolomite. Thus, conformable relations between the Wallace Creek and the overlying Morgan Corners formations are indicated.

Fauna, Age, and Correlation. The fauna of the Wallace Creek consists predominantly of brachiopods, a few trilobites also being present. Of these the junior author recognized the following genera---

Brachiopods:

Eoorthis
Billingsella
Syntrophia
Syntrophina
Finkelnburgia

Trilobites:

Platycolpus
Leiostegium

The question of the age and correlation of this formation will be discussed with that of the Morgan Corners (see page)

Morgan Corners Dolomite (Logan's A 3 in part). Overlying the Wallace Creek is a dolomite formation which corresponds to some extent at least, with Logan's subdivision A 3. Inasmuch as it is well shown near the cross-roads as Morgan Corners, that name is proposed for the formation.

Distribution and Structure. The formation can be traced northward from the International Boundary to Morgan Corners, in almost continuous exposures. Just south of the Corners it swings sharply to the east, and for one-half mile occupies a position about 200 yards south of the Bedford road. It then turns north, and is found east of the north-south part of the Bedford road for another half mile. In this distance the formation is swinging around the nose of a northeastward plunging anticline, a structure which brings the formation westward across the Bedford road and back to the Corners, where it is cut off by a fault. A small outcrop further to the northeast is composed of this formation brought to the surface by a normal fault. South of the boundary the formation can be traced around the end of a northward-plunging syncline (the St. Armand syncline) to the western valley of Rock River.

Thickness. Logan was not certain about the thickness of this member but stated that it was supposed to be about 200 feet. This seems to be a maximum estimate, for normally the Morgan Corners is about 350 feet wide across the strike, so that with the dip at 20°E., the thickness would be somewhat less than 150 feet.

Lithology. Wherever these beds are normally exposed they are predominantly black or dark gray in color, and finely crystalline compared to the dolomite of the Rock River formation. They weather to brown and buff colors. Intermingled with the dolomite are a few layers of dark, very finely crystalline limestone, which in the field can not be distinguished from the dolomite. The sand grains and chert, common in the lower or Rock River dolomite, are absent from this formation. Black has described the microscopic appearance of this dolomite in the appendix.

Upper Limit of the Morgan Corners Formation. On the eastern side of the northern end of the dolomite ridge (Plate) east of Philipsburg there is a small thickness of strata which clearly does not belong to the Morgan Corners formation. This is composed of three lithologically distinct types of rock, each about two feet thick. The uppermost bed, separated from the overlying Division B of Logan by a

drift-covered interval 150 feet wide, is a gray, fine-grained, sandy-weathering, arenaceous limestone. Below this bed, and in unconformable contact with it, is a white, extremely fine-grained and compact limestone resembling some of the beds of the Strites Pond formation. The lowest bed is a dark, dove-weathering, fine-grained, limestone, interstratified with thin semas of shaly material.

Underlying this limestone series is a conglomerate, whose thickness, while not definitely known, is probably about 50 feet. The contact of this conglomerate with the limestone above it is very irregular, and represents an unconformity, since the conglomerate had evidently been eroded to some extent before the limestone was deposited. In some places the conglomerate appears to be above the limestone, and to be, therefore, younger, but on closer examination it can be seen that the limestone beds abut against the conglomerate, and that the latter owes its higher respective elevation to more rapid and recent erosion of the limestone.

The six-foot limestone series at this locality is the beginning of the long sequence of limestone deposition of Division B, and between Division B and Morgan Corners formation there is an unconformity of considerable proportions but probably not representing any great time break.

The conglomerate which is mapped with the Morgan

Cormers formation, can be traced along its strike for 500 feet, but it is only at the north end of the outcrop and due east of Philipsburg that the limestones mentioned above as being in contact with it are exposed. As one goes along the strike, increasing thicknesses of dolomite appear on the eastern side of the conglomerate, and apparently above it, for the dips are to the east at about 20°. The dolomite is lithologically identical with the Morgan Cormers, and there is little question that it belongs to that formation, and owes its present anomalous position to thrust faulting. This fault, has, however, not sufficient magnitude or displacement to deserve a place on the map.

The dolomite phenoclasts in the conglomerate are, for the most part, so similar to the matrix that they are with difficulty distinguished as separate masses. They also resemble the underlying beds of the Morgan Cormers formation. Beginning about 100 feet from the southern end of the conglomerate bed, as exposed, numerous limestone phenoclasts occur. Lithologically these phenoclasts are identical in composition with some of the limestone beds in the upper part of the Strites Pond formation. Dolomite phenoclasts greatly predominate over limestone ones, and are more angular and smaller than the latter, their average size being twelve by fourteen inches.

A conglomerate with dolomite and limestone phenoclasts, and about the same thickness as the above, occurs two miles south of Philipsburg, or, immediately north of the boundary line and one-quarter mile east of the Philipsburg-Highgate Springs road. At this place the relationships of the four lower formations of the Philipsburg series -- those of Division A -- are confused by the structure. A dolomite formation that there lies between the Strites Pond and the Wallace has all the characteristics of the Morgan Corners formation. The conglomerate mentioned above is, then, near the top of the Morgan Corners, but it is overlain by siliceous strata that are not represented above the conglomerate east of Philipsburg. It can not be definitely stated that these two conglomerate exposures belong to the same horizon, but, because of their lithological similarity and their apparent position at or near the top of the Morgan Corners, it is likely that they do. This is made more probable by the fact that about midway between the exposure at Philipsburg and the one at the boundary line a third conglomerate exposure occurs and is near, if not at, the top of the Morgan Corners formation.

Age and Correlation. On the bases of lithology and stratigraphic position, Brainerd and Seeley (1890) and Bradley (1923) correlated Logan's subdivision A 3 with Division C of the East Shoreham section. But when this

correlation was made it was apparently believed that A 3 consisted mainly of dolomite and that this dolomite followed directly the Strites Pond formation (A 2) -- the existence of the Wallace Creek formation not being realized.

It has already been stated that the Strites Pond formation is considerably older than the Tribes Hill, with which it was correlated by Bradley. The Strites Pond carries a fauna that is not known to be represented in the Champlain Valley, and the same is true of the next higher formation of the Philipsburg series, the Wallace Creek. The Wallace Creek apparently passes upward into the Morgan Corners without any break, so that these two formations are not far removed from each other in age. Also, the Hastings Creek formation, which is the lowest formation in Logan's Division B, and comes next above the Morgan Corners, contains all of the genera listed under the Wallace Creek formation, and, although the Hastings Creek contains other faunas, which, by themselves, would indicate younger horizons, its fauna, as a group, suggest that there is no important time break between the Morgan Corners and Hastings Creek formations, -- that there is, in other words, no convincing reason for making the line between Division A and Division B of the Philipsburg series the dividing line between the Lower and the Middle Beekmantown, as Bradley has done.

If any of the formations mentioned above are represented in the Champlain Valley deposits proper they have yet to be discovered. Stratigraphically and geographically the nearest correlative of the Wallace Creek, the Morgan Corners, and the Hastings Creek (considering these three formations as a unit), is the Georgia formation of northwestern Vermont.

Division B of Logan. Logan's Division B of the Philipsburg Series can be seen in its entirety in only one section, that between Philipsburg and St. Armand Station. On the boundary line, a mile and a half southward, the higher beds, B 4 and B 5, are absent, while to the northward the outcrops are so scattered and so offset from the normal line of strike as to make their correlation with the various members of the Division extremely difficult. Unlike the lower members of the series, the rocks of this Division show considerable lithological variation within the individual formations or subdivisions. Limestone predominates, but varies widely in color and texture. Dolomitic beds are common, and sandy limestone beds occasionally occur.

According to Logan (1866, p. 278 - 279, and 844) the thickness of this Division is 1,040 feet. The total thickness of the Division is essentially as Logan has given it, but the thickness of the individual formations are not

all in agreement with Logan's figures. The thicknesses of the subdivisions, as worked out by Logan are given below together with modern estimates and formation names used in this report.

Subdivision	Thickness		Name proposed.
	Logan	McGerriglo	
B 5	350'	200'	St. Armand
B 4	300'	300'	Solomons Corners
B 3	150'	160'	Luke Hill
B 2 (top bed of)	30'		Naylor Ledge
B 2	120'	260'	Hastings Creek
B 1	120'		
	1,040'	950'	

If there be added to McGerrigle's measurements the 50 or 60 feet of strata that would appear in the drift-covered interval between Division A and B, and which we consider basal to the Hastings Creek formation, the total thickness of Division B would then be about 1,000 feet.

Hastings Creek Formation (Logan's B 1 and B 2 in part)

The Morgan Corners formation is everywhere separated from the lowest members of Division B by an area of drift. East of Philipsburg, north of the road to St. Armand, this drift area is widest, and is cut into by a small stream, locally known as Hastings Creek, which flows southward into the creek draining Strites Pond.

We propose that the two lowest subdivisions of Logan's Division B, namely B 1, and all of B 2 except the topmost bed, be placed in one formation, to be called the Hastings Creek formation. The summit bed of Logan's B 2 is obviously a separate formation, known as the Naylor Ledge limestone. This bed was not specifically mentioned by Logan even though it occurs at an important stratigraphic horizon, is easily recognized, and is a mappable unit.

Distribution. The Hastings Creek formation can be traced from the western side of the valley of Rock River, at the International Boundary line, westward around the end of a northward plunging syncline, and then in a northerly direction to the valley parallel to and south of the Philipsburg -- St. Armand road. Then, after being concealed by drift for a quarter of a mile, it appears on this road, and continues with a N. 20° E. strike for three and a half miles farther northward. Occasional outcrops, doubtfully referred to this formation, are found for about a mile still farther north.

Thickness. Logan's measurement of the thickness of subdivision B 1 apparently does not include the strata that would occur in the drift covered interval between divisions A and B. Neither are these beds included in the writer's estimate of the thickness of the Hastings Creek formation on the preceding page. If they were included, they would bring the thickness of the Hastings Creek up to about 310 feet.

Lithology. The rocks of this formation are mainly very pure limestones, varying in color between white and dark gray or almost black; interstratified with the pure limestone beds toward the base are several brown-weathering magnesian beds and occasional arenaceous strata. At the top of the formation magnesian beds again occur, and are underlain by about 60 feet of limestone which is interstratified with thin layers of shale.

The lower half of the Hastings Creek was described by Logan (1866, p. 278), under the heading of subdivision B 1 as follows: "White and dove-grey limestones, with thin raised chain-like lines of crystalline dolomite reticulating over the surfaces of the beds. Interstratified with them are a few beds of magnesian dolomite, some light grey, weathering yellowish, and some dark grey, weathering white; a bed of mottled red and white dolomite occurs about the middle of the mass". And the higher beds B 2 were described by him (1866, p. 278) as follows: "Dark grey and black limestones, some of the beds being highly magnesian. Some are mottled and weather light grey, and others are reticulated by thin raised lines of yellowish weathering dolomite".

In 1929 the junior author, assisted by Mr. J. Morin, measured a section of these rocks east of Philipsburg. The beds with their thicknesses are given below, in descending order:

Luke Hill formation

Unconformity

29. Rusty weathering grey limestone and dark, shaly ~~weathering~~ weathering limestone interstratified..... 8'

28

28. Finely crystalline, dark, brownish weathering dolomite ..... 3+'

27. Drift. (On the Boundary Line this part of the section is occupied by beds like no. 26. .....50'

26. Shaly strata, interstratified with limestone which is in places conglomeratic (intraformational) and in other places very fine-grained..... 4' 3" ?

25. Compact grey limestones, in places rather highly ~~dolomit~~ dolomitic; with peculiar dolomitic patterns, which are roughly circular in outline, and with dolomitic "channels".....90'

24. Fine-grained, grey, light-weathering limestone, probably the summit of Logan's subdivision B 1.....8' 5" ?

23. Fine-grained, grey, rusty-weathering limestone.....6' 5"

22. Drift..... 4'

21. Same as no. 23..... 3"

20. Dove-colored, light weathering limestone, with crystalline dolomitic stringers and grains.....6'

19. Drift.....4+'

18. Fine-grained, grey, rusty-to dark-weathering limestone, filling channels at the top of no. 17.....1'

17. Coarsely crystalline, grey dolomite, with some fine-grained, light colored limestone.....9' 5"

16. Drift..... 5"

15. Same as no. 17.....8'

14. Gray limestone with reticulating dolomitic bands...2' 2" ?

13. Drift.....2' 5"

12. Finely crystalline, dark colored, brown-weathering dolomite.....2' 3"

11. Drift		5"
10. Rusty weathering, gray limestone with a considerable sand content	1'	5"
9. Fine-grained, white limestone with reticulating dolomite lines	4'	
8. Finely crystalline, dark colored, brown weathering dolomite	2'	8"
77. Drift	10'	
6. Fine-grained white limestone	8'	
5. Rusty weathering gray limestone, with a considerable sand content	4'	
4. Cross-bedded white limestone, with channel markings at the top	5+'	
3. Fine-grained, white limestone with a few paper-thin partings of shaly material	4'	5"
2. Fine-grained white limestone, with reticulating "thin raised chain-like lines of crystalline dolomite"(Logan)	4'	5"
1. Fine-grained white limestone	5'	5"
Total	259'	4"

.Drift interval

Morgan Corners formation

Shallow water deposition during the formation of the lower 100 feet of the Hastings Crock is evidenced at several horizons, notably by such phenomena as cross-bedding and unconformities, and possibly by the presence of beds composed of about equal proportions of quartz sand and limestone. Cross-bedding was noticed in a white, fine-grained limestone near the base of the formation (Pl. 19). The photograph shows the relationship between strata no. 17 and 18. The largest channel, one foot and a half deep, might have

resulted from sub-aqueous erosion of soft material, but against this interpretation is the fact that the channel has to a slight extent, and near its base, undercut the limestone. To the left of the large channel shown in the photograph are smaller ones, which have very sharp outlines. It is unlikely that such outlines could be produced in unlithified sediments, especially while those sediments were still submerged. It is believed that these channels are not cut-and-fill phenomena, resulting from contemporaneous erosion and deposition, but that they mark a true unconformity, resulting from sub-aerial erosion. Erosion channels occur both above and below this horizon, but are less well displayed than those which have been described. A well marked erosional unconformity is shown in Plate 20, from a locality about two miles N.N.E. of that shown in Plate 19, and probably from a higher horizon within the Hastings Creek formation.

Further evidence of oscillations of the land during Hastings Creek time is visible at two other horizons in this formation, where arenaceous limestone beds occur. In these the sand grains are small, usually less than .2 mm. in diameter, and angular. The weathered parts of these beds, these from which the calcareous matter has been dissolved, very light in weight, gritty, and have a rusty-brown In most respects these rocks resemble those very erous beds higher in the series which were described

by Logan as "ocherous-weathering", and which he placed in his subdivision B 3: the only apparent difference is that the latter weather to a richer shade of brown.

About in the middle of the Hastings Creek formation lies the base of a set of massive limestone beds that is 90 feet thick. Stratification planes within this set are only occasionally discernible, and are too indefinite to permit an accurate measurement of the indivdual beds. The rock is dark gray, almost black, in color. For the most part it is very fine-grained, but a few crystals of calcite may be seen on any fresh surface. The weathered surfaces are light gray or dove-colored, with occasional cream-colored patches showing the occurrence of dolomitic limestone. As quoted above Logan stated that some of the surfaces are reticulated by raised lines of yellowish-weathering dolomite, the patterns produced are not true reticulates, and do not resemble those seen in the Strites Pond formation nor in the basal beds of the Hastings Creek. Occasionally the lines are a quarter of an inch wide, but they are usually less, and they enclose areas that are roughly circular (Plate), or rarely roughly five-sided.

Overlying the heavy limestones is a thin development of intraformational conglomerate. The longest diameter of the phenoclasts (pebbles) in this bed is usually not more than one inch. The matrix is also fragmental, and the whole is bound together by a calcareous cement. The rock is of

a fairly unifrom grayish-blue color on fresh surfaces, but weathers to a mottled light gray or dove. Fragments of fossils, mostly trilobites and brachiopods, are numerous.

The conglomeratic stratum is succeeded by a set of alternating limestone and shaly beds about 50 feet thick. East of Philipsburg the lower 4 feet only of this set occur, but practically the entire thickness is exposed at the boundary line and for one-half mile northward (Plate). Shaly material predominates, and encloses within its beds small nodules of very dark, fine-grained, dove-weathering limestone. This type of limestone is also interstratified with the shaly beds in layers from one to two inches thick.

The well-stratified beds described above are followed by a dolomitic bed, and this by gray and dark limestones, which are in turn followed by the massive limestone bed of the Naylor Ledge formation.

Structure. The general movements which affected the Philipsburg series caused local thrusts and (as in most of the other formations of the series) widespread though weak shearing to develop within the Hastings Creek beds.

On the Philipsburg - St. Armand road a cut has been made through the lower beds of the Hastings Creek, and has exposed a thrust of small displacement. The plane of the thrust dips about 20° to the east, and the pressure has come

from that direction. The displacement is only a few feet, but the lower beds of the overthrust block, some of them a foot and a half thick, are much broken. The beds on which the fault breccia rests are not disturbed. The trace of the fault can be followed northward at an angle of N.20°E. for 200 feet, almost to the end of the outcrop. Immediately south of the road at this point there are no exposures. East of Philipsburg a small area of brecciated rocks at a lower horizon than that of the thrust just mentioned, or about 10 feet above the base of the formation, is exposed. This area is also thought to be the location of a small thrust, but the relationship of the brecciated rocks to the strata above and below could not be observed.

Stratigraphic Relations. The top of the Morgan Corners formation is marked by a heavy conglomerate, and it is known that this conglomerate is unconformably overlain by a thin set of limestones. These limestones have been seen at one locality only, about a third of a mile east of Philipsburg, where they are separated from the base of the limestones of Logan's Division B, -- the base of the Hastings Creek formation --, by a 150-foot belt of drift. If these limestones are the first of the thick succession of the limestone strata of Division B, then Divisions B and A are separated by an unconformity.

The Hastings Creek formation is separated from the

overlying Naylor Ledge formation by an unconformity. This can be seen very clearly north of the Philipsburg -- St. Armand road (Plate 26). Definite proof of unconformability was also obtained from outcrops along the western side of the St. Armand -- Highgate Springs road, north of the boundary line. There the Naylor Ledge and the higher beds of the Hastings Creek dip westwards at steep angles, and are well exposed. The line of contact is, in places, more uneven than the one at the top of the Hastings Creek formation east of Philipsburg.

Fauna. Up to the present time only three fossils have been reported from the beds that were included by Logan in Subdivision B 1, the lower half of the Hastings Creek formation, of which but one species was identified. Several species have been collected from these beds during this work, as well as from the upper half (subdivision B 2) of the Hastings Creek. From Subdivision B 2 Logan (1866, p. 278) listed sixteen genera and ten species; these species were described by Billings (1865). Billings also reported and desc described twelve additional species from subdivision B 2.

Fossils from Logan's and from Billings' lists follow:*

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*The synonymy is from Bassler, 1915. The generic names as given by Logan and Billings are in brackets. The quotation marks are inserted by the present authors.

Subdivision B 1:

"Pleurotomaria"
"Ophileta"
Leiostegium /Bathyurus/ saffordi (Billings)

Dubdivision B 2:

Dalmanella /Orthis/ electra (Billings)
"Orthisina"
Syntrophia /Camarella/ calcifera (Billings)
Syntrophia? / Orthis / armanda (Billings)
Macluritos /Maclurea/ matutina (Hall)
Macluritos /Ophileta/ sordidus (Hall)
Ophileta levata Vanuxem
Ophileta complanata Vanuxem
Ecculiomphalus Ecculiomphalus canadensis (Billings)
E. Ecculiomphalus intortus (Billings)
E. Ecculiomphalus spiralis (Billings)
"Pleurotomaria"
"Murchisonia"
"Holopea"
"Metoptoma"
"Nautilus"
Aphetoceras or Tarphyceras /Lituites/ farnsworthi (Billings)
Orthoceras repens Billings
O. catulus Billings
O. cataline Billings
O. cato Billings
O. sayi Billings
O. tityrus Billings
Cyrtoceras /Orthoceras/ missisquoi (Billings)
C. aristides Billings
Pliomerops? /Amphion/ salteri (Billings)
Leiostegium /Bathurus/ saffordi (Bathyurus)
D[illegible]telocephalus? missisquoi Billings

Unfortunately, Logan and Billings did not state the exact horizons of Subdivision B 2 from which these fossils were collected. And this fact, in our opinion, is one of the chief causes for the confusion of ideas regarding the exact age of the lower part of Division B. Inasmuch as it has been our experience that certain of the fossils listed by Logan and Billings do not occur below the topmost bed of subdivision B 2

we have removed that bed from B 2 and made it a separate formation, the Naylor Ledge limestone. By doing so, the curved and coiled cephalopods and the Macluritos-like gastropods (Macluritos matutina, M. sordidus, "Nautilus", Aphetoceras (or Tarphyceras) farnsworthi, Cyrtoceras missisquoi, C. aristides) are removed from the fauna of B 2, and restricted in their downward range to the base of the Naylor Ledge, and should therefore be deleted from the above list. This does not entirely remove the confusion, however, as is pointed out below.

Of the twenty-two species listed above for Subdivisions B 1 and B 2, five have been removed from the Hastings Creek formation, while ten have been reported only from the Hastings Creek or other formations of the Philipsburg series. Seven species are left, which, from their occurrence elsewhere, may be useful in determining the age of the Hastings Creek formation: these are Dalmanella electra, Syntrophia calcifera, Ophileta levata, O. complanata, Eccyliomphalus canadensis, E. intortus, and Leiostegium saffordi. Dalmanella electra is generally considered to be a Beekmantown (Canadian) species; "Syntrophia calcifera" is a term which contains a number of species, and even genera, and is, therefore, of no value in correlation. Ophileta levata is given by Bassler (1915) as a Little Falls form, and the Little Falls is considered by Ulrich to be the uppermost member of the Lower Ozarkian in New York State. O. complanata is apparently quite common in Division C of

the Champlain Valley Beekmantown, and, along with Ecyliomphalus canadensis and E. intortus, has been reported by Logan (1866) and Billings (1865) from the Beauharnois formation of Southern Quebec, formations which are considered by Butts (1926, pp. 94-95) to be Middle Beekmantown in age; Leiostegium saffordi is also considered to be a Beekmantown form, although its only known occurrences are in the Philipsburg Series, in the Levis and Cow Head conglomerates, and in the Williston limestone of Vermont -- the last mentioned formation being referred to the Saratogan (Keith, 1923, p. 120).

Thus it will be seen that even among the few species listed to date which can be used for correlation purposes there is a certain amount of confusion of ages, but, except for Ophileta levata, the evidence points to a true Beekmantown (Canadian) age rather than Ozarkian, and seems to point to the Middle Beekmantown as the age of the Hastings Creek beds.

However, Ulrich is not in agreement with this age assignment, and has concluded that the Hastings Creek formation as well as the Wallace Creek and Morgan Corners formations below, and the Luke Hill above the Hastings Creek, are most properly referable to the Upper Ozarkian. These conclusions, unpublished, are based largely upon the abundance of certain genera of the Syntrophiidae and of the trilobite genus Leiostegium throughout this set of formations; genera which Ulrich considers to be diagnostic of the Upper Ozarkian.

Naylor Ledge Limestone (Summit of Logan's B 2). The Naylor Ledge formation includes only one bed, thirty feet thick, which has lithological characteristics peculiar to itself, and is separated from the overlying and underlying beds by unconformities, and has a fauna that is more or less different from those of the underlying formations. It is the youngest bed in Logan's subdivision B 2.

The best exposure of this formation is locally known as Naylor Ledge, and is on the property of Mr. Edgar H. Naylor, not far from Solomons Corners.

Distribution and Structure. Beginning at Mr. Naylor's house, on the Philipsburg-St. Armand road, this formation may be followed northward along almost continuous exposures to a position one-half mile west-south-west of Morgan Corners. Throughout this distance the strike is N.20°E. and the dip is eastward at an average angle of 20°, or somewhat less, but the last outcrop shows that this formation, like the underlying formations, was bent to the east by folding at Morgan Corners. The dips are southeastward at this place.

The most northerly recognized outcrops of the formation occur on, or immediately north of, the road from Morgan Corners to Bedford, about a quarter of a mile east of the Central Vermont Railway. There the general structure is confused, but the Naylor Ledge formation dips northward and trends about

50°E..

From a position south of the valley paralleling the Philipsburg-St. Armand road the formation can be traced to the International Boundary, with its eastward dip gradually shallowing all the way. At the boundary it swings around the nose of the St. Armand syncline, and can then be followed northward on the east side of the synclinal axis to a position about one-half mile south of St. Armand station. In its course on the east side of the axis the formation dips steeply to the west and is even occasionally overturned.

Lithology and Stratigraphic Relations. Throughout the thickness of this formation their is little evidence of bedding; the rock is massive. very fine-grained, dark gray to black limestone, weathering to a light gray color. There is indication that the upper few feet (two or three) is a darker limestone than the bulk of the formation. Ulrich has collected from both the "dark" and the "light" and claims a boulder origin for the "dark". For this we can see no justification. Shearing has affected the bed considerably, making it difficult to obtain good specimens of the cephalopods and gastropods which, on the weathered surfaces of the rock, appear to be well preserved. Corresponding to the shearing planes are numerous thin lines that weather to various shades of brown. Occasionally individual lines may be traced for about two feet, but they commonly merge with others and form

a reticulated pattern in the massive limestone. These lines are dolomitic, and, inasmuch as they occur along shearing planes, they probably originated during or after the folding and are, therefore, secondary.

Scattered over the upper surface of the bed are numerous small patches of a different type of limestone. These are easily distinguished from the main mass because they weather to a deeper shade of gray and are often speckled with brown dolomite. The grain, too, is coarser and more crystalline, and the rock is, in some cases, of the intra-formational conglomerate type. In addition to the small "patches", this rock occupies distinct channels in the massive limestone. Most commonly the channels are one to two feet in width. Their elongation roughly coincides with the dip slope. The largest channel observed is ten feet in width and extends diagonally across the dip slope for about thirty feet. As now exposed, the channels are rarely more than one foot deep, but they have been reduced by recent erosion, and were probably of much greater depth originally.. The fragmental limestones filling in these channels can be demonstrated to grade upward into the overlying, "ocherous-weathering", arenaceous limestone at the base of Logan's subdivision B 3, the Luke Hill formation.(see Plate).

The latter beds and the Naylor Lodge formation are

separated by the most definite of the many unconformities seen in the Philipsburg series. There can be little question that the channels just described had their origin during the period of erosion represented by the unconformity, and were filled in when the area was again submerged. In recent time the more massive beds throughout the Philipsburg series have been so affected by solution agencies that rills or channels are common on the surfaces exposed to the weather. The channels, now filled with lithified sediment, at the top of the Naylor Ledge formation are thought to have had a similar origin.

A more difficult problem is presented by the dolomite "blocks" found in this formation (Plates). The photographs do not show that the "blocks" have any relation to the top of the bed. Although they occasionally do occur at the top (Plate), they are also found as much as twenty feet below it. They are all fine-grained, dark-colored, brown-weathering dolomite. There is no apparent variation in their composition, and they were all evidently formed under the same conditions. Like the surrounding limestone, the "blocks" are much sheared, and are cut by gash veins filled with calcite. The veins except in a few instances can not be traced from the dolomite "blocks" into the limestone, but although sometimes nearly two inches in diameter in the middle of the dolomite, thin to nothing before reaching its

margins. The outlines of the "blocks" are definite, and usually quite angular; there is no evidence of gradation from dolomite to limestone.

The problem of the origin of these masses of dolomite is a pressing one. Many, if not most, of them appear as discrete dolomite patches, entirely surrounded by limestone, and as such the first thought that strikes the observer is that they are pieces of another formation which have reached their present position by some kind of transportation. A good many dolomite masses belie this conclusion however. In some cases it is possible to see an extention upwards towards the top of the Naylor Ledge formation, and that extention is always tabular and nearly vertical. At present the Naylor Ledge is honeycombed with solution channels, some of which are ten or more feet deep and a foot or a few inches wide. Many can be definitely seen to widen downwards. If these should be filled today (as they are with soil, etc.) the filling would present precisely the same appearance as the dolomite "blocks" and their upward extrusions. Better and more conclusive evidence can be seen at the outcrop opposite the Hastings Monument Cemetery, one and a half miles south of Morgan Corners. There in one case the dolomite is stratified and the beds, dipping away from the center with an increasingly high dip upwards (see figure) suggest the attitude of loose material that has

dropped down from above, accumulating as a debris cone on the floor of the cavity. At this locality too, may be seen the intermingling of this brown dolomite with the gray fragmental material described above. The latter is without a shadow of a doubt the basal part of the succeeding Luke Hill formation, and the dolomite with which it is interstratified must be contemporaneous with it. Gray fragmental limestone and brown dolomite can be seen in alternating layers of the order of an inch in thickness to the number of a dozen or so in one outcrop. These brown blocks are remnants of cave pillars and roof according to Ulrich (1931), the cave occupying the space now taken by the Naylor Ledge limestone. The evidence given above is quite sufficient to deny the existence of a cave where the Naylor Ledge now is, and to intimate that any caves thereabouts were cut out of the Naylor Ledge itself just prior to the deposition of the Luke Hill. Ulrich has made much, in unpublished communications, of what he calls a remnant of a dolomite bed from which he would derive many, if not all of the dolomite blocks under the cave hypothesis. This remnant has been carefully examined and proves to be not a remnant, but the filling of a wide depression in the eroded Naylor Ledge, and is covered by the gray fragmental limestone. Except for a few rare cases where the dolomite and gray fragmental limestone are interstratified the dolomite is always the lower of the two and filled the deepest irregularities of the karst surface on the Naylor Ledge.

This is followed by the gray fragmental limestone which approaches continuity in distribution, and is in turn covered by the ocherous weathering continuous bed which all agree to be the Lake Hill formation. Further remarks anent this situation are recorded under Age and Correlation.

Fauna. This uppermost bed of Logan's B 2 is the most fossiliferous of that subdivision. In it occur, for the first time as far as the Philipsburg series is concerned, curved and coiled cephalopods, numerous straight cephalopods, Euconia, and progenitors of Maclurites which resemble that genus but probably do not truly belong to it. Forms resembling the Cyrtoceras, Nautilus, and Lituites of Logan and Billings, or anything even remotely resembling Maclurites have not been found below the Naylor Ledge formation in spite of extended search. It is found that the following forms listed by Logan and Billings from B 2 do not range below the Naylor Ledge:--

Maclurites matutina (Hall)
Maclurites sordidus (Hall)
"Nautilus"
Aphetoceras farnsworthi (Billings)
Tarphyceras farnsworthi (Billings)
Cyrtoceras missisquoi Billings
Cyrtoceras aristides Billings

And, of these, "Nautilus" and the "Maclurites" are possibly incorrectly identified, for the true types of these genera are not found in the large collection from these beds in the United States National Museum nor in our collection.

Aphetoceras farnsworthi, Tarphyceras farnsworthi, and the two species of Cyrtoceras of the above list have been reported from Philipsburg series formations only, therefore, they are of little value in making definite correlation. Much of the dispute regarding the mode of sedimentation responsible for the formation of the Naylor Ledge limestone involves a close study of the large collection of fossils in our collection. This, the junior author has not yet had the opportunity to do. Sufficient preliminary examination has, however, been made to warrant the above statements.

Age and Correlation. In the preceding discussion of the Naylor Ledge, it is considered that that formation occurs in its right and natural position as far as age is concerned, as determined by superposition; that is, that it is younger than the Hastings Creek, immediately below, and older than the Luke Hill, immediately above.

The cave hypothesis alluded to above has recently been advanced by Ulrich (1931, p. 348). This is to the effect that the Naylor Ledge limestone is the filling of a cave developed in the rocks of Upper Ozarkian age and filled with sediments of Upper Canadian time. This is necessitated, according to Ulrich, because of the presence of what are to him Upper Canadian fossils in the Naylor Ledge, and what are to him Upper Ozarkian fossils in the next succeeding formation, the Luke Hill. If the paleontological evidence is reliable

then the superposition is misleading, and a sharp overturned fold, a thrust, or other fault, or an explanation such as Ulrich's is in order.

The chief faunal evidence leading to the cave theory is the presence of coiled cephalopods in the Naylor Ledge. Such are said by Ulrich not to range downward into the Ozarkian. However, the junior author has found them some 50 feet above the base of the Luke Hill. A fossil that was probably included by Billings under "Lituites farnsworthi" has been identified by Ulrich as a species of Eurystomites which he considers to be typical of the Upper Canadian (Upper Beekmantown, essentially). But associated with this form and with other curved and coiled cephalopods generally considered to be of Canadian, or Beekmantown, age, there are brachiopods and trilobites which Ulrich regards as quite typical of the Upper Ozarkian. How, then, to explain this apparent mingling of forms from rather widely separated epochs? There would seem, outside of a revision of the stratigraphic value of the fossils concerned, to be only two possibilities -- either by faulting or by the cave idea. Inasmuch there is not the slightest evidence of faulting or of folding, the cave theory alone remains to be discussed.

Disregarding for the present, the paleontological evidence, the physical evidence, presented below, appears inimical to the cave hypothesis.

1. The stratigraphic relations of the Naylor Ledge;-

At the base the Naylor Ledge is unconformable to the Hastings Creek formation. Such a relation could develop whether the Naylor Ledge followed the Hastings Creek in natural order or as a much later cave-filling, therefore, this contact has little bearing on the problem.

The nature of the contact with the formation above may be expected, however, to be of prime importance, and it offers evidence distinctly unfavorable to the theory that the Naylor Ledge is the filling of a cave. If the Naylor Ledge were the filling of a cave then the contact between it and the Luke Hill (above) should be sharp, there should be no gradation of the first into the second or no interbedding of Naylor Ledge material with Luke Hill material, and there should be no pebbles of the Naylor Ledge in the Luke Hill; such considerations are necessarily implied in the cave-filling theory, for, according to that theory, the Luke Hill was already in existence before the Naylor Ledge material filled the cave below. But, in a few places, restricted, but pertinent, there is evidence near the contact of the two formations of a reworking of Naylor Ledge material and the incorporation of that reworked material with shaly material of the Luke Hill type; also, definite pebbles of material indistinguishable from the Naylor Ledge occur in the basal few inches of the Luke Hill at two localities observed.

The largest pebble seen was irregular, not rounded, and two inches in longest diameter. Such evidence, with the obvious implications involved, would seem to be disastrous to the theory of cave-filling.

2. The lithology of the Naylor Ledge.

The Naylor Ledge formation comprises three distinct types of rock, although all are calcareous:

(1) The main mass of the formation, which Ulrich interprets as the "cave-filler"; light and dark shades of gray in color, white- or dove-weathering, and very fine-grained.

(2) "Blocks" of a rather fine-grained, dark-colored, brownish-weathering dolomite, cut by numerous calcite veins.

(3) Irregular patches and channel-like forms composed of dark gray limestone of small angular fragments, numerous fragmentary fossils, and a calcareous matrix.

Our interpretation of (2) and (3) is that each is a type of "channel-filling"---material deposited in irregular depressions or hollows or solution channels in the Naylor Ledge formation after that formation had been completely lithified, exposed and deeply cut to a karst surface as described above. Ulrich's interpretation is that (2) represents roof pendants, or in some cases it may be, roof supports, and that (3) represents blocks that have fallen from the roof of the cavern

Why there should be two types of "channel filling",

(2) and (3) above, may seem to be more easily answered by Ulrich's theory than by ours -- they either fell in from the roof of the cavern or they are remnants of the rocks which originally occupied the thickness which was later to be dissolved away to produce a cave. But the question may also be answered, by the perfectly justifiable assumption that they represent two stages in the filling up of the erosional irregularities developed on the Naylor Ledge. One of these, the first, was more susceptible of dolomitization than the other, though why is not understood.

The theory that type (3) represents fallen blocks is supported at first sight by the occurrence between the Naylor Ledge limestone and the Luke Hill thinly bedded shaly limestones of a dolomite layer which, as exposed, measures about 15 feet in length and 2 feet in thickness. A closer inspection of all the details proves beyond a doubt, as explained above, that this dolomite "remnant" is nothing but the earliest filling of a low wide depression on the surface of the Naylor Ledge.

The calcite veins provide another powerful argument against the theory that types (2) and (3) are remnants and fallen blocks, for they show that our application of the term "channel-filling" to them is appropriate. Inasmuch as these veins do not occur in the surrounding Naylor Ledge limestone, or in the overlying Luke Hill limestone, it would

appear that they owe their origin not to dynamic agencies but rather to shrinkage. Supporting this belief are the facts of the case. The cracks very seldom continue through the "channel-fillings" into the main limestone mass; approximately 85% of the cracks observed stop just before the "channel-filling" edge is reached; 10% reach the edge, and perhaps 5% go through into the main limestone mass. Now, unless these cracks were in the so-called "channel-fillings" originally and the "channel-fillings" actually dropped in they must be shrinkage cracks, formed during the contraction of the sediments during the lessening of volume, due, perhaps, to drying out, perhaps to dolomitization. And the fact that a few go into the main limestone mass from the "fillings" shows that these cracks developed after the "channel-fillings" and the limestone of the Naylor Ledge proper were brought into contact. On this latter count, therefore, these "channel-fillings" could not have fallen in from roof rocks. And, too, if we think of the "channel-fillings" as remnants or roof pendants then the shrinkage cracks must have developed before the white lime muds, later to be the Naylor Ledge limestone, surround them; in such an event there does not seem to be any reason why 85% or so of the cracks do not continue to the edge of the "channel-fillings" but pinch out, or decrease in width, before the edge is reached. To consider a roof pendant, or a cave pillar traversed by open fissures up to two inches wide is

consider an absurdity.

The above is our interpretation of the cracks found in the "channel-like" structures and the "block-like" structures in the Naylor Ledge formation. Ulrich, however, claims that the cracks may not be due to shrinkage; rather, their development in the structures mentioned and non-development in the Naylor Ledge limestone proper is because of the difference in rock composition -- the dolomite blocks and the fragmental limestones, types (2) and (3) above, being more liable to fracture under stress than the fine-grained limestone.

3. the dimension of the postulated cavern

The very size of the postulated cavern operates against the theory. The height of the cavern, represented by the thickness of the Naylor Ledge formation (30 feet), is, of course, within bounds, but the thickness or height is surprisingly constant wherever the formation is exposed. And, as a corollary of constant height or thickness, wherever the beds immediately overlying the Naylor Ledge are exposed they are found to be of identical character from one locality to another -- always such beds are the "ocherous-weathering" limestones, distinctive in their lithology, and richly fossiliferous. Such features would be expected if the relations between the Naylor Ledge and Luke Hill were normally unconformable. It is evident that the fact of constant thickness could be used against the idea of an unconformity; an

unconformity implies that the lower formation has been subjected to some kind of erosive action, and it is not unusual for a formation to be worn deeply in some parts and only worn to a minor extent elsewhere within the same region. But, granting a formation of essentially uniform composition, as is the Naylor Ledge, and a wasting action which involves solution rather than any truly erosive medium, the results now observable would readily have been produced.

The formation is exposed nearly continuously from the boundary line past Philipsburg to Morgan Corners, a distance of five miles. Northward from here it appears meagrely but sufficiently to show that it, like the formations above and below, rounds the nose of a northward-plunging anticline, giving a total strike-wise length of six miles. At the boundary line the Naylor Ledge rounds the nose of a northward-plunging syncline and swings back to the north -- it is continuously traceable from a point on the west side of the synclinal axis to a point on the east side of the axis along a distance of three miles, the distance from point to point at right angles to the synclinal axis is slightly under one mile. Thus, according to Ulrich's theory the cavern, of which the Naylor Ledge formation is the filling, had a linear extent of at least six miles, and a maximum observable width of somewhat more than one mile. But, a cavern with such dimensions would need massive supports, and

it is strange that no interruption of the formation, corresponding to such supports, have been found, and the problem of filling a cavern a mile deep with sediment and fossils raises other difficulties not easily overcome.

In view of the physical evidence above described, the faunal evidence as interpreted by Ulrich fails to be convincing. The Hastings Creek, Naylor Ledge, and Luke Hill formations are regarded as successive strata in the local development. Unless this be disproved, the faunal evidence must be made subservient to the stratigraphic evidence. As noted in the Introduction a later and fuller treatment of the paleontology of this, and other beds, is forthcoming.

Luke Hill Limestone (Logan's B 3). The Luke Hill formation corresponds to Logan's subdivision B 3 of the Philipsburg series. The name is derived from the ridge extending northward from the boundary line on the west side of the ~~St. Armand~~ Edmunds Corners - Highgate Springs road.

Distribution and Structure. This formation has practically the same distribution as the Naylor Ledge, and, like the latter, it is best exposed on the farm of Mr. Naylor, north of the Philipsburg - St. Armand road (Plate). The formation also outcrops south of the valley paralleling the road, and can be traced in continuous outcrop for one mile southward to the boundary line. On the line the upper beds

are arranged in the form of a trough, the synclinal axis being about 500 feet west of the St. Armand road. Strata in the eastern limb of the syncline may be followed northward for three-quarters of a mile along a N.30°E. strike. At the eastern edge of the outcrop the beds dip steeply to the west, occasionally becoming vertical or even slightly overturned, and are often locally faulted. A short distance westward, however, the dips flatten ~~out~~, so that it is possible to determine the position of the synclinal axis only approximately.

Thickness. The thickness of the Luke Hill can not be definitely determined, since the upper beds are not exposed and no contacts with the overlying formations have been definitely recognized. ~~XHXXXXXXXXXXXXXXXXXXXX~~ in places where the succession is clear. In the best section, that between Philipsburg and St. Armand, 110 to 120 feet of strata are seen in continuous sequence, but the top of this sequence is separated from the beds assigned to the next higher formation, by a fault. At a distance of 75 feet, is a small outcrop whose rocks bear more resemblance to the Luke Hill beds than to those of the younger formation. Consequently these have been placed with the Luke Hill. The minimum total thickness of that formation would, therefore, be about 160 feet. This is only ten feet more than the thickness assigned to the formation by Logan, in 1863.

Lithology. The basal deposits of this formation have already been described in considerable detail as channel fillings and patches of crystalline and fragmental limestone on the surface of the Naylor Ledge formation. Overlying the channel fillings, and in some places grading downward into them, is a thin bed of very sandy limestone that weathers to a red-brown color; this is the ocherous-weathering bed of Logan's section and is remarkably constant wherever the base of the Luke Hill is seen. The thickness of this bed does not exceed six or eight inches. It is overlain by limestones that are just as arenaceous, and that weather to a rotten-stone similar in every respect to that beneath, except that its color is a lighter shade of brown. The latter limestones are common in the lower fifty feet of the formation, and are interstratified with occasional beds of limestone that contain very little quartz sand. The arenaceous layers vary from one inch to fourteen inches in thickness, and occasionally display cross-bedding. A mile and a half south of Morgan Corners twelve feet of slightly calcareous sandstone, almost quartzite, occurs.

Higher in the formation arenaceous limestone beds, as such, are rare, although much of the limestone contains scattered and angular grains of sand. These beds are well described by Logan (1866, pp. 278-279): "Dark bluish-grey, reddish-grey, and black, thin bedded nodular limestones, interstratified with thin layers of bluish-grey slate,

probably magnesian. Although thin bedded, the layers are aggregated in considerable masses, which have little tendency to separates in the planes of deposit. In the escarpments of these strata, the more calcareous parts of the rock being dissolved away by atmospheric waters, the slaty portions stand out in bands, which weather yellowish" (Plates).

Throughout the formation are beds which weather to yellows and browns, but the most pronounced coloring is that displayed by the lowest bed. This coloring is due to the presence of limonite. The apparent concentration of the iron in the lowest bed probably resulted from the damming up of the iron-bearing solutions at the top of the dense and relatively impervious Naylor Ledge formation -- that is, at the unconformity between the Naylor Ledge and the Luke Hill.

Stratigraphic Relations. The Luke Hill formation is definitely delimited at the base by an unconformity, but its summit is indefinite and no contacts with the overlying formation can be seen. It is true that the lower beds of the overlying formation are dipping to the east at angles from 5° to 7° steeper than the highest exposed beds of the Luke Hill, but in a region that has been considerably affected by movement it would be rash to suggest, without other evidence that this difference in dip represents a stratigraphic disconformity. The lithology of the two formations indicates that essentially the same conditions of deposition prevailed

throughout the upper 100 feet of the Luke Hill and the overlying Solomons Comers formation. Thus, there is, physically, no direct compelling evidence of any break between the two formations. According to Ulrich, however, the Luke Hill formation is Upper Ozarkian, while the overlying formation (Solomons Comers formation) is Upper Canadian. There ought to be a break between the two if these age assignments are correct. Whether or not a faunal break occurs will be discussed later.

Fauna. The work of Logan (1866) and Billings (1865) does not aid us in preparing a list of fossils from this formation. Logan stated that "The genera and the described species are nearly all identical with those of the previous division" (that is, with his undifferentiated subdivision B 2), and that "Lituites" was common toward the top. But very few of the gastropods and cephalopods mentioned by Logan as occurring in B 2 have been seen by us in B 3 (the Luke Hill). There is, however, no question that many of them go through, for they occur in the higher formations. In 1865 Billings described fossils which very probably came from this formation, although they were not directly stated to have done so, and were simply recorded from the "Philipsburg Series". Of those which Billings described, the writers have found the following in the Luke Hill formation (Billings genera in brackets):

Syntrophia / Camarella / celeifera (Billings)
Pliomerops? / Amphion / salteri (Billings)
Leoistegium / Bathyurus / saffordi (Billings)
Hystricurus / Bathyurus / cordai (Billings)

We have found, in addition, a few straight cephalopods, and one coiled form, either Aphetoceras or Tarphyceras. The gastropods are representee by species of Ophileta, Ecoyliomphalus Hormotoma, the first being especially abundant. The most abundant trilobites ate species of Leiostegium. The families Syntrophudae and Orthidae embrace practically all the brachiopods collected. Cystid plates are common in the basal bed.

Age and Correlation. Previous to the pronouncements of Ulrich, the Luke Hill formation has been considered as of Beekmantown age from the time of Logan (1863) to that of Bradley (1925), the latter considering it to be Middle Beekmantown in age, and like Brainerd and Seeley (1890), correlatable with the East Shoreham Beekmantown. Ulrich, however, places this formation in the Upper Ozarkian and, as stated in the discussion of the age and correlation of the Georgia, correlates it with the Georgia.

Solomons Corners Limestone (Logan's B 4). Logan's subdivision B 4 is the Solomons Corners formation of this report. The name is derived from the junction of the Philipsburg St. Armand road with a north-south road which begins about three-quarters of a mile west of St. Armand. At this junction and to the northward the formation is typically exposed.

Distribution. The formation is well exposed northward from Solomons Corners for one mile; in this distance the outcrops are continuous, and have a maximum width across the strike of about 1,400 feet. The few exposures farther north are separated by wide areas of drift, but they show that this formation, like the older ones, was folded over the Morgan Corners anticline. A mile east of Morgan Corners the strike varies between N.75°E. and 90°E., and the dips are southward at an angle of 45°. East of the large outcrop displaying this structure is a smaller one which shows that the formation is swinging back to the northerly direction. The strike is N.55°E. and the dip is southeast at an angle of 20 . About a mile to the northwest is the most northern outcrop that can be referred definitely to the Solomons Corners formation. South of the valley paralleling the Philipsburg-St. Armand road a small thickness of this formation appears on either side of the axis of the St. Armand syncline. Probably no greater thickness than 50 feet is exposed, for the dips are shallow at this place.

Thickness. Logan estimated the thickness of this formation at 300 feet, an estimate which needs no amending. As stated above, the greatest width across the strike of the beds, as exposed north of Solomons Corners, is 1,400 feet, and, with the average dip of 11°, the thickness would be 275 feet. The base of the formation is not exposed, but no more than 25 feet should be added on that account.

Lithology. A good general summary of the rocks of this formation is given by Logan: "Black slaty thin bedded nodular limestone, with a cleavage independent of the bedding. The rock generally weathers to a grey, occasionally tinged with yellow; it has a somewhat scaly fracture and breaks with the cleavage, rather than with the bedding". It may be added that the escarpments of these rocks have a banded appearance, due to the interbedding and difference in weathering of the limestone and shaly layers (Plate). The shaly beds weather both black and brown, and the purer limestone beds weather light gray. In thin section the cleavage is shown well.

The formation begins with a dark, very fine-grained limestone, with a few thin shaly reticulates, all highly sheared. Above this the same type of limestone is interstratified with black- and brownish-weathering shaly layers. Toward the top of the formation, in the upper 100 feet, dark colored, fine crystalline, brown weathering dolomites are occasionally interbedded with the limestone and shaly strata, and here also a few arenaceous limestone beds occur.

Structure. Apart from the normal structure of the rocks of this formation as a whole, there are certain complications that are not readily explained. These are breccias that are made up of angular fragments of limestone, derived from the associated beds of the formation. The

fragments vary in size from two inches or less to blocks several feet in diameter, and are jumbled together without tendency toward definite order or arrangement (Plates).

In Plate , thin dark lines in the white limestone are extremely contorted, while the limestone itself is drawn out so that it varies considerably in thickness, and fragments have been broken from it and mixed with the shaly material. From Plate , itself, the impression may be gained that some of the structures were the result of movement in unconsolidated sediments, but these structures are directly associated with the breccias mentioned above, and which are clearly broken beds, broken after they had become lithified.

The areas of brecciation seen by the writers are five in number, and average about 100 feet square. Two of them are located in the upper part of the formation, are approximately at the same horizon, and are separated from each other by drift. It is possible that these are connected under the drift, or were originally connected. If so, this zone of brecciation would be about 500 feet long and 100 feet wide, the longer dimension corresponding to the strike of the formation. Two other breccia exposures occur just below the middle of the formation, but these are about a half-mile apart, and it is not possible to say more than that they are at approximately the same horizon. The fifth brecciated area is about 50 feet below the general horizon of the latter two.

Although only one contact (Plate) was seen between the breccias and the normal beds, the field relationships leave little doubt that the former are relatively shallow, probably no more than 25 feet thick, and that they are enclosed within the latter -- that is, the breccias are overlain and underlain by regularly stratified beds, and give place to these beds along the strike. At the contact, blocks of the breccia are lying upon the normal beds and against their truncated edges.. This suggested at first that the breccia marked the location of a solution cavern into which the blocks had fallen from the overlying beds, the roof. If this were the case the structures in question could be termed founder breccias, but there is little real evidence to support this view. They are more likely to be analogous to similar types of breccia seen in the Hastings Creek formation, which are unquestionably the result of thrusting.

Stratigraphic Relations. It has already been stated that the evidence at hand does not favor the presence of any break between the Luke Hill and the Solomons Corners formations. Rather does there seem to be gradation from one to the other, so that the boundary between the two is arbitrarily drawn. The exact upper boundary of the Solomons Corners formation is also arbitrary. It has been placed at an unconformity (Plate), above which the beds are on the whole more massive and more calcareous than they are below. The unconformity chosen is

one of four that occur within a thickness of 50 feet. It was taken because it was the most obvious, though not the lowest. Fossils were collected immediately above all of the four conformities, but did not show any recognizable difference in age.

Fauna. In 1863, Logan stated that this formation "holds fossils, of which the genera appear to be chiefly Pleurotomaria, Orthoceras, and Lituites; the only described species being Lituites imperator" (p. 279). These are the only fossils that have previously been directly referred to subdivision B 4 of Logan. In 1865, Billings described several fossils from the upper part of the Philipsburg series in the Philipsburg - St. Armand section, but the subdivision in which they were found was not stated. The same may be said of Bradley, 1925. In the Appendix to Ells' report, 1896, lists of fossils collected from the Philipsburg series are given by Ami. Although it is not definitely stated, it is most probable that the lists given by Ami, which are quoted in an abbreviated and modernized form below, were made up of fossils collected from the Solomons Corners formation or from the St. Armand formation (B 5).

Ells (1896, pp. 123-125) -- road between Philipsburg and St. Armand:-

*Orthis armanda Billings
*Dalmanella electra (Billings)
Orthis minna Billings
Syntrophia lateralis (Whitfield)
*S. calcifera (Billings)
*Pleurotomaria missisquoi Billings
Seelya difficilis (Whitfield)
*Euconia beekmanensis (Whitfield)
Ectomaria missisquoi (Billings)
Oxydiscus palinurus (Billings)
Eotomaria cassina (Whitfield)
Plethospira cassina (Whitfield)
P. arenaria (Billings)
Euomphalus circumliratus Whitfield
Ophileta complanata Vanuxem
Eccyliopterus volutatus (Whitfield)
Maclurea ponderosa Billings
Fusispira obesa (Whitfield)
*Eccyliomphalus lituitiformis (Whitfield)
Orthoceras explorator Billings
*O. catalina Billings
Cyrtoceras missisquoi (Billings)
Cameroceras brainerdi (Whitfield)
*Protocycloceras lamarcki (Billings)
P. whitfieldi Ruedemann
Schroederoceras eatoni Whitfield
S. eatoni var. cassinensis Whitfield
Eurystomites kelloggi Whitfield
Agnostus galba Billings
Remopleurides affinis Billings
*Lloydia saffordi (Billings)
Hystricurus conicus (Billings)
H. cordai (Billings)
*Bathyurellus expansus Billings
B. glandicephalus Whitfield
*Asaphus canalis Conrad
Illaenus simulator Billings
Amphilichas minganensis (Billings)

Ells (1896, pp. 131-132).-?One and a quarter miles est of Philipsburg, N. of the St. Armand road. In addition to the species marked by an asterisk on the previous list there occur the following:-

Orthis corinna Billings
Triplesia radiata Whitfield
Pleurotomaria vagrans Whitfield
Archinacella pileolum (Whitfield)
Triblydium acutum (Whitfield)
Eccyliomphalus intortus (Billings)
Ophileta bella Billings
Protocycloceras furtivum (Billings)
Ooceras raei (Whitfield)
O. kirbyi (Whitfield)
Aphetoceras famsworthi (Billings)
Tarphyceras famsworthi (Billings)
Bolbocephalus seelyi Whitfield

The problem of the faunal separation of the Solomons Corners and St. Armand formations will be considered more extensively in the paleontological report to follow.

Age and Correlation. The faunas of the Solomons Corners (B 4), St. Armand (B 5), and Corey (C 1) formations of the Philipsburg series show them to be of essentially the same age, therefore, the discussion of their age and correlation is postponed until the fauna of the Corey formation has been listed. Suffice it to say here that the Solomons Corners, as well as the other two formations mentioned, are considered to be of true Beekmantown (Canadian, as distinguished from Ozarkian) age, probably Upper Beekmantown, and that their

closest correlatives are the Fort Cassin formations of Vermont State.

St. Armand Limestone (Logan's B 5). The St. Armand formation of this paper is identical with subdivision B 5 of Logan, and takes its name from the village of St. Armand Station.

Distribution and Structure. This formation has a very limited distribution, occupying an area of about half a square mile in the vicinity of St. Armand Station. The eastern boundary of its outcrop is a cliff or very steep slope overlooking the valley of Rock River; for three-quarters of a mile this boundary nearly coincides with the road to Morgan Corners. Where the road makes a turn to the northwest the thin bedded limestone and shaly strata of the upper part of the formation are exposed, dipping westward at angles of less than five degrees. East of the road at this place massive beds belonging to a lower horizon within the formation appear, having folded under the axis of the St.Armand syncline. A short distance west of the road the thin bedded limestones dip northward at about two degrees, and farther westward they dip to the east at angles varying between one and seven degrees. Between St. Armand Village and the turn of the road these beds dip steeply to the west, but, a short distance farther west, they fold under the axis of the St. Armand syncline and

assume a low-angled easterly dip.

Elsewhere this formation is to be seen along the northern half of the road from St. Armand to Rosenberg, where it is in contact with the Milton dolomite of the Pigeon Hill block. Immediately north of the Maple Grove Farm it is converted into a breccia as shown in figure . Further north it shows as fensters in several places within the Milton dolomite, or east of the dolomite breccia which must overlie it. At Morgan Corners a large mass a mile long and a quarter of a mile wide has been faulted into position along the frontal thrust. The dips and strikes here show a very complicated structure. And southwest of Bedford is a mile long outcrop of this formation which lies on the western arm of the Morgan Corners anticline. Scattered outcrops can also be seen around the nose of and on the eastern side of the same anticline.

Thickness. Measurement of a section acrosss the strike of the St. Armand formation along a line about three-eighths of a mile north of the Philipsburg-St. Armand road, gives a thickness of 200 feet, or 150 feet less than that assigned to this formation by Logan (1863, p. 279).

Lithology. As described by Logan (1866, p. 279) the rocks of this formation consist of "Black limestones, some of them massive, weathering light bluish-grey, inter-

stratified towards the bottom with occasional black and dark grey magnesian bands, some of them weathering yellowish and others white; they are much intersected by joints running in various directions. Towards the top, they are interstratified with thin bedded dark grey limestones. About 150 [actually 40] feet from the summit, beds of this kind rest upon a massive layer of black limestone, filling up hollows in its surface".

A detailed section of the rocks of this formation north of St. Armand is given below, in descending order:

Drift, no higher beds exposed in this section

36. Grayish, fine-grained, light- and brownish-weathering limestone, interstratified with shaly stuff; all in thin beds.....40'+

35. Dark gray, fine-grained limestone with some shaly and dolomitic material..... 9'

34. Concealed..... 2'

33. Gray, arenaceous, ocherous-weathering limestone in beds about 1" thick..... 1'5"

32. Dark, fine-grained, light-weathering limestone; stratification shown by thin lines of brownish-weathering shaly material..... 1'

31. Well stratified bed of shaly material and grayish limestone; rest unconformably upon Nos. 29 and 30..... 5'

Unconformity.

30. Well stratified bed, made up of about equal proportions of pure limestone weathering dove and dolomitic limestone weathering brownish..... 8"

29. Dark gray, fine-grained, dove-weathering limestone in massive beds. Small blebs and patches of buff-weathering dolomite on the surface of the limestone in many places; other common surface markings are irregular grayish-weathering bands resembling mud-flows50'

28. Concealed..... 3'

27. Same as No. 30..... 5'5"

26. Dark, fine-grained, light gray weathering limestone... 2'

25. Buff-weathering dolomite, with numerous thin quartz veins..... 1'5"

24. Same as No. 26..... 6'5"

23. Dark, fine-grained, light-weathering limestone, with numerous thin, reticulating shaly lines, which give the bed a nodular appearance..... 6'±"

22. Buff weathering dolomite..... 2'

21. Dark-gray, arenaceous, brownish-weathering dolomite... 2'

20. Fine-grained, dark, light gray weathering limestone... 6"

19. Buff weathering dolomite..... 2'

Unconformity?

18. Limestone as in No. 23..... 6'5"

17. Fine-grained, dark, light-weathering limestone..... 1'

16. Dolomite patches in narrow drift area..... 2'5"

15. Fine-grained, dark, light-weathering limestone..... 4'5"

14. Concealed..... 1'

13. Fine-grained, dark, light-weathering limestone..... 4'5"

12. Dolomite, same as No. 13, but weathers brown..... 1'3"

11. Fine-grained, grayish limestone, separated into thin layers by shaly material; in places cross-bedded, and in places unconformable upon No. 10 (Plate).... 2'±"

Unconformity

10. Brownish-weathering, arenaceous, dolomitic limestone.. 1'5"+

9. Fine-grained, dark, light gray weathering limestone... 1'±"

Unconformity

8. Mainly concealed, but occasional patches of limestone like No. 9 shows through the drift.....14'

7. Fine-grained, dark, light gray weathering limestone, with some shaly and dolomitic material..... 8'

6. Concealed..... 3'

5. Limestone as in No. 7..... 3'3"

4. Concealed..... 8'

3. Very fine-grained, dark, light gray weathering limestone..... 2'5"

2. Finely crystalline, dark, brownish-weathering dolomite. 1'

1. Thin, interbedded, dark and gray layers of shaly and sandy limestone..... 3'

Unconformity. 208'8"

Solomons Corners formation.

The black massive, limestones mentioned by Logan have their greatest development about the middle of the formation; below they are interstratified with many dolomitic and occasional shaly and arenaceous beds; and they are overlain unconformably by very impure thin-bedded limestones.

The long outcrop southwest of Bedford shows remarkably well the various stages in the formation of a pseudo-conglomerate. Much of the limestone is massive, other parts show the beginning of segregation of shaly material along stratification planes and also along cleavage planes at a shallow angle to the bedding. In some cases the shaly material which tends to segregate along stratification planes undulates widely from them, producing wavy lines, whose curves may and frequently do touch curves of

adjoining wavy lines. Both the latter, and the intervention of cleavage segregations tend to separate elliptical or lozenge-shaped masses of limestone surrounded by black residual shaly material. From examples in which the above phenomena are easily apparent, to others, in the same bed, where the original massive limestone has been so "broken up" as to resemble a true conglomerate, there are all gradations. The end product, if seen by itself would certainly be called a type of conglomerate, or breccia, and yet the "phenoclasts" have not moved from their original position. The only movement has been a rearrangement of the shaly material and a replacement by it of the limestone along stratification or joint seams. In a region where true conglomerates and breccias abound such simulations are all the more remarkable.

What rearranged the shaly material? Secondary?

Stratigraphic Relations. The St. Armand formation is separated from the underlying Solomons Corners formation by an unconformity, which is, however, not considered to be of any great stratigraphic importance. The upper boundary is not known, for the highest beds are not exposed in any exposure. No such conditions exists as that reported by Bradley (1923, p. 11), who stated that the higher beds of Division B "can be traced from the vicinity of St. Armand village continuously to the region where they are succeeded by the beds of C". The Corey formation (Logan's C 1) is everywhere separated from the underlying beds (St. Armand B 5) by a considerable

area of drift. The fossils, however, show that there is no great time interval between the two.

Fauna. Logan (1866, p. 279) stated that the fossils found in this formation are "chiefly of the genera Eospongia, Pleurotomaria, Murchisonia, Holopea, Orthoceras, Nautilus, and Bathyurus; the only described species being Bathyurus saffordi".

Billings, in "Paleozoic Fossils", described several species from the upper part of the Philipsburg and St. Armand section, but only two of these were ascribed to subdivision B 5, Orthoceras porcous and O. xerxes.

There has already been given, in the faunal list of the Solomons Corners formation, those fossils which were listed by Ami in the Appendix to Ells' report (1896) and which probably were collected from the Solomons Corners or the St. Armand formation or from both formations.

Bradley (1923, p. 20) stated that both B 5 and C 1 contained, among others, the following genera of gastropods and cephalopods: "Murchisonia, Holopea, Maclurea, Euomphalus, Raphistoma, Lophospira, and Orthoceras". Two fossils identified specifically by Bradley in 1925 and reported from subdivision B 5 (St. Armand formation) were Cybele? pervetusta Bradley, and Retigurus subrectus Bradley. Fossils reported from the

upper B series by Bradley which may possibly have been collected from the St. Armand formation were Leiostegium quadratum (Billings), Lloydia saffordi (Billings), and Maclurites ponderosus.

Age and Correlation. The age and correlation of the Solomons Corners, St. Armand, and Corey formations will be discussed after the Corey faunas have been listed. It may be repeated, however, that these three formations are considered to be of Upper Beekmantown age, and that there closesr correlatives are the Fort Cassin formations of Vermont state (Division D and E of the Champlain Valley Beekmantown).

Corey Limestone (Logan's C 1). Logan (1866, p. 848) stated that subdivision C 1 was well displayed "on the land of Mr. Corey, on the sixth and seventh lots of the seventh and eighth ranges of Stanbridge". Although this property is now in other hands, the fact that it was mentioned by Logan in connection with subdivision C 1 and was designated on his map of the Philipsburg Series, justifies the use of the former owner's name in the nomenclature of formations. Its rocks are being extensively quarried by the Shawinigan Chemicals Company, so that a stranger to this area would have no difficulty in ~~locating~~ finding the formation.

Distribution and Structure. The northern end of the Corey formation is a quarter mile south of the Canadian

Pacific Railway branch line that connects Stanbridge Station with the towns of Bedford and Farnham, and about one and a half miles W.40°S. of Bedford and the same distance E.25°S. of Stanbridge Station. This is also the location of recently begun, but already extensive, quarrying operations under the control of the Shawinigan Chemicals Company. From this locality the formation runs almost due south for three-eighths of a mile, dipping, in this distance, about 30°E; it then turns S.25°E. and follows this direction for another three-eighths mile before disappearing beneath the drift. In this latter part, most of the dips where observable appear to be north or northeast at low angles, but there are disconcerting exceptions, and the evidence of a definite though unimportant synclinal structure, which Logan observed within the rocks of this formation, cannot now be seen though such a structure is not out of harmony with the trend and apparent dips of the strata.

Thickness. No accurate measurement of the thickness of the Corey can be made, for neither the base nor the summit are seen. That part which is exposed is very massive and, inasmuch as stratification planes are rarely seen, the individual beds can not be measured. The width of the largest outcrop is about 650 feet, and, with the dips at 25°, a minimum estimate of the thickness of the Corey would be 275 feet. Logan (1866, p. 845) reported the thickness to

be 150 feet, but this does not check with his measurements of the dip and maximum exposed width of the formation. On page 849 he stated that "The largest exposure is on the seventh lot of the eighth range [Stanbridge], showing a broadth of about 350 yards, dipping S.78°E. < 16°-20°W. These measurements indicate a thickness of between 300 and 375 feet.

Lithology. The rocks of the Corey formation are, in the main, extremely pure limestones. Analyses made by the Shawinigan Chemicals Company showed the average sample to be about 98% calcium carbonate. The color on fresh surfaces varies between gray and black, the weathered rock is light gray or dove. The limestone is fine-grained, dense, and compact. Occasional semi-crystalline patches occur, and crystals of calcite occur throughout the rock. Sand grains are common at three horizons in the formation. One of these horizons is about 20 feet above the exposed base, and is 2 feet thick; another occurs about the middle of the formation, , and the third is approximately 50 feet from the top. In the last two horizons sand grains are found throughout a thickness of at least 10 feet. The grains stand out prominently on the weathered surfaces, are often well rounded, many are frosted and pitted, and diameters up to 2 mm. are common. The average size of the sands grains is about 1 mm. Although the majority of the grains are rounded, they are not smooth

but distinctly rugose, and the edges of the minute pits which often cover their surfaces are also rough. Although these grains are without question wind blown their pitted surface may be due to subsequent solution ~~corroding them~~ by corrosion. The surrounding fringe of calcite crystals noted by Black (see Appendix) may also be the result of selective solution and deposition.

At the north end of the Corey exposures, immediately west of the quarry, a small amount of black shale has recently been uncovered by blasting. The shale is black, fine-grained, carbonaceous in appearance, and greatly sheared, veined, and slickensided throughout. As exposed, the greatest, or strike-wise, dimension of the shale is about 40 feet, and it is no more than 10 feet thick. The difference in lithology between the shale and the Corey limestone is striking, but it is impossible to determine whether the contacts observed were sedimentary or fault contacts. It is quite possible that they are sedimentary, and that the shale is a lens either within, or at the base of, the Corey limestone. The two nearest outcrops of the slates of the Western District, are three-eighths of a mile northwest and one-half mile west of the Corey exposures, and these are not lithologically comparable to the "lens" of shale mentioned above. However this is a possibility which further excavation at the quarry may substantiate. The only other rock similar to this shale

is that of the slate quarry at Mystic which belongs to the Western District.

Stratigraphic Relations. Bradley (1923, p. 12) stated that the "faunal similarity between B 5 and C 1 is important because it corroborates the structural evidence that C directly overlies B. There is no evidence of uplift and erosion". However, whether the succession is conformable or unconformable can not be decided, for no contacts between the two have been observed. There is very little difference in the faunas, and they could probably both be assigned to the same general horizon in the Beekmantown, so that, if an unconformity does exist between them, it would represent only a relatively slight time interval. The relationships with the overlying beds are even more obscure, and will be discussed later.

Fauna. The fossils from this formation mentioned by Logan (1866, p. 845) are as follows:-- "several undescribed species of Murchisonia and Pleurotomaria, Ecculiomphalus canadensis, E. intortus, E. spiralis, several undescribed species of Ophileta, Maclurea ponderosa, several undescribed species of Orthoceras, and one Nautilus. Toward the base, Maclurea ponderosa seems to be somewhat smaller than in the upper part of the deposit". Logan also stated that these "testaceae.....appear to have the peculiarities of being

large-sized and thick-shelled, and of occurring in numerous isolated patches, which vary in diameter from about three to ten feet".

Among the fossils described by Billings (1865) three are referred to this formation, namely, --

Ophileta uniangulata (Hall)
[Now called Ophileta ponderosus Billings]
Maclurites ponderosus (Billings)
Orthoceras atticus Billings

As stated above, Bradley reported that the following forms are common to the St. Armand and the Corey formations (b 5 and c 1) -- "Murchisonia, Holopea, Cyrtoceras, Ecculiomphalus, Maclurea, Euomphalus, Raphistoma, Lophospira, and Orthoceras". The only fossil specifically mentioned was Maclurites ponderosus.

Age and Correlation of the Solomons Corners, St. Armand, and Corey Formations. These three formations of the Philipsburg series generally have been considered as of Beekmantown age, and, in this report are lumped together in the Upper Beekmantown (Upper Canadian) division of the time scale. This age determination is based largely on the presence of the gastropod genera Euconia, Euconospira, and Maclurites, and the occurrence of curved and coiled cephalopods, all in considerable abundance, in the three formations.

The results of previous attempts at age determination

and correlation of these formations are summarized briefly below:--

1. Considered by Logan and Billings, in 1863 and 1865 respectively, to be about the horizon of the "Calciferous" (Beekmantown).

2. Brainerd and Seely (1890) correlated the upper part of Division D at East Shoreham with the Luke Hill and Solomons Corners formations at Philipsburg, therefore considering them to be Beekmantown in age. Division E of East Shoreham was correlated with the lower part of the St. Armand formation, also of Beekmantown age. The higher beds of the St. Armand, however, and the Corey, were thought to be Chazy in age and correlatable with the Chazy of western Vermont. The following quotation (1890, p. 508) is from their report: "the first four members of Logan's division B correspond to our Division D, both in lithological character and in fossils..... The magnesian beds of our division E are, however, but poorly represented in the lower part of Logan's division B 5 [St. Armand], but in a similar way they thin out and disappear in the eastern part of Addison County, Vermont. The higher beds of B 5 at Phillipsburg, and the beds of C 1 seem to be represented in western Vermont, but by the lower beds of the Chazy".

3. Ells (1896) considered the Solomons Corners formation to be Beekmantown in age, while he classified St. Armand and

the Corey as Chazy.

4. Raymond (1916, p. 526) stated that "the so-called Chazy in the section between Philipsburg and St. Armand contains no Chazy fossils, and belongs to the Beekmantown". That is, the Solomons Corners and the St. Armand formations are definitely stated to be Beekmantown in age, and, although the Corey is not mentioned directly, it must have been placed in the Beekmantown also, for the shales and conglomerates above it are said to be Beekmantown.

5. Bradley (1923) placed the entire Philipsburg series in the Beekmantown, dividing it into Lower, Middle and Upper. The Middle Beekmantown included all of Logan's Division B and C 1 -- B 4, B 5, and C 1 corresponding to our Solomons Corners, St. Armand, and Corey formations respectively. "The advent of the Middle Beekmantown....is sharply marked by the appearance of Ophileta complanata, and the close is equally sharply marked by the occurrence of a typical gastropod and cephalopod.fauna" (1923, p. 20).

No conclusion of your own

Basswood Creek Shale (Logan's C 2). Logan (1866, p. 845) reported that black slates "or possibly thin bedded black limestones, with a few thicker beds towards the top" overlay the massive Corey limestone. To this thin bedded formation he assigned a thickness of 170 feet, but stated that the mass was "very imperfectly seen". No locality where

this formation could be seen ~~at all~~ was mentioned, and, up to the time of Bradley's work on the Philipsburg series, the subdivision had evidently not been recognized by later workers. Bradley (1923, p. 12) stated that "The existence of Logan's C 2 between these conspicuous beds of C 1 [the Corey] and the conglomerate of D has been doubted by some because of the nearness of outcrops of C 1 to D 1 on the sixth and seventh lots of the seventh and eighth ranges of Stanbridge. Although D 1 is very poorly exposed, the present writers found indications of black slates in several places underlying the first conglomerate band of D. On lot seven, range seven, a small outcrop of slate was found within a stone's throw of C 1 on the south and D 1 to the north. It is probable, however, that Logan's thickness of 170 feet is too great. C 2 is probably nearer to 50 feet in thickness. The dips of C 1 in this region show the same synclinal arrangement noticed at St. Armand station. The slope of the trough become more gentle to the northeast".

It may be remarked, in passing, that the structure to be inferred from Bradley's last two statements is wrong, for the St. Armand syncline and the syncline affecting the Corey (C 1) and the St. Armand (B 5) formations southwest of Bedford are quite distinct, and are separated by the Morgan Corners anticline.

There is no doubt that both "black slates" and "thin bedded black limestones" underlie the lowest conglomerate of Division D, but similar strata also appear above this conglomerate, and, owing to the confusion of structure in the region southwest of Bedford, it is often difficult to determine whether one is dealing with the older or the younger slates and thin limestone beds. However, at the south end of a long and relatively narrow outcrop, which crosses the dividing line of the Lacolle and Sutton quadrangles about one mile southwest of Bedford, the lowest conglomerate of Division D is underlain by thin-bedded limestones. These limestones are black, fine-grained, and dove weathering, and are divided into beds about one inch thick by thin seams of shale. They are underlain by black, brittle, thin-cleaving slate. The total thickness of the slate and limestones is about 40 feet. No contact between any of the members in this section was observed.

Another outcrop that displays shaly strata beneath the conglomerate lies three and a half miles almost due north of the exposure mentioned above, and three-quarters of a mile slightly south of west of Mystic. This outcrop is west of the general strike of the main, or lowest, conglomerate band, but this position is due to faulting, or possibly to folding, as will be discussed later. At this place the conglomerate is in contact with the underlying shaly strata, and the

relationships are distinctly unconformable. The shale or slate is not the same as that which underlies the conglomerate southwest of Bedford, for the latter is black, brittle, and thin-cleaving, while the former is dark gray in color, has faint color bands on the weathered surfaces, is to some extent calcareous, and does not cleave readily, although it is considerably sheared. In the outcrop west of Mystic this slightly calcareous shale is associated with a very small amount of the black thin-cleaving slate. No contacts were observed, but the calcareous shale appeared to underlie the slate.

The succession of strata as worked out from numerous separated outcrops, between the lowest subdivision of Logan's Division D and the Corey limestone is, then, as follows, in descending order:

Logan's Division D

Unconformity

3. Black, fine-grained, light gray- or dove-weathering limestones, in beds up to one inch in thickness; the beds of limestone being separated by thin seams of shale.

2. Black, hard, brittle, thin-cleaving, argillaceous slate.

1. Dark gray, calcareous shale; color bands from one-quarter inch to one inch wide on the weathered surfaces; considerably sheared.

Corey limestone

The above succession is Logan's C 2 as here revised.

There is, then, an unconformity of considerable physical proportions between C 2 and the lowest conglomerates of Logan's Division D. In the outcrop west of Mystic, conglomerate rests unconformably on the oldest member of C 2; in other words, the black slate and the thin-bedded limestone members were, in this place, cut out by erosion before the conglomerate was deposited. Thus this unconformity must represent a relatively important period of erosion, one that was long enough sustained to remove at least 40 feet of strata from certain areas, 40 feet being the approximate thickness of the two higher members of subdivision C 2. Because the conglomerates are either Upper Chazyan or possibly Lower Trenton in age, it was to be suspected that an unconformity existed between them and the Corey limestone (C 1), for the latter is of Upper Beekmantown age.

To sum up, the Basswood Creek formation consists of three lithologically distinct members -- a lower calcareous shale member, a middle argillaceous slate member, and an upper thin-bedded limestone member. The total thickness of these three members is probably not more than 100 feet. No contact with the underlying Corey formation (C 1) has been observed, but C 2 is known to be unconformably overlain by conglomerates. No fossils have been found in this subdivision and it is, therefore, impossible to state definitely whether it is Beekmantown or Chazy in age. However, since it lies

below an unconformity of considerable physical proportions, and since the beds above the unconformity are Chazy or younger, it is probable that it is Rockmantown. If so, it might possibly be considered as an upper, shaly member of the Corey formation, deposited in a sea relatively less deep than that in which the massive Corey limestones were formed. There is more justification, however, in considering it to be a separate formation. The name is chosen because its lowest member is exposed on the western side of Basswood Creek, west of Mystic.

Division D of the Philipsburg Series. Logan, in 1865, included a series of strata 2,800 feet thick in his succession. This series was supposed to be composed of three subdivisions the lowest containing two main bands of conglomerate, separated by slate, and the upper two being composed mainly of slates, with occasional bands or lenses of limestone conglomerate. Division D has long been of interest to paleontologists because of the excellent collecting afforded by many of the boulders in the conglomerates, but most of the interest has been restricted to the conglomerates and their fossils, and little attempt has been made to determine whether or not Logan's conclusions in respect to the structure and succession of D were correct. There is little doubt that Logan's section is essentially a

natural one -- that is, that heavy conglomerates are overlain by black argillaceous slates, and these in turn by slates and limestones that are more or less magnesian. The existence of as many bands of conglomerate as are indicated by Logan must be questioned.

In this report the conglomerates of Logan's subdivision D 1 will be referred to as the Mystic limestone conglomerate formation* and the slates of subdivision D 2 and D 3 as the Stanbridge slate formation, for the conglomerate exposures are best seen at the village of Mystic and the slates are widely distributed over Stanbridge township.

Mystic Conglomerate (Base of Logan's D 1). Logan (1866, p. 845) defined the lowest subdivision of D as follows: "Black limestone conglomerates, composed chiefly of the ruins of the thick bedded limestones of division C.....There appear to be at least two principal bands of this conglomerate, each varying in thickness in different parts from about 50 to 100

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* Although Logan (1866, p. 860) used the term "Stanbridge conglomerates" he had no thought of designating a formation by name. Instead he was merely using a convenient geographical name, of no more nomenclatorial significance than "northern" or "southern". And again, in 1896 Ells used the term "Mystic slates" on the map accompanying his report. No mention of this name as of formational significance occurs in the report. Its use there can be dismissed as casual, and need not be perpetuated.

feet. There is an interval between them of from 100 to 150 feet, occupied by black slates holding rounded masses of limestone, which convert parts of the mass, varying in thickness from ten to twenty feet, into slaty conglomerates. In some parts, either the interval between the main two bands of conglomerate increases considerably, or there is a third band with similar slates intervening between it and the second. The whole is contained in a thickness of from 250 to 300 feet".

These are the conglomerates from which almost all of the fossils of Division D have been collected, and the chief problem in connection with them is, therefore, not the age but the number of the conglomerate bands. Are there at least two and possibly three conglomerate beds as Logan indicated, or, as our present field work shows, a single band, occasionally repeated by faulting?

Ells (1896, pp. 34-35) gave a brief discussion of the strata of Division D, but he made no essential changes in either the structure or the succession recognized by Logan. In 1905, and again in 1916, Raymond mentioned these strata, but in respect to their age only. In 1923 Bradley discussed certain outcrops of conglomerate in some detail, stressing particularly the lithology, certain structures within, and the origin of, the conglomerates. He apparently accepted the succession and structure of Division D as worked out by Logan.

Distribution and Structure. The discussion below deals with the distribution and structure of the conglomerate band at the base of Logan's D 1, and not with that subdivision as a whole; it is impossible to separate any slates that would without question have been referred to that subdivision by Logan from the slates of D 2.

The most easily accessible conglomerate outcrops are those about one mile west of Bedford, on the road to Henryville. Between the exposures on the Bedford road and the southwest bank of Pike River are three smaller outcrops of conglomerate. Logan (1866, p. 852) described these outcrops as if they were a single exposure, and stated that "it exhibits both of the bands of conglomerate of D 1". Neither here nor on the northwest side of the river, where, after a drift-covered interval of three-quarters of a mile, the conglomerates again appear and can be followed for a mile, and a quarter to Mystic, is there any evidence of two bands. In this distance (about two miles) between the Bedford road and Mystic the average strike of the bed is N.20°E. and the dips are easterly at angles varying between 25° and 60°. The irregularity in the dip and the frequent offsetting of individual outcrops to one side or the other from the general line of strike is most probably due to transverse dislocations of small displacement.

The outcrops of the conglomerate at the village of Mystic and westward are so arranged that the establishment of a single band rather than two or three is attended with

considerable difficuly. The apparent anomalies in this locality however, are due to faulting or folding or both. Immediately east of the Canadian Pacific Railway at Mystic there is an outcrop of conglomerate which is being undercut on its eastern side by a stream, known variably as Basswood Creek and Beaver Brook. The general course of the stream is interrupted by the conglomerate mass, so that for 150 feet its direction is N.14°W., after which it cuts through the north end of the conglomerate outcrop and flows almost due west for a quarter mile. East of the conglomerate, in the bed of the stream and on its eastern band, are slates. Although no definite contact between the conglomerate and the slates was observed, the direction of the stream, N.14°W., may correspond with such a contact. The slates are black, thin-cleaving and argillaceous, and have occasional beds (averaging two inches or less in thickness) of argillaceous, limestone and black, fine-grained, dove-weathering limestone. Near the contact with the conglomerate the slates are much more disturbed than they are farther east. The strike of the slates nearest the conglomerate varies between N.17°E. and N.38°E., and the dip varies between 15°E. and 80°E., and have resulted from dragging along a fault. West of the southern end of this conglomerate outcrop, and a few feet west of the railway, a second outcrop of conglomerate occurs. This is underlain on the north and northwest sides by slates

that are black, argillaceous, and greatly sheared. The actual contact between the two types of rock was not observed but could be located within a few inches; its direction is N.41°E.. The slate dips under the conglomerate. It is possible that this slate is a part of Logan's subdivision C 2 (the Basswood Creek formation of this paper). About 300 feet southeast of the above is the eastern end of a third outcrop of conglomerate; the strata of this outcrop strike east-west, or even south of east -- in other words about at right angles to the normal strike -- and the thickness measured across the strike approximates the average thickness of the conglomerate bed.

West of the second outcrop mentioned above, and separated from it by a drift-covered interval of about 400 feet, is a fourth, and isolated, conglomerate mass. Northwest of the north end of the outcrop, and about 100 feet distant, a small amount of argillaceous limestone, or calcareous ~~strike~~ shale is exposed in the bed of Basswood Creek, immediately below the dam at the Wallbridge Mills. The last mentioned conglomerate outcrop owes its position to faulting and the calcareous shales which underlie it are a part of the Basswood Creek formation -- probably the lowest member of that formation.

The outcrops mentioned above are all in the Sutton Quadrangle. A quarter of a mile west of them, along the

eastern margin of the Lacolle Quadrangle are four small outcrops of conglomerate that have not heretofore been mentioned in the literature. These are arranged in a north-south line, and are included within a length of a quarter of a mile. Roughly paralleling these outcrops, and about a quarter of a mile west of them, a relatively long and narrow exposure of calcareous shales occurs. These shales are unconformably overlain by conglomerate at their north end, and the relationships between the two have already been described in connection with the succession of the Basswood Creek formation.

Thus, in the neighborhood of Mystic, within a rectangular area one-half mile long across the strike and one-quarter mile broad along the strike of the strata, four bands of conglomerate appear at the surface. From the areal distribution within this small area alone it seems perfectly logical to assume that there are four distinct conglomerate bands interstratified with slates. But in adjacent areas there is but a single band or bed. The repitition, then, in this rectangular area is due either to a small series of folds, all overturned, so that their axes dip to the east at an angle of about 45°, or to a series of faults. Inasmuch as the distribution of the three beds concerned, i.e. the Basswood Creek shale, the Mystic conglomerate, and the Stanbridge slates, is not in harmony with any conceivable

arrangement of folds, faulting is the only alternative. A succession of normal faults, with downthrow on the west side would repeat the main band. The continuity of these faulted members southward appears to be limited by a dip fault which breaks the main band almost one mile south of Mystic. Northwards another fault, not so far identified, probably limits these bands.

A mile north of Mystic one of the larger outcrops of conglomerate is seen. About 150 feet from the south end the continuity of the exposure is broken, and an offsetting of about 30 feet, due to faulting occurs. A short distance south, and east of the above, are two smaller outcrops of conglomerate. Between these two and the first mentioned there should run a small transverse fault. These outcrops are east of the Mystic-Farnham road and south of the road leading from Notre Dame de Stanbridge to North Stanbridge.

One-half mile N.5°E. of the largest outcrop mentioned above, and just east of the Mystic-Farnham road, conglomerate is associated with slate and a considerable amount of quartzite, which latter appear to be interstratified or infolded with the conglomerate.

On the Mystic-Farnham road, about a third of a mile north of the last mentioned outcrop and at the junction with an eastward wagon road, near the house of Mr. Fournier, there

is an exposure of black, argillaceous, thin-cleaving slate. This is, without doubt, west of the St. Lawrence and Champlain Fault, and has nothing to do with the Philipsburg Series except in so far as it has been affected by the overthrusting of that Series. A third of a mile east of this outcrop there is exposed on the wagon road a small amount of black, thin-cleaving slate, interstratified with a few quartzite beds, from one to three inches thick. Immediately to the east and south of the slate and quartzite beds is the Mystic conglomerate The slates strike N.30°E. (the apparent strike also of the beds in the southern part of the conglomerate outcrop), and their dip is east at about 15°. If these slates belong to the Philipsburg Series they are a part of the Basswood Creek formation (C 2), for they underlie the conglomerate and are apparently in the same stratigraphic position as the Basswood Creek. But no quartzitic rocks occur in the strata known or supposed to belong to that formation. Beds of quartzite and sandstone are, however, common in the slates west of the Champlain Fault, and the small exposure in question is, therefore, more properly placed with the latter.

The conglomerate outcrops to the east and south of the slate exposed on the wagon road have a total length of about 1,300 feet. In the southern part the strike is N.30°-40°E., gradually changing to N.45°-50°E. in the northern part. About 700 feet from these outcrops, in a N.70°E. direction, is

another and small conglomerate mass. In every case the dips are southerly. Almost paralleling these on the north, and separated from them by a drift interval 200 to 400 feet wide, is a second group of conglomerate outcrops. The general strike of this group is about N.70°E.. Since the dip here, too, appeared to be southward, this latter group appears to owe its position to the same kind of faulting which dislocated the main band at Mystic.

However, Logan cohsidered that these two groups of conglomerate outcrops were on the northern and southern limb respectively of a sharp anticline, and in his description, stated that the course of the conglomerates "across this lot [21, Range VI, Stanbridge] is about N.40°E., and gaining the north side of the lot, toward the east end, the upper band is seen to make a turn in folding over an anticlinal axis, on the north side of which it returns in a course about S.70°W., for 600 yards, showing a high dip to the westward of north". A very careful examination of this outcrop failed to show a northwest dip in the conglomerates. Such suggestions as these were, e.g. alignment of boulders, etc., all indicated a southerly dip. True, the slates adjacent to the conglomerates dip to the northwest, and it may have been on this evidence that Logan based his structure. This would be a natural assumption, for Logan believed that these slates belonged to subdivision D 2 (see Logan 1866, atlas). From lithological

evidence, as well as the evidence of a break between the slates and the conglomerates suggested by the crumpling of the former near the contact and their northwest dip and the southeast dip of the latter, it is believed that the slates do not belong to D 2, but to the rocks on the western side of the Fault, -- in other words, that the trace of the St. Lawrence and Champlain Fault passes between this most northern group of conglomerate outcrops and the slates immediately to the north of, and almost in contact with, this group. Returning to the outcrop on the Bedford-Henryville road (see ante p.) conglomerate again appears about 200 feet south, and the same direction west of it.

A third of a mile S.20°W. of these exposures is a small outcrop of conglomerate; another occurs almost due south of the last and a quarter of a mile distant. All of these outcrops belong to the same band and the same structural unit. The last two mentioned outcrops of conglomerate lie upon opposite sides of a minor synclinal axis, as shown by the distribution of beds lower in the series outcropping nearby. The continuation of the stratum around the end of the syncline is cut off by the Philipsburg thrust. Five scattered outcrops of conglomerate between the last mentioned one and the vicinity of Bedford indicate the course of the band around the next syncline to the east, and this band, about three-quarters of a mile southwest of Bedford is again interrupted by a fault.

The next outcrop along the presumed course of the band is nearly two miles south of Bedford on Dutch Street. At this place the dips are 25°E., and the strike is N.15°-20°E.. Eight hundred feet east of the more southern outcrop is a small exposure of calcareous shale, which belongs to the Stanbridge formation.

The most southern exposures of this conglomerate are three miles S.45°W. of those on Dutch Street, and are two in number. These are on, and south of, the road running from Rosenberg to the St. Armand-Morgan Corners road, and immediately east of the Central Vermont Railway. The strike of the one on the northeast is N.55°E., and the dip is southeast at 30°. Logan (1866, p. 850) stated that these two outcrops "may probably belong to the two bands in part 1 of Division D", failing to recognize that these two outcrops lie on opposite sides of the Solomons Corners syncline. One half mile northeast of these outcrops is a small exposure of conglomerate on the west side of a north-south road, lying on the southeastern limb of the same syncline.

Thickness. The outcrops of the Mystic conglomerate are scattered and scarce, particularly in critical areas, which, with minor structural complications led Logan to postulate at least two bands of conglomerate in D 1. Logan estimated the total thickness of subdivision D 1 to be from

250 to 300 feet. Of this, each of the two principal conglomerate bands accounted for 50 to 100 feet, while the slates between them made up the remainder. However, the present interpretation is that but one band of conglomerate exists, with shaly strata belonging to subdivision C 2 below, and similar strata of subdivision D 2 above. On this basis the thickness of D 1, or the Mystic formation, is the thickness of the conglomerate band alone, and is probably no more than 75 feet. It is impossible to give the exact thickness, for the upper contact has never been observed, and the lower contact only occasionally. The thickness of the rocks exposed varies between 20 or 25 feet and 75 feet, the average being about 50 feet. And, as is to be expected of a conglomerate bed, the true thickness probably varies considerably from place to place along the strike.

Lithology. Although this bed has always been termed a limestone conglomerate, this does not mean that all the phenoclasts are of limestone. The term is justified because probably more than 90 per cent of the phenoclasts are composed of light gray to black, fine-grained, dove-weathering limestone. But there are phenoclasts of finely crystalline, dark-colored, brownish-weathering dolomites, probably making up nine per cent or more of the total. In addition, there are occasional black, argillaceous, thin-cleaving slate, and, very rarely, sandstone or quartzite phenoclasts. One block of slate, measuring about one and a half by three feet, was seen in

the road-cut where the Bedford-Henryville road crosses the conglomerate band. This is definitely a phenoclast, but such may not be true of the slates seen in one of the conglomerate outcrops between that road and Pike River. At the south end of the second outcrop south of the river dark gray, highly sheared, argillaceous slate, interstratified with thin, black limestone beds, lies between two narrow bands of conglomerate. The total width of the outcrop across the strike is about 50 feet, the slate being 10 feet wide. The strike of the slate and the conglomerate is approximately the same, but the former dips to the east at an angle of 60°, while the dip of the conglomerate, although in the same direction, appears to be more gentle. The slate is overlain and underlain by conglomerate on its east and west sides, appears to give place to the conglomerate at the north side, and goes under drift at the south. This might conceivably be a lens of slate in the conglomerate, or it's aberrant dip proclaims the probability of its being a large phenoclast.

Size and Shape of Phenoclasts. The size and shape of the phenoclasts vary considerably -- so much so that, particularly on the basis of shape, the formation may be said to contain two types of conglomerate. Although these types can be recognized, it must not be supposed that definite boundaries exist between them, or that within any one type all the phenoclasts correspond to the general description

of the type. Much the same division into types was noted in the description of the Lacolle conglomerate (ante, p.).

In the first or predominant type of conglomerate (Plates and) the phenoclasts are subangular, occasionally well-rounded, and vary in size from pebbles one-half inch in diameter to blocks with a length of twelve feet and a width of eight feet. Apparently restricted to this type are the slate phenoclasts which, however, are not rounded, and the sub-angular to rounded sandstone phenoclasts. The largest phenoclast of sandstone seen was about six inches in diameter. Also apparently restricted to this type are the dolomite phenoclasts. These vary in size from small "pebbles" to "boulders" four feet long and two feet wide. As a rule they display little angularity. Relatively pure limestone phenoclasts predominate, and grade upward in size from small fragments in the matrix to masses measuring eight by twelve feet. The larger masses are not rounded, and their contacts with the matrix and the other phenoclasts are sharp and uneven. Many of the limestone phenoclasts are themselves conglomeratic -- that is, there are here boulders of conglomerate within conglomerate. In these the phenoclasts are small, and sub-angular to angular for the most part, only occasionally being well-rounded.

In this type of conglomerate the matrix is a fragmental

limestone that is uniformly light gray to dark gray in color on fresh surfaces, and weathers to a general dove color, but there are color distinctions sufficient to make out rounded and angular fragments and to show that the matrix is not, as a rule at least, a homogeneous rock. In appearance the matrix is similar to the conglomeratic boulders mentioned above, and sometimes it is impossible to determine whether a particular area of rock is matrix or phenoclast. In the past there has been an evident confusing of boulders with matrix on the part of those who have studied this conglomerate formation. It has been stated that Beekmantown fossils occur in the matrix, but because phenoclasts of Chazyan age are not now known to be present in the formation it follows that the Beekmantown fossils reported must have been discovered in phenoclasts. In places the phenoclasts are packed in so closely that the matrix is either absent or insignificant in amount. The cement is predominantly calcareous, sometimes calcareo-magnesian, and occasionally argillaceous. No orderly arrangement of the phenoclasts was seen, except that their longer axes were usually parallel to the strike of the formation. There is neither obvious bedding nor evidence of any sorting.

The second type of conglomerate differs from the one just described in the shape of the phenoclasts, as well as in their more uniform lithology. In this conglomerate the

phenoclasts are lath-shaped, varying in thickness from one-half inch to two feet or more. A typical example of this conglomerate is shown in Plate ; the largest phenoclasts is two and a half inches wide and twenty-five inches long. Invariably the phenoclasts are composed of dark gray or black limestone, fine in grain, and weathering light gray or dove. The matrix, or cement, is sometimes of the same type of limestone as the phenoclasts, but commonly is a calcareo-magnesian, brownish-weathering shale. The latter type of matrix is shown in the photograph (Plate). The laths are often arranged in rows, which are, in a general way, parallel to one another and to the strike of the formation.

Bradley (1923, p. 13) remarked on this type of conglomerate as follows: "Associated with these rounder fragments are the more common elongate pieces which range from one-half inch to two feet in length and from one-half to one and a half inches in width. These long fragments have a general alignment normal to the strike and clearly show that they are the broken, reworked slabs of a former thin-bedded black limestone whose fragments have not been transported very far".

Such distinctions can not be made at all localities where the conglomerate bed occurs. Some outcrops might be considered as intermediate between the two types. An example

of this is shown in Plate ; it will be noticed that the phenoclasts vary greatly in size, that they are definitely not lath-shaped, and that they are just as definitely not rounded, although they have lost some of their original angularity. The matrix or cement is a calcareo-magnesian shale, and surrounds phenoclasts varying in size from small grains to blocks measuring nine by twelve inches. From the point of view of distribution this intermediate conglomerate is not important, as it occurs at but few localities and occupies limited areas, usually within outcrops that are largely composed of the type first described. One of these occurrences is probably that described by Bradley (1923, p. 13) "To obtain a complete picture of this conglomerate [formation] we must study the outcrops on lot two [?] and twenty-two, range six. In one place the fragments have a peculiarly brecciated appearance. Pieces of dove gray pure limestone compose the greater part of the beds. The paste is of darker material, in places slaty and largely calcareous. In one place above the more brecciated zone, a bed of massive, partly broken gray limestone occurs. No paste seems to be mixed in it with this limestone,, the broken fragments seem to have been recemented by lime dissolved from themselves. From this rock a good collection of fossils was obtained".

Origin of Conglomerates. Two theories relating to the origin of the Mystic conglomerate formation have

already appeared in the literature. Logan stated that the conglomerate of subdivision D 1 were composed chiefly of the ruins of the thick bedded limestones of Division C and that many of the boulders contained fossils, the species being characteristic of C 1. Bradley differed from Logan on this point, and evidently considered that the conglomerates were mainly derived from original strata in Division D, not from older beds.

"Logan's conclusions that the lower strata of D were formed from the breaking down of the massive beds of C 1 is not substantiated by fossil evidence. Nowhere in D has the thick-shelled gastropod fauna of C 1 been found. In fact, gastropods are conspicuously absent from the fauna from D. Likewise the lithology of the conglomerates indicates that originally the strata of D were predominantly very weak and thin bedded. There is no evidence of any thin bedding in C 1.

"Although the section from D 1 upward is in need of revision, particularly the great thickness of slate which occupy the spaces between the ridges of more resistent limestone conglomerate, a few facts are clearly present which throw light on the genesis of D. The intercalation of thin dolomitic beds with much of the slate, the great abundance of slate, as well as the presence of shallow water organisms in the paste

of the conglomerate indicate a shallow water origin. The general absence of rounding in the fragments of the conglomerate and their general alignment gainsay transportation and point to deformation of the unconsolidated beds in situ. This deformation was probably due to the same forces which formed the synclines and anticlines in the more massive underlying beds. The sub-angular appearance of the fragments argues for a submergence and prompt recementation of the broken beds". (Bradley, 1923, p. 14).

As far as the source of the phenoclasts is concerned Bradley was not justified in contraverting Logan's opinion that the conglomerates were formed from the ruins of the Corey formation (C 1). It has been our experience that the majority of the fossiliferous phenoclasts in the conglomerate do carry a "thick-shelled gastropod fauna", and that the majority of the phenoclasts are lithologically indistinguishable from the Corey limestones. A similar fauna, with additions, and a similar lithology is found also in the fifty-foot bed or beds near the middle of the St. Armand formation (B 5). We have no hesitation in stating that the first type of conglomerate described under the Mystic formation -- the predominant type -- was formed largely through the breaking down of the Corey and St. Armand formations.

But these formations were not the sole contributors

of phenoclasts to the conglomerate. In an outcrop west of Mystic, in the Lacolle Quadrangle, one phenoclasts is lithologically identical with that of the beds at the base of the Luke Hill formation (B 3) and carried a trilobite fauna, of which by far the most abundant genus was Leiostegium. Only in the basal beds of the Luke Hill and in older beds is Leiostegium so abundant; from that fact as well as from its peculiar lithology there is little doubt that the phenoclast referred to came from the base of the Luke Hill formation. Phenoclasts of a more common and purer type of limestone, and also replete with Leiostegium almost to the exclusion of other forms, were discovered in the summer of 1929. These were found about three miles north of Mystic, at the east end and south side of the wagon-road running east from the Mystic-Farnham road. At this place the Leiostegium-filled phenoclasts were common, and most of them were composed of a fine-grained, dark gray limestone that weathers to a light gray; these are lithologically similar to beds in the lower part of the Hastings Creek formation (B 1-B 2) in which Leiostegium is common.

Thus there is little doubt that the majority of the fossiliferous phenoclasts, at least, in the Mystic formation were derived from lower formations in the Philipsburg Series (those included in Divisions B and C). But in the Mystic conglomerates there are phenoclasts of Chazyan age,

while in the Philipsburg Series below the conglomerates there is no bed that could have been the parent of these phenoclasts; they must, therefore, have been derived either from some area other than that containing the Philipsburg Series, or as is most likely, from beds that were deposited on top of the Basswood Creek formation (C 2) and then completely eroded prior to the deposition of the Mystic conglomerates.

Stratigraphic Relations. It has already been stated that the Mystic conglomerates are separated from the underlying beds by an unconformity, the importance of which is shown by both physical and faunal evidence. In one place the conglomerate overlies the upper, thin-bedded limestone of the Basswood Creek, in another the conglomerate was seen in actual contact with the lowest member of that subdivision indicating that 40 or 50 feet of strata had been removed by erosion before the conglomerate was deposited. And, it may be that in some places all three members of the Basswood Creek had been removed and that erosion had cut down to the Corey formation, for, occasionally, and always toward the base, distinctly congloneratic strata overlie large masses of limestone resembling the Corey and which are just as distinctly not conglomeratic.

The conglomerate bed is overlain by the gray and black, calcareous shales and slates of Ligan's subdivision

D 2, but no contacts between the two have been observed, and their relationships, whether conformable or otherwise, are not known. Both conglomerates and shales (at least the basal part) are considered to be Chazyan, and it is probable that no important time gap occurs between them.

Fauna. To repeat here the long lists of fossils recorded by Logan, Billings, Ami and Ells would be both tedious and practically useless. Short lists by Logan can be seen on pp. 845, 850, 860 of the Geology of Canada, 1863. Billings, in Paleozoic Fossils, 1865, mentions or describes nearly a score of species from the conglomerate. Ami gives six lists of fossils from the conglomerate at as many localities. Bradley also recorded some trilobites from this formation. These lists are of little value for there was little, if any, effort made to record the fauna of separated boulders. Raymond (1925, pp. 169-170) was the first to recognize this, as will be apparent from the following quotation. It is clear that what Raymond calls a Normanskill fauna is identical with what Ulrich calls Chazyan, see, forward, next page. "Boulders of both Beekmantown and Normanskill age are found in this conglomerate, with the result, the fossils from these not having been kept separate, that considerable confusion has existed as to the composition of this fauna. The following trilobites were collected at this locality [lot 22, Range VI, Stanbridge] from a single boulder by Professor Schuchert

and the writer.

Arthrorhachis galba (Billings)
Remopleurides affinis Billings
Bathyurellus expansus Billings
Nileus scrutator Billings
Nileus macrops Billings
Bronteopsis marginata Raymond
Telephus sp. ind.
Illaenus incertus Billings
Illaenus simulator Billings
Acidiphorus scorpionis Raymond
"Bathyurus" breviceps Billings
Eotenonotus westoni (Billings)
Kawina vulcanus (Billings)
Pliomerops biliratus Raymond

Another boulder contained:-

Arthrorhachis galba (Billings)
Robergia breviceps Raymond
Homotelus pelops (Billings)

In the United States National Museum there is a large collection of fossils from the conglomerate, listed as coming from "near Mystic", and from localities "196" and "196a". Both the latter localities are in lot 20, Range VI, Stanbridge, but 196a was supposed by Walcott, the collector, to be a lower horizon than 196. The fossils of the larger collection have been provisionally identified by Ulrich, and the list is published here with his permission.

List of fossils from locality "196":-

Brachiopods:

Lingula sp.?
Obolus? sp.
Schizotreta sp.
Acrotreta or Conotreta sp.
Schizambon cf. duplicamuratus Hudson
Plectambonites? acuminatus Ulrich
Strophomenas of the group S. sinuata
Leptaena sculptilis Ulrich
Species of Leptaena and Orthis
Hebertella sp.?
N. gen. and n. sp. related to Parastrophia
Camarella varians Hall
New species, probably of Camarella (two)
cf. Porambonites

Cephalopods:

four genera and species

Gastropods:

Tryblidium sp.
Archinacella propria Raymond
Sinuites -- 2 species
Oxydiscus sp.
Bucanidae -- new genus (suggests an uncoiled Conradella or Oxydiscus).
Lophospira cf. perangulata
Lophospira sp.
Eccyliomphalus fredericus Raymond
Eccyliomphalus ? sp.
Eccyliopteris sp.
Trochonema sp.
Gyronema sp.
cf. Gyronema rotalinea Raymond
Holopea sp.

Fusispira sp.
Subulites prolongatus Raymond
Clisiospira n. sp.

Trilobites:

Harpes ottawensis? Billings -- Seems to be the Chazy form referred to this species by Raymond
Harpides cf. atlanticus Billings
Agnostus galba (Billings)
Lonchodomas sp.
Remopleurides 2 new sp.
R. canadensis? Billings
R. cf. affinis Billings
Amphilichas sp. ?
Telephus mysticensis Ulrich
T. mysticensis var. simulator Ulrich
Leiostegium sp.
Nileus cf. affinis, and two other species
Illaenus -- 5 species
Asaphus? sp.
"Cheirurus" mercurius Billings
Pygidium, cf. one referred to "Cheirurus" vulcanus by Billings
Pseudosphaerexochus prolificus Billings
Ceraurus (? n. sp.)
Ceraurus cf. polydorus (Billings)
Sphaerexochus cf. parvus Billings
Cybeloides, 2 species.
Encrinurus sp.
Acidaspis? cf. Ceratocephalus narraweyi Raymond
Triarthrus fischeri Billings
Pygidium....? "Triarthrus fischeri" or Sphaerexochus ??
Genus ? suggests Cyphaspis or Lloydia
Genus ? cf. Menocephalus
Genus ? seems to be related to Thaleops

Ostracods:

Leperditia aff. L. bivia White
Leperditia sp. 2
Isochilina sp.
Leperditella sp.
Eurychilina sp.

Cirripedia:

Turrilepas sp.

Bryozoa

Drymotrypa ? sp.

In the course of our collecting we have accumulated twenty-five drawers of fossils from these conglomerates more than half of which are of the faunas listed above by Raymond and Ulrich. Much time will be required to elaborate them, and the results must await the paleontological memoir to follow. From the stratigraphic point of view, the conclusion that the conglomerate carries Chazy fossils fixes its age as no older than Chazy and the assumption is that it is probably late Chazy, or not impossibly lower Trenton, in age.

Age and Correlation. There was an early tendency to correlate the Mystic conglomerate with somewhat similar conglomerate at Levis. Logan believed the two to be equivalent, although he clearly stated that none of the fossils from Division C at Philipsburg had been found in the Levis rocks. Fossils from A and B, however, Logan knew had been found at Levis in large numbers, and he listed eight characteristic

species. The only legitimate conclusion to draw from this is that rocks of equivalent age to Divisions A and B were exposed in the vicinity of Levis. The Levis conglomerate, instead of being somewhat younger than the Mystic is actually somewhat older, belonging to Division B in time.

Ells (1896, p. 34) stated that the fossils found in the paste of the Mystic conglomerates indicated that "the rocks themselves are probably the equivalents of the Chazy", a correct conclusion, although it is doubtful whether he had seen any fossils from the paste. He also believed that the slates above the conglomerates were Chazy in age.

Raymond (1905, p. 379) recognized the Fort Cassin fauna among the fauna of the conglomerates, as is shown by the following statement: "Pseudosphaerexochus vulcanus, which is the only trilobite common to the Calciferous and Chazy, occurs with the rest of the Fort Cassin fauna at Stanbridge, Quebec". The same author (1916, p. 327) reported at a later date as follows: "The 'Chazy slates' of Ells at Mystic and vicinity are the shales and conglomerates of the Levis formation", which conclusion is indefensible.

Still later, however, Raymond (1925, p. 170) reported a trilobite fauna of Normanskill age from boulders in the conglomerate (ante, p. 190), and stated that "This fauna is of some interest, since it is the only trilobite

fauna of Normanskill age yet found between Newfoundland and Virginia. Curiously, although the genera are those found in Newfoundland, many of the species are so far known from this locality only. A positive correlation can not be made with present knowledge, but the presence of Ectenonotus, Bathyurellus, and Acidiphorus indicates that the fauna is of about the same age as that of divisions K and M of Newfoundland".

The "Normanskill" fauna found by Raymond and Schuchert was from a locality on lot 22, Range VI, Stanbridge. A second "Normanskill" fauna locality was reported by Bradley (1933, p. 20) from "near Mystic station", about two miles south of the first locality, but within or associated with, the same conglomerate bed. Bradley stated that this fauna "differed markedly from the typical Upper Beekmantown fauna of this region" and made the unnecessary assumption that it "is possible that the Normanskill has been infolded at this locality". This explanation was forced upon Bradley because of his belief that the conglomerate bed was Upper Beekmantown in age.

The latest published word on the age of the Mystic conglomerates comes from Ulrich (1929) who writes as follows "the Mystic boulders.....probably wedge in between Stones River and Blount formations of the South", and are therefore of Middle Chazyan age. The conglomerate must therefore be

Middle Chazy in age or younger. The age of the Stanbridge slates is not without bearing. Graptolites are common in the lower part of that formation, and in every case they belong to the Normanskill fauna, or Lower Trenton. Hence, because of the supposed lack of an unconformity between the two concerned formations it is quite likely that the Mystic conglomerate is nearer Lower Trenton than Middle Chazy. Indeed it might properly be considered a basal conglomerate to the Stanbridge slates, and as such would be Lower Trenton.

Stanbridge Slate (Logan's D 2 and 3).

Distribution. Occupying the eastern portion of the area of this report is a wide expanse, about 100 square miles, of slaty rocks, a small part of which has already been described under the Georgia formation. The remainder is overlain on the east by a Lower Cambrian thrust fault block. To the north it continues beyond the limit of the sheet. To the south it is bounded by a thrust which brings the Georgia above it, and only on the west can it be seen in stratigraphic contact with other rocks, namely the Mystic conglomerate of the Philipsburg Block. This slate body is therefore the highest member of the Philipsburg series, and consists of slates with interstratified beds of limestone and quartzite; the outcrops are scattered and small but reasonably ~~f~~; the structure is complicated and can only rarely be carried from one outcrop to another.

Logan traced these slates from Quebec southward to the border in a belt from five to forty miles wide. He gave no name to them, however, except to refer to them as the "lower" or "subjacent" black shales, erroneously considering them to be the lowest part of the Quebec Group. Ells mapped this belt, dividing it without apparent justification into two formations which he called the Farnham slates and the Mystic and Bedford slates. However these subdivisions were not defined, and their limits on the map will not bear critical examination. There seems to be not the slightest justification for his broad synclinal structure (1896, pp. 26-27 J). All in all no name previously used seems satisfactory, and we here use the name Stanbridge, because the greater part of the slates of this division occur within that township.

Lithology. The rocks of this formation show the greatest diversity of characteristics. In general they are dark gray to black, thin-cleaving slates, much sheared, rarely showing any trace of stratification. Where bedding is shown it is marked by fairly wide bands within the slate not due to obvious differences in texture but made apparent by differences in color. More rarely, though more obviously, bedding can be seen wherever calcareous or arenaceous strata are interbedded with slates. They weather medium to light gray or buff. Along with the above come lesser amounts of dense almost gritty slates many of which ~~frequently~~ break with

splintery cleavage, yielding "pencils" of slate upon breaking. This type rarely weathers to a different color, maintaining its black color probably because of a high carbon content. Both the above types carry graptolites of equivalent age so that the distinction is of no stratigraphic value. The slates not infrequently become rusted upon weathering, probably due to the oxidation of minute crystals of pyrite, which are occasionally as large as a pea. Interstratified with these argillaceous slates are beds of limestone, between which and slate there are all possible variations. The limestone beds are rarely of the fine-grained dove type so characteristic of the underlying formations, although that type is present; the most common kind is a black semi-crystalline limestone occurring in bands from an inch to rarely more than a foot thick. These dark limestones carry fossils and in one or two places bear rounded and frosted sand grains. In the lower part of the formation one or two beds of limestone conglomerate occur, but cannot be traced far along the strike. Sandstone beds are uncommon. There is one bed three feet thick near the border of the area north of Sweetsburg, but except for that arenaceous beds are thin. They are, on the whole far more common in the northern part than elsewhere. Rounded quartz grains within the limestone beds are not rare, one of the limestones in the Yamaska gorge at Cowansville being nearly one half ~~composed of them~~

Structure and Stratigraphy. Logan's description of his divisions D 2 and D 3 are repeated here because though these descriptions refer to local development in the vicinity of Mystic, it is there that the slates are in contact with underlying formations.

Subdivision D 2. "Black and greenish argillaceous slates, probably interstratified with occasional thin calcareous bands, and thin lenticular patches of limestone conglomerate, as well as more important bands of yellow-weathering dolomitic slates. The whole is terminated by a band of black limestone conglomerate similar in character and thickness (from 50 to 100 feet) to those already mentioned [D 1], and containing Maclurea ponderosa in one of the few places in which the band has been seen. This whole mass of strata is very imperfectly exposed, and much uncertainty exists as to its true general character. Its thickness may be from 750 to 1000 feet". (1863, p. 845).

Subdivision D 3. "Grey and black striped slates, some parts of which are calcareous, and weather slightly brownish. They are interstratified with occasional thin beds of black limestone, weathering light-grey, as well as many strong and solid beds of brown-weathering magnesian limestone, and brown-weathering dolomitic slates. Some of the latter are marked by an abundance of fucoids resembling

Buthotrephis flexuosa of Emmons. Occasional beds of sandstone, from one to three feet in thickness, are met with. About the middle of the mass there has in one place been observed a bed of limestone conglomerate from five to ten feet thick, and other smaller ones may occur in different parts of the vertical thickness.....1500 feet". (1863, pp. 845-846).

Judging from these descriptions, there is very little lithological difference between the two subdivisions, and it is there not surprising that no one since Logan's time has been able to distinguish between them.

Logan described the occurrence of his subdivisions D 2 and D 3 at some length, but the "conglomerate band at the top of D 2" (1866, p. 853) cannot now be identified in any of its outcrops except the most northerly one, and there the dip, as noted by Ells, is to the south, and not to the north as Logan recorded. And Logan's anticlinal (p. 854) which he considered might be the continuation northward of the Morgan Corners anticline, is but one of the multitude of minor flexures, of no general structural importance, with which the Stanbridge slate is ~~affiliated~~ characterized throughout its entire extent.

Although the conglomerate outcrops alluded to above no longer exist, Logan's general idea that these might be a conglomerate horizon above the base of the Stanbridge seems

to be substantiated by exposures around Bedford where paralleling the band of the Mystic conglomerate on the north and east is a chain of limestone conglomerates, strangely enough falling on the trend line shown by Logan in the Atlas accompanying Geology of Canada, 1863, which, beyond the curve of the Bedford syncline, trend about N.50°E. and the beds dip east at about 30°. This band would just about link up with Logan's lost exposures and end with the outcrop on lot 22, range 5. This, as far as we have been able to find is the only horizon within the Highgate formation with any semblance of persistence.

Since 1896 the slates above the Mystic conglomerates have received very little attention, and no one has attempted to revise the structure and succession worked out by Logan. It may be suggested, however, that on purely lithological grounds (the criterion used by Logan) there is no justification for the two subdivisions, D 2 and D 3. The lithology of D 2, as defined by Logan, is practically identical with that of D 3; and, ~~since~~ as the fauna does not give evidence to the contrary, the section would be simplified by referring both of Logan's subdivisions to one subdivision, which we have called the ~~Mystic~~ Stanbridge formation. This would then be defined, broadly, as a slate formation -- one in which there are numerous interstratified beds of relatively pure limestone and dolomitic limestone, with masses of limestone conglomerate

and occasional beds of sandstone.

With this in mind, then, the lowest part of this formation is contiguous to the Mystic conglomerate. This, in connection with the observed general northnortheastward plunge of the folds, would demand that on the whole younger and younger beds should be met to the east and north. This seems, in a very general way, to be substantiated, for the Mystic conglomerates are never seen again, and although calcareous beds and limestone conglomerates are characteristic of the base and occur throughout the entire area, only in the northeastern part are siliceous beds common. If this is anything more than a will-o'-the-wisp it might point to the gradual change in lithology from bottom to top of the formation, the basal beds, and probably the greater part of the formation being calcareous shales, which in the upper part as exposed in the Sutton Sheet give way to purely argillaceous and even arenaceous beds. This is in accord with the general tendency in the Middle and Upper Ordovician in the northern Appalachian trough, a silting up of the geosyncline with the beds becoming coarser and coarser towards the top.

Everywhere the slates are isoclinally folded or nearly so. Except for the bed of conglomerate described by Logan passing west of North Stanbridge, there is no horizon known to us which can be considered as in every sense continuous.

On the map accompanying Ells' report are a few boundary lines within the limit of this formation in the vicinity of Cowansville. Here and there outcrops of limestone occur on these lines, but the justification for drawing them as continuous lines, and closed lines at that, is sadly lacking. There are far more limestone outcrops distant from those lines than there are situated upon them. It should be said by way of explanation that the base of the map used by Ells was prepared by Logan, and withheld by his successor, Selwyn. The boundary lines referred to were in all probability sketched by Richardson, who spent several seasons mapping in the Eastern Townships.

Along the eastern limits of this slate body the Oak Hill thrust has brought another slate body into contact with it. There is never any difficulty in telling the two slates apart. The Stanbridge is always fissile, rarely banded, or if so by color only, and weathers down to low inconspicuous outcrops. The Lower Cambrian slate, above the thrust, is more apt to break into irregular fragments, is never fissile, and is always sharply banded with thin quartz sand layers in marked contrast to the black color of the argillaceous part of the rock. Moreover this type is more resistant and usually is exposed in prominent outcrops.

Nevertheless, in some places, half-a-mile or

more west of the present trace of the thrust low outcrops may be seen in which both the unbanded (Stanbridge) and the banded (Lower Cambrian) slates occur together. In such cases the rocks are invariably very badly smashed and intricately contorted. The interpretation is that the overriding Lower Cambrian slate and the overridden Stanbridge slate became inextricably mixed ~~in the rifting process~~ so that some of the superior slate was forced into the inferior, and some of the latter was caught up and incorporated within the former. Good examples of this, ~~which might be called plastic brecciation were such a term not a contradiction~~, can be seen one-half mile west of St. Armand Center, and near the bridge two miles north of the same place. Such complications which are the rule close to the fault have made the precise limiting of its position very difficult.

Fauna. In the general vicinity of Mystic several new fossiliferous localities have come to light. On the road leading north from North Stanbridge, "fucoids" occur in considerable abundance on a small number of bedding surfaces. These are straight, or slightly curving, branching from a quarter to a half an inch wide, but appear to be of no stratigraphic importance. Logan noted the occurrence of similar forms but gave no locality. 800 feet along the road leading east from the four corners a mile south of Mystic we found the pygidium of an Asaphus-like trilobite. Cruptolites

were found by Logan at localities ? no longer identifiable but we have found several new ones. Two miles north of the four corners one mile west of North Stanbridge occur the following:-

Didymograptus sagitticaulis
Dicellograptus gurleyi
Climacograptus bicornis
Diplograptus sp.

Three-eighths of a mile north, and on the east side of the road:-

Climacograptus bicornis,

Two miles north of North Stanbridge, just south of and opposite a schoolhouse:-

Glossograptus cf. encharis
Dicellograptus cf. gurleyi
Diemonograptus ramosus
Climacograptus bicornis (pellifer type) t/
Glossograptus sp.
Leptograptus flaccidus var. spinifer, mut. trentonensis
Climacograptus bicornis

Further north, 2,000 feet west of Fordyce Corners, 3 miles west of Cowansville, in a low roadside cut:

Diplograptus foliaceus var. acutus
Glossograptus sp.
Didymograptus sagitticaulis
Dicellograptus cf. intortus
Climacograptus bicornis
Diplograptus sp.

With scarcely an exception, all the graptolites from the above

localities indicated a Normanskill age for the shales. Traces of graptolites were recorded from several localities by Ells, although we were not able to verify that statement.

The limestone beds in the northern part of the area are frequently fossiliferous. Ami gives several lists from localities in the vicinity of Cowansville and Farnham which may be condensed as follows:-

Bolboporites americanus (identification uncertain)
Pachydictya sp.
Lingula cf. iole
An Obolellid brachiopod
Dalmanella testudinaria
Leptaena sp. decipiens
Plectambonites ?sericeus
Strophomena sp.
Orthis cf. electra
O. cf. deliceatula
Triplecia ?calcifera
Ptilodictya cf. acuta
Stenopora
Ampyx halli
Lichas sp.
Trinucleus sp.
Triarthrus sp.
Asaphus-like fragments
Agnostus sp. cf.
Pterygometopus callicephalus
Turrilepas sp.

In addition to the above, and it must be said that the identifications are not altogether reliable today, we have found a great many places in the northern part where

the limestone yielded fossils. mostly however, too fragmentary to identify. In the slates and limestones of the gorge of the Yamaska River below the dam at Cowansville are graptolites, brachiopods, bryozoa, and an Ambonychia-like shell, all difficult of identificatiog but not differing essentially from the assemblages quoted above. At an outcrop south of the road half-a-mile east of East Farnham in crystalline limestone with abundant crinoidal fragments we found a single plate of Cheirocrinus.

Age and Correlation. These slates, as they occur in the vicinity of Mystic, have been assigned by various authors to places from the Beekmantown to Trenton inclusive. They overlie the Mystic conglomerate which contain boulders of Chazy limestone, and hence cannot be older than Chazy and are most likely either younger or at the oldest Upper Chazy. The graptolite fossils all indicate Normanskill age. Other fossils such as Ampyx indicate but do not demand Chazy age. The most logical conclusion seems to be that even though these shales may have commenced to be laid down before the end of Chazy time they certainly continued to form through at least the early Trenton with no indication of their upper time limit.

Stratigraphy of the Granby Slice.

So little of the Granby Slice occurs within the Sutton sheet that a description of its stratigraphy can be

of but little value. Two or three outcrops of well banded red and light gray shales are known, and although they occur over a limited area, they are so scattered that the details of the stratigraphic succession and the thickness of the beds cannot be worked out. A few miles further north, in the vicinity of Granby, these shales outcrop over a much greater area, and are obviously folded, and no doubt detailed work could show a thickness of hundreds if not one or two thousand feet. They are more or less continuous, along the front of the folded belt, as far as Quebec, where they outcrop on both sides of the river above the city, their red color giving the names to Cap Rouge, and taking their name from the village of Sillery.

Structure of the Eastern District.

The Eastern District is as complicated as the Western is simple. All of its rocks partook of the folding and thrusting of the Appalachians. In attempting to vizualize the structure of this region one must keep in mind that the rocks of the Eastern District, lying to the east of the present trace of the St. Lawrence and Champlain fault, were deposited in a basin or trough located at an unknown distance eastward of their present position and that they owe their present position to tectonic forces which carried them westward as overthrust blocks. The distance of these displacements is unknown, but it was probably to be measured in tens of miles. The Eastern District consists of the exposures of three separate

thrust blocks or slices. The one on the west we call the Philipsburg block, the one to the east the Pigeon Hill block, the latter being the northern extension of Keith's Central Sequence.(1924, p.), and the one just showing on the north the Granby block.

The dominant structural features of the district i.e. are two thrusts. The course of the western one of these, which we name the Philipsburg thrust, has already been given in detail (ante, p.). From under this there emerges the thrust bounding the Granby block, which thrust we shall not name at present. The other, and more eastern, thrust runs northnortheast along the eastern edge of the valley of Rock River, that is, along the western edge of the Lower Cambrian exposures from the boundary line to Rosenberg. There it apparently swings sharply to run in an east-northeast direction, but its course could not be traced definitely beyond that place. South of the boundary line this thrust follows a southsouthwest direction to a point somewhere between Highgate Springs and Swanton villages, where it seems to merge into the Philipsburg thrust. For convenience, this more eastern of the two main thrusts may be termed the Rock River thrust. To explain the difficulty of delineating the position of the Rock River thrust further north than the vicinity of Rosenberg it may be said that the southwestern portions of both Philipsburg and Rock River blocks are hard non-shaly rocks,

Something omitted here

in both cases succeeded in normal stratigraphic position. Only where the non-shaly rocks occur can the boundary between these two blocks be mapped accurately. East of St. Armand shales normally overlie the dolomites and the limestones of the Pigeon Hill block. East of Bedford other shales normally overlie the uppermost limestones of the Philipsburg block. Where these hard rocks are lacking, however, the two shale bodies are in contact. Essentially similar petrographically, having suffered practically equivalent folding, and being nearly barren of fossils, these two shale bodies can rarely be separated. The reasons for tracing the fault as on the map are given ~~here~~ under the discussion of the Georgia formation.

The eastern boundary of the Eastern District is a continuous thrust fault, named the Oak Hill Thrust, which brings a thick series of Lower Cambrian strata, mostly clastics, to rest upon the shales of the Philipsburg and Pigeon Hill blocks. ~~These Lower Cambrian beds will be described in a subsequent report.~~ Although these overriding rocks are to some extent intermingled with the Stanbridge slates, as described above (p.), there is nothing in the distribution of the rock types to justify Harvie's conclusion (1915, p. 99) regarding the areal relationships of the Georgia and the "Farnham" slates, nor for his conclusion that "the measured throw of the fault is 11 miles".

Philipsburg Block.

Folding. Between the Philipsburg and Rock River overthrusts mentioned above lie the beds of the Philipsburg series which, between the boundary line and the latitude of Rosenberg, form a northward-plunging syncline; to this the term St. Armand syncline is applied because its axis pass through St. Armand Village. At the western margin of the syncline, as exposed, the dips are to the east, gradually shallowing eastwards until at the axis they are almost horizontal. In the eastern limb of the fold the dips are steep, quite commonly almost vertical, and in places overturned to the west. The syncline is best displayed in the boundary line section, between Missisquoi Bay and Rock River. From the latitude of Rosenberg the synclinal axis swings to the east-northeast, to parallel roughly the trace of the Rock River thrust. North of this latitude the structure becomes more complicated, the western limb of the St. Armand syncline being sharply folded to form subsidiary synclines and anticlines, with northeasterly and east-northeasterly trending axes. North of Bedford folding roughly parallels the general northeast structures of the region. In the continuation northward and eastward of the Philispburg block the Stanbridge slates overlying all other members of the Philipsburg series, are intensely contorted. Above the Mystic conglomerate there are no competent beds of any

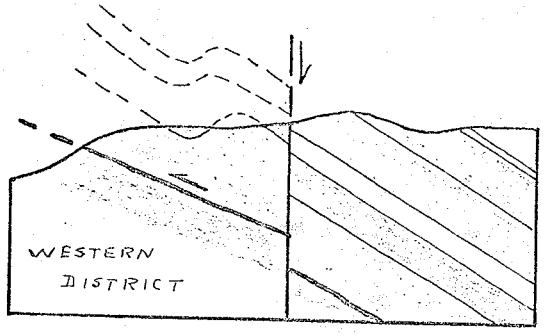
importance. Crushing and smashing of the unresistant shales by the overriding superjacent blocks has rendered any but the most general structural tendencies within the ~~Hyatt~~ Stockbridge? shales undecipherable.

Faults. Beside the folding there are numerous complications caused by the cross faults of peculiar character. Immediately east of the village of Philipsburg is one of these cases. Going east from the Champlain Hotel at Philipsburg which lies on the band of the Rock River dolomite, one crosses first a stream which presumably runs along the strike of the Strites Pond formation, for although in this place there are no outcrops, the limestone occurs north and south along the stream valley. Beyond the railroad is a low ridge of Rock River dolomite, then the low ground occupied by the ball grounds. Beyond this a wooded hill, with abundant outcrops of Morgan Corners dolomite, dipping steeply to the east on the western side, but becoming less steep going eastwards. Nearby outcrops show that the ball grounds are underlain by Strites Pond limestone. Hence there must be a fault along the western edge of the wooded hill, cutting out the Wallace Creek limestone. (See mss. fig. 4a).

Similarly the apparent vagaries in the distribution of the Wallace Creek and the Morgan Corners for three miles north of Philisphurg call for explanations. Half a mile or

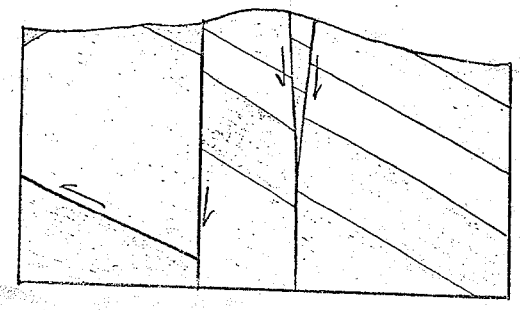
Fig. 8

a



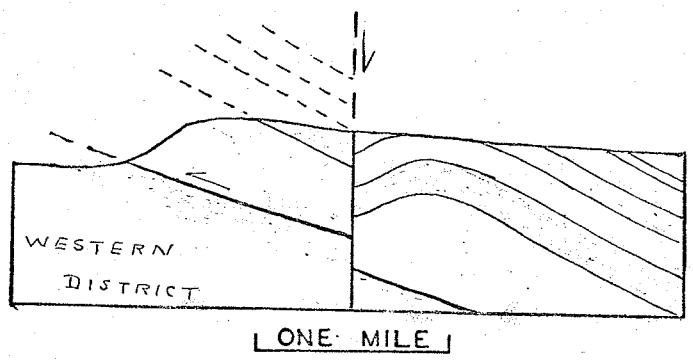
SECTION FROM PHILIPSBURG EASTWARDS

b.



ENLARGEMENT OF ABOVE TO SHOW MANNER OF FORMATION OF THE "SLIVER" OF WALLACE CREEK

c.



SECTION ALONG INTERNATIONAL BOUNDARY LINE

LEGEND

LUKE HILL HASTINGS CR. WALLACE CR. ROCK RIVER

NAYLOR LEDGE MORGAN SOR. STRITES POND BERVILLE

so southeast of Philispburg is a complication in which the Strites Pond and Wallace Creek strike into the Morgan Corners dolomite, and northwards of this are "slivers" of the Wallace Creek within the Morgan Corners. A fourth locality occurs along the International Boundary a mile or loss from the Lake. There Morgan Corners and Strites Pond lie side by side although the Wallace Creek is present in an adjacent anticline to the east. Faulting is the only possible explanation for these stratigraphic discrepancies.

In each of these cases the anomalous stratigraphic successions can be resolved by the presence of a strike-wise normal fault, with downthrow on the east side; the only complication not thus explained is the repetition of the Rock River dolomite just east of Philipsburg. Here the abnormally high dips of the Morgan Corners dolomite are due without a doubt to drag along the fault, and the Rock River dolomite is probably folded into a shallow syncline. Under this interpretation the ball grounds would be underlain by the Strites Pond limestone, but by a narrower strip than to the north. Other minor folds complicate the succession in the border fault outcrop, but here this folding is a combination of shallow anticline and syncline and occurs to the east of the fault. These relationships are all shown in the accompanying figures.

In the vicinity of Morgan Corners, where the strikes turn towards the northeast and where an anticline, which we will call the Morgan Corners Anticline, first appears, there is still a greater local complication. Here a block of the St. Armand limestone, a mile long and a quarter of a mile wide, occurs along this limit of the folded rocks, bounded on the southwest by Rock River dolomite and Strites Pond limestone, on the northeast by Naylor Ledge limestone and Hastings Creek limestone, and to the southeast along the strike, by the Morgan Corners dolomite. Hence all boundaries must be faults, and it might appear that this fault block consists of part of the St. Armand formation which reached its position by means of a normal fault breaking down the western limb of the Morgan Corners anticline. However the great complexities in the dips indicate a more strenuous experience. Not only is the St. Armand block much contorted, but the Strites Pond limestone, Wallace Creek limestone and Morgan Corners dolomite too are crumpled with folds of very small dimensions relative to the main folds. These complications suggest rather that the St. Armand limestone on the western limb of the Morgan Corners Anticline was grounded on the main thrust plane, and that a secondary thrust developed, now the southeast boundary of this St. Armand block, carrying the lower strata over the St. Armand, both suffering deformation in the process.

Another fault striking about 135°, cuts across the Philipsburg block about 10 miles northeast of Morgan Corners.

Beyond the vicinity of Bedford only three formations outcrop, the Basswood Creek shale, the Mystic limestone conglomerate and the Stambridge shale. The two shales are hardly distinguishable, so that the prominent outcrops of the Mystic limestone conglomerate are all we have to guide us in unravelling the structure. This formation, is first seen southwest of Rosenberg, where it outcrops on both limbs of the St. Armend syncline. Its outcrops on the west limb northeastwards are very few, but upon crossing the axis of the Morgan Corners anticline outcrops are more satisfactory and it continues around the expression of that anticline, doubles around the neighboring syncline, and on the west limb of which it may be seen fairly continuously for five miles or so, the last outcrop being at the end of a private road leaving the main Bedford-Farnham road a mile and a half north of Mystic.

At Mystic Village this formation is repeated three times across the strike. The structure here is without doubt due to a series of normal faults which repeatedly bring the stratum down to the present erosion surface.

In review then, the Philipsburg Block consists of several formations folded into open anticlines and synclines,

except the incompetent shale beds at the top which have been contorted extensively. It has been brought against the "unfolded" rocks to the west by a thrust fault, and is itself covered on the south by the Pigeon Hill Block and further northeast by the Oak Hill Block. At the northernmost end of the Philipsburg thrust in this area there emerges from beneath the Philipsburg Block still another, the Granby Block.

The Pigeon Hill Block. Lying upon the Philipsburg Block is a second thrust slice which we have designated the Pigeon Hill Block. On the west this is in contact with the Philipsburg Block. On the east it is covered by the Oak Hill Block of Lower Cambrian rocks. ~~The contact between these two latter forms the boundary of this report.~~

The strata of this block are similar to those of the Philipsburg Block in one respect only. The lower ones are competent dolomites and limestones, the upper ones shales. In age there appears to be little correspondence.

The structure of the competent formations is a very flat anticline, along the crest of which the oldest member the Milton dolomite, is exposed (a lower formation, the Mallett dolomite, is common south of the boundary line, but is present in Canada in one small outcrop only).

A higher formation, the Highgate limestone, shows, by its tendency to sweep around the northern end of the Mallett, the anticlinal nature of the latter, whose dips are very shallow, rarely exceeding 15°. To the east of the Highgate is a wide expanse of shales here referred to the Georgia. Although these shales here and there contain limestone beds, on the whole they are essentially similar to the Mystic shales to the north. Hence the precise boundary between this and the Philipsburg Block cannot be accurately drawn where the shales of the two blocks come together. The course of the boundary as shown on the map is explained on page .

Between the Milton and the Mallet in Vermont there lies the Colchester shale. This is missing in Canada, but the junior author (1930) has mapped its extent in the adjacent part of Vermont and from the areal distribution there faults are indicated whose probable continuations into Canada are shown on the map. Because of the absence of the Colchester between the Milton and the Mallet in Canada the boundary between these two formations is also drawn as a fault.

A most interesting structural relationship between this block and its surrounding is shown in the vicinity of Rosenberg. There, the heavy-bedded Milton dolomite has overridden the St. Armand limestone. The latter is both

thick and thin-bedded. Just north of the Grove Hill Farm house (about one and a half miles N.N.E. of St. Armand station) a limited but actual contact between the dolomite and the thin-bedded limestones is exposed. At the contact the limestones and dolomite are ground together, forming a crush-breccia, in which the fragments seldom exceed six inches in length by two or three inches in width. On the western side of the thrust the thin-bedded limestones and shaly strata stand almost vertically and are in some places broken and disturbed to a depth of 20-25 feet below the approximate position of the thrust-plane. About 30 feet to the east of the spot where the actual contact was observed, thin-bedded limestone shows up through a small area of drift, and as it lies east of the thrust trace, constitutes a fenster, and thus indicates that the fault is low angled. In one place, however, the contact between the Milton and the St. Armand is nearly vertical. This implies that subsequent to the thrusting readjustment by means of normal faulting took place.

Beginning one-half mile north of this locality, and continuing around the northern end of the dolomite to Rosenberg, is a brecciated zone varying in width, as exposed, between zero and 500 feet or more across the strike. This zone is composed of large masses (some of them being 100 feet long or so) of massive dark and light gray limestone

of the Beekmantown (St. Armand), intermingled with smaller quartzite and dolomite blocks of the Lower Cambrian formations (Milton and possibly Mallet). This might be called a giant-breccia zone. Within this zone are "layers" of the dolomite, standing almost vertically, which have caught up between them thin slices resembling the thin-bedded limestone and shaly strata previously mentioned, these latter again appear on the western side of the brecciated zone, lying, to judge from their dips, beneath that zone.

The greatest width, across the regional strike, of this brecciated zone is ~~33 chains~~ 2200 feet, so that for not much less than half a mile the thrust surface remained at about the same elevation. This is one of the best evidences we have for flatness of the thrust plane. Three fensters of the St. Armand, the largest ~~20 chains~~ ½ mile long, may be seen near the road leading south from Rosenberg.

The Granby Block. Little can be said of this block, for but the tip of it enters our area. Its rocks are Sillery slate, continuous from this place to and beyond Levis. From the northern limit of our area this block, bounded by what we shall call the Granby Block Thrust. When its course northwards shall be better known an appropriate name may be given.

General Relationship of the Frontal Thrust. It is a not uncommon conception that from Gaspe to the Hudson River there exists a single thrust fault, somewhat interrupted, but essentially continuous, bounding the folded Appalachians from the unfolded rocks to the west. Nothing could be farther from observed or inferential truth. This misconception has resulted largely from the adoption of the name "St. Lawrence and Champlain Fault". An alternative designation, "Logan's Line", is more in harmony with the facts, which appear to be as follows:- Between Gaspe and the international border a line, by no means continuous, can be drawn which separates mountain-built folded rocks (Quebec Group of Logan) on the east from the unfolded rocks on the west. This "line" is in places a thrust, in others a later normal fault. In the limited region north and south of the international boundary the "line" is made up of at least three different thrusts. The futility, then, of designating this limit as a single fault and giving it a name which should be applicable over its entire length of several hundred miles should be apparent. Observations then show that this line has no structural homogeneity, although as a boundary of great value it has important reality. Logan's line is a very satisfactory designation, doing honor to the man whose labors established this great line of separation. All other names should, in our opinion, be restricted to component parts.

IGNEOUS GEOLOGY

There is no special problem or significance attached to the igneous aspect of the geology which is manifested by five dikes only, two near the eastern margin of the Lacolle sheet, three within the Sutton sheet. Four of these approximate the composition of the "Camptonite" dikes so common around the Monteregian Hills and doubtless are to be related to the Monteregian petrographic province, though not obviously related to any one visible magmatic mass. The fifth is a medium grained syenite, similar in many respects to the syenite of Brome Mountain only three miles away and indubitably genetically connected with that magma. We may say then that the dikes of this area are all offshoots of Monteregian magmas.

Throughout the remainder of the Sutton sheet, ~~and in the Memphremagog sheet, except in the vicinity of the Stanstead granite,~~ dikes are rarities. ~~Even the Sutton Mountains with their pneumatolyte type of metamorphism contain but five or six dikes.~~

HISTORICAL GEOLOGY

We are dealing in this area with four separate sedimentary series, all coming within the Cambrian and Ordovician periods. The ages of the various component members, as worked out from their fauna and other considerations are indicated on the table opposite page . All of the rocks occuring in this area are marine, except possibly the wind blown sand bed at the top of the Potsdam. However, it will be seen at a glance that sedimentation was not continuous in any of the three divisions concerned, and not only that but rarely were sediments being deposited in two divisions simultaneously (Upper Chazy, Upper Ozarkian), and at only obe time were all three subdivisions submerged (Lower Ozarkian).

The four divisions mentioned above have already been described under the following headings:-

1. Western District
2. Philipsburg group of the Eastern District
3. Pigeon Hill group of the Eastern District
4. Granby group of the Eastern District

The rocks of division 1 are typical of the succession throughout the northeastern part of the Interior Basin of North America. Its beds are continuous to and beyond Quebec City on the one hand and into New York State and Ontario on the other. ~~This was an area characterized by vertical deformation only indirectly~~

~~on account of the overriding~~ folded Appalachians. The rocks of divisions 2, 3, and 4 are typical of the Appalachians from the points of view of structure and sedimentation. Their several formations were laid down in what has been called the "Levis Channel", a through-going sea-way stretching along the northeastern part of the Appalachian belt. In contrast to the more stable "Chazy Basin" in which the rocks of the Western District were deposited, this channel was relatively mobile. Sedimentation progressed irregularly throughout it. Local warpings separated sub-channels in which independent sedimentation progressed. Although this was, too, a characteristic of the Chazy Basin to a minor degree, it was the dominant note in the Levis Channel.

As defined by Ulrich and Schuchert (1902, p. 638) the Levis channel extends froms New Jersey to Newfoundland, being bounded on the west and northwest by the "Appalachian valley barrier or fold", and on the east and northeast by the "Green Mountains barrier", ~~while~~ parallel with but shorter than the Levis channel, and immediately northwest of the Appalachian valley barrier, lies the Chazy Basin, with its typical Chazy deposits and fauna. Thus, the Levis channel and Chazy Basin respectively correspond in a general way with the "eastern basin" and "western basin" of Logan, who, at least as early as 1855, recognized that the present trace of the St. Lawrence and Champlain fault (he called it an

anticline) was a line of separation between two quite different sets of formations of about the same age. As mapped by Ulrich and Schuchert (1901), the "Appalachian valley barrier or fold" corresponds in geographic position with the St. Lawrence and Champlain fault trace. Quite obviously the fault itself was not the "barrier or fold", ~~(although it may have developed therefrom)~~, for it lies to the west of the original position of the barrier.

In ~~this area~~ the oldest formation exposed is the Mallet dolomite of Lower Cambrian age. In northwestern Vermont this is underlain by older formations, and, inasmuch as the lower part of the Mallet is cut off by a thrust it is reasonable to assume that the earlier history of northwestern Vermont is not dissimilar to that of our area. In discussing Cambrian stratigraphy of Vermont, Keith wrote as follows (1923, p. 112):- "Land lay near at hand in the Adirondack region and its extensions of those days to the north and south.....East of this lay the Lower Cambrian sea, its western margin directly in this area and its eastern shore at a considerable but unknown distance east of the Green Mountains.

"The position of the strand in this region is well shown by the Monkton quartzite, whose red muds and sands give plain evidence of subaerial deposition, and whose occasional

marine fossils show incursions of the sea. At the same time the clean sorted sands of the Cheshire quartzite [in the Eastern Sequence of Keith] with a few marine fossils were originally deposited many miles further east under the clean sea water .....

"A similar plan of the land and sea is recorded in the Winooski marble, especially in its topmost quartzite layers which duplicate the Monkton. By later formations, the Mallet and Colchester, deeper waters are shown, but terrigenous beds are numerous, and intraformational conglomerates show that the sea waters were very shallow from time to time and that there was even strong and local removal of the Mallett dolomite. At the end of the Colchester the land was uplifted and sub-aerial erosion of this region began".

Thus at the beginning of recorded history in this area we envisage a wide trough of marine water with one strand east of the Sutton Mountains, the other without question to the east of any modern outcrops of the Milton-Mallet group. These rocks have, in common with all of the strata of the Eastern Series reached their present position by thrusting from the east. There is no way of computing the amount of movement, possibly only a few miles, possibly a few tens of miles. Inasmuch as neither Lower, Middle nor anything save Uppermost Cambrian is found in the undisturbed strata of the

Western District, that area was probably doubtless land during the greater part of Cambrian time. The Levis Channel therefore probably had its western shore line several miles to the east of the present boundary thrust, the presumption being in favor of the larger of the two suggestions given above. Even so this trough would have been fifty miles wide at least, and not improbably twice that. Its western shore was low with, as Keith suggests, subaerial deposits bordering it which occasionally were submerged. Its eastern border is more problematical. Further to the east thick clastic sediments of Lower Cambrian age occur which show that high land existed there at that time. Of this bordering land mass little direct evidence now remains and none of the sediments except the later slates seem to be related to it.

Following the erosion period noted by Keith submergence again occurred with a repetition of Mallet conditions, for the Milton is distinguishable from the Mallet only with difficulty. This was a submergence of long duration, for the Milton is 700 feet thick, but at no time was the sea deep, for cross bedded sandstones, arenaceous dolomites and conglomerates occur throughout. At the end of the Milton, that is at the close of the Lower Cambrian emergence again occurred and continued through the Middle Cambrian and part of the Upper Cambrian. During this time the St. Albans shale and Mill River conglomerate formations were deposited further south,

followed, as is the Milton in our area, by the Highgate limestones. The St. Albans shale is possibly a result of the shallowing of the sea and may have been deposited in our area only to be eroded upon complete emergence. The Mill River conglomerate appears to be a basal conglomerate unrepresented north of the boundary line. Submergence in Upper Cambrian (Lower Ozarkian) time brought about the deposition of the Highgate limestones whose basal beds are unknown in our area. The rapid alternations of thin beds of limestone and shale in the Highgate suggest that it was formed near enough to the strand to be continually affected by climatic or physiographic rhythmic cycles. Keith has suggested that glacial conditions were responsible for this, which, however, seem very unlikely.

Prior to the deposition of the Highgate, while the Levis channel region was still emergent, the Potsdam sandstone of the Western District was deposited. The Potsdam sea was probably shallow, to judge from the common occurrence of cross-bedded deposits and from the absence of rigorous sorting among the sand grains. It may be that during some part of Potsdam time the Levis and Chazy basins of deposition were connected; for the Potsdam is found at East Shoreham, and, if the correlation of the Rock River dolomite, the lowest formation of the Philipsburg ~~series~~ group, with the Little Falls is correct, the Potsdam may underlie that ~~series~~ group.

It then appears that at the close of the Cambrian the entire region became emergent. During this time the sands of the Potsdam began to be reworked by the wind and possibly the Sillery shale began to be deposited as a sub-aerial marginal sediment. The Philipsburg Basin was the first to be submerged in Ordovician time (at the beginning of Upper Ozarkian time) and thenceforward for the remainder of the Ozarkian it remained under water with only minor unconformities to point to slightly oscillating conditions. The Pigeon Hill Basin too was emergent between the deposition of the Highgate and the Georgia, and remained so probably until the beginning of Hastings Creek time, although there is some reason for thinking that the deposition of the Georgia shales began rather earlier. These Georgia shales, the equivalent of clear water limestones to the west, clearly point to a land mass to the east that was undergoing decomposition and erosion and at the same time rising. This elevation filled the nearby seas with silt and mud, which however was not abundant enough to modify the dominantly calcareous sediments in the western part (Philipsburg Basin) of the trough (a second and later uplift took place in the Upper Chazy and later, resulting in the deposition of the Mystic shales). Following the formation of the Georgia shales we have no further record of sedimentation in the Pigeon Hill Basin, though it is likely that shales were continuously deposited there throughout the

Ordovician. The Chazy Basin was dry at this time, for no equivalent beds occur in the Western District so that at this time water was restricted to the geosyncline itself, muds being laid down on the east from an unknown shore-line, limestones (Luke Hill) in the clear central part, and no evidence of the western margin, except that it was within the present area of the folded rocks.

Although in the Philipsburg Basin there is a very full development of the Upper Ozarkian beds, this series was not deposited in a continuous sea. There was a period of uplift and erosion between Strites Pond and Wallace Creek time; a second between Morgan Corners and Hastings Creek time -- this being more pronounced than the first, and marked by a heavy conglomerate, as well as by direct evidence of erosion; a third between Hastings Creek and Naylor Ledge time; and a fourth between Naylor Ledge and Luke Hill time, this being very well marked by erosional features. These are proved by true unconformities, representing time breaks of considerable duration. Less pronounced oscillations are recorded in numerous layers of intraformational conglomerate, by thin beds of shale and thicker beds of sandstone interstratified with the dominant limestones, and by minor unconformities and cross-bedding.

Following the submergence which led to the deposition of the Luke Hill formation, this whole region, with probably

most of the Champlain Valley, was raised above sea-level, during Lower and Middle Canadian time. During Lower Canadian time the Mohawk Valley region may have been submerged and the Tribes Hill limestone deposited. Marine conditions may also have held sway then along the western slopes of the Adirondacks, where formations occur which are correlated with the Tribes Hill. There is nothing in the Champlain Valley which can be correlated with the Tribes Hill, and no formation there is definitely referred to the Lower Beekmantown.

Marine conditions became relatively widespread in the Champlain Valley and St. Lawrence region in Middle Beekmantwon (Middle Canadian) time, when the Ogdensburg and related formations on the western side of the Adirondacks, the Beauharnois formation of Quebec, and "Division C" of the Champlain Valley "Beekmantown succession" were deposited. Neither in the Eastern District of our area, nor in the Levis channel area as a whole, is there any certain record of the Middle Beekmantown; so that this area was probably above sea-level at that time. In Upper Beekmantown time conditions were reversed in this area, for the Western District was raised above sea-level, while the Philipsburg Series was submerged. This depression resulted in the formation of the Solomons Corners, St. Armand, Corey, and Eaglewood Creek formations. The sedimentary evidence indicates that, on the whole, the Upper Beekmantown sea was clearer and more stable

than that in which the lower seven formations of the Philipsburg Series were deposited, although oscillations were common and occasionally drained the sea entirely from the region, as is shown by rare beds of intraformational conglomerates and several minor unconformities. The sea was probably most free of sediments during the uppermost Beekmantown when the very pure Corey limestone was deposited. A rise of the neighboring shore is indicated by the development of the Basswood Creek shales, just prior to what was another complete withdrawal of the sea from the Champlain Valley - St. Lawrence Region.

The events of Chazy time in the Western District have already been described in detail (see page). In the Philipsburg Basin, between which and the Chazy Basin a barrier had arisen, probably as far back as the Uppermost Cambrian, there are no beds of Lower or Middle Chazy, but that these existed is probable because of the abundance of boulders in the Mystic conglomerate with a Chazy (horizon as yet unknown) fauna. Because this conglomerate contains boulders at least as old as the lower part of the Lake Hill and at least as young as Chazy, it has drawn upon nearly 1,035 feet of beds that are elsewhere there. To make all of these available, no matter whether we consider the conglomerate marine, subaerial, or glacial, there must either have been very marked faulting or strong warping. The latter seems to be the more likely. A gentle tilt of 2° would have brought the entire Lake Hill to the surface

within seven and one half miles, and a tilt of 4° within four miles and a tilt of 6° within two miles. It may be that this warping was merely an expression of the broader uplift which was to cause so much erosion as to blanket all other previous formations with muds, the Stanbridge shales. These probably began in Upper Chazy time and continued certainly through Lower Trenton time and not improbably lasting to the close of the Trenton. In the meantime following the Upper Chazy, withdrawal of the sea occurred in the Western District, for there is no Lowville or Black River, or any trace of them in the pebbles of the Lacolle conglomerate. Submergence must have occurred during or at the close of the Lower Trenton, for although no beds of that age are known, the Lacolle conglomerate has abundant phenoclasts with its fauna. This means, too, that subsequent to the Lower Trenton both uplift and erosion occurred so that when the succeeding submergence took place the basal deposit was the Lacolle conglomerate. This is more probably Middle than Lower Trenton. From that time on marine conditions prevailed through Trenton time, into and possibly through the Utica, the Trenton and Utica beds being shales, which like the Georgia, and later the Mystic, represent the accumulations of decomposition products of the now rapidly rising Appalachia. How long the sea remained in this region we have no knowledge. But because Foerste (1916) has reported 2,515 feet of Richmond and 50

feet of Queenston along the Nicolet River, 50 miles north of this area, it seems probable that these periods should not have been represented here. Moreover, south of the Nicolet River, around St. Hyacinth, the Queenston is known to be 1,000 feet thick. In all probability then, at least the western part of this region remained under water throughout Ordovician time, the eastern parts becoming emergent somewhat sooner.

The problem of the time of the folding and thrusting is by no means a simple one. There is no evidence of more than one orogeny having affected the Eastern District. On account of the age of the beds concerned the folding must be post-Utica. However, there are but three orogenies of importance that have affected the Northern Appalachians; these are the Taconic at the end of the Ordovician, the Acadian during the closing stages of the Devonian and the Appalachian or post Pennsylvanian. Schuchert has marshalled the evidence for discounting the importance of the Appalachian orogeny except in Nova Scotia. Moreover, the folded rocks of the Philipsburg Series are cut by the dikes associated with Brome Mountain, whose age is unknown, but probably either Devonian or Carboniferous. There remain therefore the Taconic and the Acadian. Within the limits of the area here considered there is no conclusive evidence leading to the choice of either one, except that the complete lack of secondary cleavages,

folding, etc., might lead one to favor the Acadian. However, in the Memphremagog sheet, twenty-five miles east of the eastern border of our area the Ordovician shales were strongly folded and Silurian beds were deposited on their eroded surfaces. That folding is then Taconic. The Silurian and presumably conformable Devonian beds themselves were later folded in what was the Acadian disturbance. None of the folds of this latter orogeny are overturned, and exhibit no thrusting ~~characteristic~~. There seems therefore to be every reason for assigning the folding and thrusting of the Cambrian and Ordovician at Philipsburg, in large part at least, to the Taconic orogeny.

It would appear, then, that at the close of the Ordovician the deeper part of the geosyncline, or at least the eastern part, was severely compressed, with folding and thrusts induced by unbalanced pressure from the east causing ~~severe~~ crumpling within the incompetent beds but less crumpling and more lateral movement among the competent limestones and dolomites. The latter formed thrust slices, of which the Granby slice is one, the Philipsburg slice a second and the Pigeon Hill a third. Folding of the limestones and dolomites of these slices is largely a matter of drag by overriding fault slices. Such superjacent slices caused intense structural deformation amid the softer shales with which Ordovician sedimentation presumably closed, and they have been contorted beyond solution, largely because of the block

of Lower Cambrian beds which overlies the Oak Hill thrust.

In its maximum expression this thrusting probably extended several miles to the westward, at least we would say as far as the Richelieu River. In fact, the Tracy Brook fault may be an evidence of the collapse of the central part of the Lacolle quadrangle on account of the overloading consequent upon the transfer of thrust material westwards. In this case the Tracy Brook Fault would be late Taconic in age. We can, however, little more than hazard this suggestion. Schuchert, in the paper referred to above assigns the post-folding normal faults to the Acadian disturbances, instead of to the Triassic as urged by Keith.

The minor faulting so characteristic of the belt close to the line of outcrop of the Wallace Creek formation is in all probability closely associated with the folding. The faults can be looked upon as minor readjustments necessitated by the new arrangements of the masses, some of which were unstable, and reached stability by means of normal faults.

~~With this point in view, then~~ there is no direct record of any geologic happenings, save erosion, between the end of the Ordovician and the Pleistocene. Nevertheless, in Devonian time the Western District at least may have been submerged in the early Devonian for, as is well known, Helderberg limestone once existed in the igneous breccia

of St. Helen's Island. It is barely possible, too, that the Eastern District was occupied by a throughgoing Silurian and Devonian trough parallel to and not impossibly continuous with the Memphremagog trough. Schuchert (1932, p. 321) records a Devonian exposure in Vermont not far from the line of strike of the Philipsburg slice. Of these mid-paleozoic events we have no direct evidence. To be sure there are dikes belonging to Brome Mountain, and one of the Monteregian Hills, in this area, so that Devonian or Carboniferous vulcanism was probably a factor in the climatic and physiographic development of that time. Diking however was uncommon, and scarcely affected the rocks of the ~~present~~ area. Only five dikes have been recorded.

Erosion, long continued, reduced the local Taconic folds to a peneplain by Middle Silurian time after which they with possibly their veneer of Silurian and Devonian sediments were probably uplifted during the Acadian disturbance and again reduced to a peneplain long before the advent of glaciation. It is ~~improbable~~ probable that the present surface is only the last of a series of erosion cycles. ~~A discussion of this will be deferred to a treatment of the Sutton Mountains, in which the evidence is less meager.~~

Glaciation left little mark hereabouts. Nowhere is the drift known to be thick, and rock outcrops, in the

How do you know, certainly are few in most of the area, and absent at the Champlain Sea blanket it.

hilly Eastern District are very common. Solution and weathering have obliterated all traces such as striations on limestone outcrops. The habitual appearance of outcrops is governed, not by glaciation giving a roches moutonnées appearance, but by the bassett edge habit of gently tilted beds. Outcrops are in the Eastern District, then, characteristically steep on the west, gentle on the east. That this characteristic survived glaciation is good evidence of the weakness of glacial action. Local sand and gravel plains are not uncommon, and are much valued for their road building contents.

The Champlain submergence inundated this region in post-glacial time (Goldring, 1922). Fossils of this submergence occur over the area in several places. The retreat of this sea left the surface much as it is now and inaugurated the present cycle of river erosion.

ECONOMIC GEOLOGY

The economic products of the area of this report all belong to the non-metallic group. They are as follows, approximately in the order of their present day importance.

1. Limestone for building nad ornamental purposes.
2. Limestone for the manufacture of calcium carbide.
3. Sand and gravel for road metal.
4. Crushed limestone for road metal and fertilizer.
5. Slate.
6. Peat.
7. Marl.

1. Limestone for building and ornamental purposes. The only rocks being worked at the present time for these purposes are the limestones of the Strites Pond and Wallace Creek formations of the Philipsburg Series. A quarry has been opened in each of these formations in Philipsburg. The main, or larger, quarry is near the top of the Strites Pond formation, whereas the other, about 300 feet southeast of the main quarry, is near the base of the Wallace Creek formation. Both quarries are now operated by the Wallace Sandstone Quarries, Ltd. They were formerly under the control of the Missisquoi-Lautz Corporation, Ltd.

The smaller quarry is in what is locally known as "black marble". It has been opened to a depth of about 15 feet through thin-bedded fine-grained, black limestones, interstratified with thin seams of shale. It measures about

45 feet in length, that is, along the strike of the beds, and 30 feet in width.

The following description of the larger quarry is taken from Parks*, who gives in his report a plan to scale of the company's property, detailed descriptions of various kinds of marbles obtained, and an account of the equipment used.

"The property of the company consists of 317 acres; 160 acres in the parish of St. Armand West, and 157 acres in the village of Philipsburg, Missisquoi County.....Locally the rock consists of a series of limestones more or less metamorphosed into marble.....While much of the stone might be considered marble the more desirable portion is found in a belt about 1000 feet wide near the eastern side of the property".

"The quarry is at present about 500 feet long and 100 feet wide; it has been sunk through the following beds:-

"5ft. -- Grey stone only occasionally used.
5 ft. -- Grey stone only occasionally used.
4 ft. 6. in. -- Grey stone only occasionally used.
11 ft. 6 in. -- Solid bed of mottled stone.
3 ft. -- Vert gris) in one bed
1 ft. -- Dark grey)
3 ft. 6 in. -- light grey

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* Parks, W. A. Report on the Building and Ornamental Stones of Canada, Volume III, Province of Quebec. Canada, Department of Mines, Mines Branch, pp. 212-219, 1914.

3 ft. 6 in. -- Green veined stone; cut parallel to the bedding it is known as 'regina' and vertical to the bedding as 'rex'. The lower six inches which is of a darker green colour is called 'emeraldo'.
3 ft. 6 in. -- Sovereign grey.
1 ft. -- Seagreen.
9 in. -- Vert rose.
2 ft. -- Hard bed, not used.
3 ft. 6 in. -- Bolder grey.
5 ft. -- Silver grey.
1 ft. -- Regale } in one bed.
2 ft. -- Dark grey }
3 ft. 6 in. -- mottled dove.

"Core drills show that grey and greenish varieties continue to a depth of eighty feet or more.

"The chief joints run with the strike (a little east of north) parallel to the long diameter of the quarry. These fractures have caused the rejection of considerable material, but as the quarry increases in depth, they are found to become much less frequent.....

"The quarry is sunk deeper at the southern end and the various beds are left exposed as a series of steps. This method makes any bed accessible in case a large order is received for that particular variety. Good flat floors are presented as successive layers are removed; these floors slant about 20° to the east in accord with the dip of the beds".

According to the information supplied to the writers by T. S. Allen, manager of the company, the yearly production during the past twelve years has been 30,000 cubic feet. Mr.

Allen writes; "In recent years, architects have had access to the foreign marbles of Europe and these have been used in large quantities for decorative purposes, but for utilitarian purposes, such as toilets, floors, wainscotting to corridors, Missisquoi Marble has been favoured and has been greatly in demand".

According to Parks (op. cit., pp. 72-76) stone for building purposes was previously obtained from the Chazy limestones on the western side of the Richelieu River (Grande Ligne and Legeault quarries). The lithology of these rocks has already been given in some detail, and is therefore not repeated here. Parks writes as follows:

"Stone for building and other purposes has been procured in this area for many years. Formerly the output found its chief application in local buildings but of recent years a large amount of crushed stone has been shipped to Montreal and other points.....Certain parts of the Grande Ligne beds are of reddish colour and coarse crystalline grain and would make a creditable marble." None of these quarries have been operated for years.

2. Limestone for the manufacture of Calcium Carbide.

Calcium carbide is produced by heating pulverized lime rock and coke in an electrical furnace. The purest limestones are the most desirable. More than one per cent magnesium or a trace of Phosporous render a limestone unfit for the purpose.

Two exposures in the Lacolle area have been found entirely suitable for this purpose. Quarrying was carried in for several years in limestone which is part of the St. Armand formation at about half a mile north of Morgan Corners. Operations here were discontinued in the latter part of 1928, because the rock then being met with was unsuitable on account of a high percentage of SiO_2. The equipment was transferred to a new quarry site about two and a half miles to the northeast. The old quarry was operated by the Canada Carbide Co., Ltd., until 1926, when that company's interests were brought out by the Shawinigan Chemicals Company, Ltd. It is the latter company which operates the new quarry to the northeast of Morgan Corners.

The "carbide rock" of the abandoned quarry is a very fine-grained, massive, light gray limestone, frequently mottled with spots of white calcite. Bedding is very difficult to determine, but can be distinguished by slight changes in the color of the rock. This limestone is exceptionally pure, as is shown by the following analysis*:

Insoluble mineral matter.....	0.28%
Ferric oxide.....	trace
Alumina.....	0.04
Calcium carbonate.....	98.93
Magnesium carbonate.....	1.07
	100.32

* Goudge, M. F. - Prelim. Report of the Limestones of Que. and Ont. Canada, Dept. of Mines, Mines Br., No. 682, p. 12, 1927.

The quarry is about 1,300 feet long and of varying width up to 200 feet. It had been opened to a depth of 60 feet or more before being abandoned.

The new quarry, northeast of Morgan Corners and a mile and a half southwest of Bedford, is in the limestone of the Corey formation of the Philipsburg Series. Like the "carbide rock" at Morgan Corners this limestone is very pure, containing about 98 per cent calcium carbonate. Recent analyses made by the operating company show $CaCO_3$ 97.7 per cent, with Fe_2O_3, SiO_2, and $MgCO_3$ more or less equally divided in the remainder. Alumina is present in only a trace. Although it is very fine-grained, it differs from the rock of the old quarry in being generally darker in color and in being very fossiliferous; also, certain layers of the rock have a very considerable content of quartz sand. This part of the formation is unfit for the carbide process. At this quarry a crushing plant has been established, and the stone is now crushed and partly pulverized before shipment to Shawinigan Falls, thus greatly reducing the cost of transportation. About 50 men were employed here in the summer of 1929.

According to a personal communication from the general manager of the company the product is almost entirely devoted to the carbide process. In spite of the prevailing conditions at the time of writing (1932) there has been shipped

from the new quarry annually from 500 to 1,000 tons of agricultural lime, from 3,000 to 5,000 tons of crushed stone for road material, and 100,000 tons of limestone for the carbide process. The last mentioned product is shipped to Shawinigan Falls, Que.

3. Sand and gravel for road making purposes/ Glacial and post-glacial sand and gravel are widespread over this area and are more commonly used than crushed rock for road metal. The reddish color of the roads in the vicinity of Cowansville, Sweetburg and Dunham, is due to the abundance of pebbles of red Sillery slate in the gravels. The Sillery slate outcrops widely north of this area around Granby.

4. Crushed limestone used as road metal and fertilizer. Since the establishment of a crushing plant by the Shawinigan Chemicals Co. at their quarry near Bedford, much of the waste rock has been used as road material (mainly as surfacing), and the finer, or pulverized, rock has been sold for fertilizer. Production figures are given above.

5. Slate. At Mystic there is a quarry in slate of good quality, and apparently quantity enough to repay extensive and intelligent operation.

The rock body lies west of the Philipsburg thrust over which the beds of the Philipsburg Series passed, the

movement and the accompanying pressure imparting to it the slaty cleavage. At the same time, these rocks, (Iberville shales), were folded, but in contradistinction to the crumpled contortions characteristic of the overriding Stanbridge slates, the Iberville rocks maintained their structural form almost perfectly.

At about the close of the World War quarrying operations were begun, aided by local capital and enterprise. For a variety of reasons the venture was not successful and after about three years operations ceased entirely. Later, Mr. Milward of Cleveland, purchased the property, but has so far not carried on any work.

The present pit, cut across the strike, is fifty feet long, 20 feet wide, and at least 20 feet deep, at present probably half filled with water. The rock is cleaved into thick and thin bands, with interstratified limestone lenses, and the whole is folded into a very apparent syncline. Some of the slate from lower levels shows very high dielectric properties, and appears to be suitable for switchboard purposes. Macroscopic examination discloses no pyrite, nor is there any appreciable discoloration of the product.

Peat. In the northeastern corner of the quadrangle, between St. Alexandre d'Iberville and Ste. Sabine, is a muskeg-like swamp. Drainage ditches through the swamp show a layer

of low-grade peat, one and a half feet thick, immediately below the surface. The peat is underlain by black soil, rich in organic matter. Between Ste. Sabine and Notre Dame de Stanbridge, Morphion Creek, which drains southward from the swamp cuts through sand and gravel and then through clay into a peaty substance.

The swamps along the western margin of the quadrangle also contain peat, but the thickness of the deposit is not known. Apparently this deposit is the eastern limit of a wide area to the west and north that is underlain by peat, for Logan (1863, p. 782) writes: "On the south side of the St. Lawrence, there is a large area occupied by peat on the west side of the river Richelieu. It covers portions of the seigniories of De Léry and Lacolle, and of the townships of Sherrington and Hemmingford, embracing perhaps fifteen or twenty square miles. This area is drained in part by the Lacolle River. It has not been carefully examined as yet; but it contains in some parts, particularly it is said in Sherrington, a very great thickness of peat. Of two specimens from this township, one, which was dark colored, fine grained, compact, and so heavy as to sink in water, gave only 3.53 per cent. of ash; while the lighter peat, from near the surface of the bog, yielded 4.66 per cent. of ash. Both of these are very pure; and the compact peat, which is remarkable from its great density, and its freedom from earthly matters, is particularly worth of mention".

Marl. A marl deposit is found around the margin of Strites Pond, south of Philipsburg. This deposit is described by Logan (1863, p. 766) as follows: "Marl..... appears all around the margin of a small lake, and probably covers between thirty and forty acres. Its thickness in some parts is seven feet. This marl....contains fresh-water shells, [and] rests upon a deposit containing marine shells, probably of post-tertiary age". As far as is known, this marl has never been used for agricultural or other purposes.

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APPENDIX

Report by Maurice Black upon thin sections of rock of the Eastern District.

Introduction. The lowest rocks described in the following notes consists of sandstones and dolomite rocks, characterized by an abundance of large, extremely well rounded sand grains. The absence of detrital feldspar suggests that the quartz grains had a long sedimentary history before they were enclosed in the limestone, and their almost spherical shape is characteristic of wind-rounded sands. There can be little doubt that the sand in the Lower Cambrian rocks and in "Division A" was derived only very remotely from crystalline rocks, but had been reworked from one sediment to another for a considerable time, and in its final condition had been rounded and winnowed by wind.

In "Division B" there is a significant change in the sand grains, showing that sediment from a new source was finding its way into the region. In the lower part of this division, traces of microcline begin to appear, and in the Luke Hill, both microcline and oligoclase are for the first time abundantly represented in the sandy and silty beds. Further, the spherical quartz sand, characteristic of the underlying formations, is no longer found, and its place is taken by angular and smaller grains. Thus we have indications

that the crystalline rocks were now contributing directly to the sediment, and it is significant that this change in detrital minerals coincides with the unconformity which underlies the Luke Hill.

Two types of dolomitization can be recognised in these rocks. Firstly, there are fine-grained, well-bedded dolomite-rocks, which have the characteristic structures resulting from almost contemporaneous dolomitization; and secondly, there are more or less coarsely crystalline dolomite-rocks, which can frequently be related to fissures, fault planes, stratigraphical contacts, and other planes of weakness. In such cases the dolomitization took place after lithification, and the dolomite crystals may sometimes be seen veining a partially altered limestone; in other examples the magnesian solutions appear to have diffused more or less evenly through the rock.

Amongst the dominantly calcitic rocks, the calcite-mudstones and calcarenytes are of greatest interest. The calcite mudstone are extremely fine-grained and even textured rocks, usually of high purity. They were probably deposited as a fine-grained calcareous mud, resembling the "white marl" or "drewite" of the Bahamas. The stratigraphical relationships of calcite mudstones usually indicate deposition in extensive

tracts of shallow water under lagoon conditions (1), which not infrequently accompany slow transgression of the sea over an almost level surface of slightly older limestone.

The calcarenytes are sandstones in which the detrital grains are of calcite or dolomite, and not of quartz. As the sand grains and the matrix both consist of carbonate minerals, the calcarenytic structure is liable to be destroyed by recrystallization or by dolomitization, and the original "sandy" texture has doubtless disappeared from many calcarenytes as a result of these processes. Amongst the limestones described below, recognizable calcarenytes are found in the Strites Pond and the Corey; here the detrital grains invariably consist of calcite mudstone, and recrystallization of the matrix has, in some cases, blurred the outlines of the sand grains. Examples of calcarenytes with sharp, unrecrystallized margins, are provided by H. 193 and H. 198.

Description of Rock Types

Milton Dolomites and Sandstones

Slides 11-18
Figures 1-6

The standard lithological types in this system are crystalline dolomite-rock and dolomitic sandstone with extremely well rounded quartz grains. In addition to these characteristic rocks are several variant types caused by the presence of impurities, either original or introduced later, which have influenced the diagenetic change in the rock, and have consequently modifed the resulting texture.

Amongst the purer dolomites, Fig. 1 (slide 17) is a typical example of a rock of medium coarse grain, the average diameter of the grains being a little over 0.5 mm. There is very little quartz in the rock, and the dolomite crystals all tend to assume a rhombohedral shape, in spite of their being closely packed together. This tendency to form well shaped rhombohedra is even more strongly marked in specimens where there is an appreciable amount of fine-grained impurity, which has been pushed aside as the dolomite crystals grew, and thus allowed them to assume their characteristic form. (e.g. fig. 2, slide 15). In fine-grained dolomite-rocks which contain only small quantities of silica (e.g. slides 16 and 18), this mineral is found as small scattered grains, with

ragged outlines, and although the grains can in some cases be seen to lie along bedding planes, their original detrital shape is completely lost, no doubt as a result of corrosion. In such rocks, wherever grains of silica and dolomite come into contact, it is always the dolomite which shows its own crystal outlines at the expense of the quartz. In other instances, small, somewhat angular quartz grains, of the order of 0.05mm. in diameter, are present in considerable quantities, producing silty rocks in which the detrital grains are not corroded to the same extent as in the purer dolomites.

In strong contrast with the small, angular, quartz grains described above are the large, very well rounded sand grains of the dolomitic sandstones. These grains are mostly between 0.5 and 1.0mm. in diameter, and almost all of them consist of fragments of single quartz crystals, many of which ~~frequently~~ containing abundant needles of rutile. No feldspars appear to be present. Where the sand grains are not in contact, the rock takes the form of a sandy dolomite with the sand grains scattered along the bedding planes, and it seems quite possible that they were blown into the Cambrian sea by periodic off-shore winds. With an increasing proportion of sand grains, the dolomitic matrix is liable to be replaced by silica (see slides 12, 11; figs. 3 and 5), and all stages of silicification are represented, including pure quartzite with no trace of

dolomite left (e.g. slide 13, fig. 5). In most cases, the secondary silica is in optical continuity with the quartz of the detrital grains, and shows a tendency to form terminated prisms (slides 11 and 13, fig. 6) but in some specimens, the cement consists of patches of cherty silica.

Rock River Dolomite.

Slides 1-10
Figures 7-11.

The rocks of this division show a range of textures similar to that found in the Milton dolomites and sandstones, though the proportion of sandy rocks is very much less than in the underlying system. The Rock River consists of grey, coarsely crystalline, dolomite-rocks for the most part, but includes beds of a fine-grained rock composed of small, closely packed dolomite rhombs. In these finer grained rocks, the dark colored, carbonaceous impurities, where they are present are concentrated in the interspaces between the dolomite rhombs, throwing the latter into brilliant relief (e.g. slide 1, 9, fig. 7, 9). Every gradation is found between textures of this kind and a tightly packed mosaic of anhedral crystals, everywhere in contact, and often showing wavy outlines (slide 2). Most of the specimens are intermediate in texture (slides 3, 8, and 10; fig. 9). In these relatively pure dolomite-rocks, quartz is present in very small quantities only; where it takes the form

of detrital grains, these are extremely ragged in outline, and appear to have suffered solution during the dolomitization of the rock. In other instances, for example in slide 2, there are minute veins of quartz filling cracks; these appear to have been deposited after the dolomitization of the rock, since they truncate or cut through crystals of dolomite.

At some horizons in this formation, large, spherical, quartz sand grains are abundant, enclosed in an otherwise pure dolomite matrix. With an increasing proportion of sand, the rock passes into a dolomitic sandstone (slide 7, fig. 10), very similar to those found in the Cambrian. There are no feldspar grains, and nearly all the quartz grains are fragments of single crystals. The margins of the sand grains are not etched or corroded, and in some cases, secondary silica is found, either in crystalline continuity with the sand grains, or as a finely crystalline cement between them. Where all the dolomitic matrix has been replaced, an extremely pure quartzite results (slide 5) closely resembling the similar rocks of Cambrian age (see figs. 3 and 4).

In the non-arenaceous parts of the formation, secondary silica appear as chert, consisting of minute crystals of silica, enclosing similarly small grains of carbonate, some of which can be recognised as dolomite. Scattered through the chert are strongly zoned rhombs of dolomite (fig. 11). The dolomite

surrounding the chert has all the characters which result from secondary ("vein") replacement, and it seems most probable that the rhombs in the chert were formed during the early stages of dolomitization of an original calcite mudstone, producing strings of dolomite rhombs, comparable with those found in the partly dolomitized calcite mudstones shown in figs. 12 and 15. The silicification of the rock appears to have taken place later and to have acted selectively upon the calcite mudstone. Thus the chert nodules probably are pseudomorphs of residual patches of undolomitized limestone.

Strites Pond Limestone.

Slides; 11.E.5; 11E.10; 11.F.2; 11.F.22.
Figures: 12-15.

This is essentially a limestone formation, usually fine-grained and light colored. There is a development of dolomite near the base, but thin sections of this rock very clearly indicate that it is a replacement rock, formed by solutions entering the limestone through fissures; in some instances, indeed the dolomitization is clearly related to belts of shattered rock along fault planes. Petrologically, the dolomite is closely similar to the secondary dolomite at the top of the Rock River, and it seems highly probable that secondary alteration of the top of the Rock River and the base of the Strites Pond took place at the same time, which

must have been appreciably later than the lithification of the original limestones. There are no "contemporaneous" dolomites amongst the specimens examined from this division.

The following are descriptions of representative specimens from this division:

Calcite Mudstone, near the base of the formation, in the transition zone between A1 and A2. Fig. 12 and 13.

This rock has a smooth, conchoidal fracture, and consists of white or grey calcite mudstone, with strings and minute veins of dolomite intersecting them. Microscopically, it is made up of a fine grained ground mass of calcite, with a few grains of detrital quartz. The dolomite crystals are in the form of strong idiomorphic rhomboherdra, up to 1.0 mm. in diameter. They are quite obviously related to a network of cracks in the rock, and indicate alteration of the limestone to dolomite by solutions entering through fissures formed after the lithification of the rock.

Other specimens (see fig. 13) show spherical sand grains set in a matrix of dolomite. Although most of the sand grains are of quartz, there are others, of the same shape and diameter as the quartz grains, but consisting of dolomite in smaller and darker crystals. Most of these carbonate grains have suffered recrystallization, but others still retain their fine grained, carbonate mudstone texture.

Calcite-sand Limestone (Calcarenyte), 100 feet from the base of the formation.

This is a greyish white limestone, and although it is distinctly fine grained, it has a rough fracture quite unlike that of the rock described above. In thin sections, this interesting rock is found to consist of round grains of fine textured calcite rock, with the interspaces filled by a more coarsely crystalline matrix, contrasting sharply with the evenly fine texture of the sand grains. As the rounded grains show no signs of concentric structure, and are too fine grained to allow of their having been recrystallized, the possibility that the rock appears to be a calcite-sandstone, with detrital grains of calcite mudstone set in a cement of later calcite crystals.

Chert Limestone and Calcareous Sandstone, 100 feet from the top of A2.

(a) Calcite Mudstone. This is a fine-grained, white limestone, which encloses the chert nodules referred to below. There are irregular spaces in the fine grained rock, filled by coarser crystals of calcite. This is a texture frequently found in calcite mudstones, and appears to be connected with irregular shrinkage on lithification.

(b) Chert. In hand specimens the chert is black, but in thin sections the pigment is so finely disseminated that it gives the whole slice a pale brown color, and cannot be resolved into separate particles under the microscope. The rock consists of small, brown-stained crystals of quartz, and there are also patches of unstained silica, which appear to be filling cavities in the main mass of the tinted quartz. The pigment of the chert seems to have been precipitated with the silica, for it is absent from the few grains of sand which are enclosed in the chert, and also from the later veins and druses.

11.E.10.A.(c) Calcareous Sandstone. This rock contains two sharply distinct types of sand grain, set in a matrix consisting largely of calcite. The larger quartz grains average 0.5mm. in diameter, and are well rounded, but the smaller grains are sharply angular, and are nearly always less than 0.1 mm. in diameter. The presence of two distinct grades of sand in one sediment suggests that the sand was transported by two distinct agencies, and it is possible that the angular grains were water transported, whilst the almost spherical ones were wind borne. No feldspar was seen in the rock at all. Scattered through the rock is a dark mineral in well formed cubes; some of these show the brassy luster of pyrite, but the larger proportion of them are deep red in color, and transparent. The refractive index is extremely high, and it appears that the original cubes of pyrite have been pseudomorphed by hematite. In some grains the process is not complete, and part of the cube still retains the properties of pyrite. The groups of hematite and pyrite grains are usually surrounded by green stains in the carbonate minerals, possibly due to traces of ferrous carbonate.

A slice was cut to show the contact between this sandstone and the white calcite mudstone which underlies it. The actual line of contact shows a layer of secondary quartz coating the calcite mudstone and enclosing small detrital grains of quartz. Above this is a slight concentration of

hematite and pyrite, and of detrital grains of minerals of high specific gravity. They are all in very small grains, and include zircon, tourmaline)pleochroism pale brown-grey to black), and rutile.

11.F.2. Dolomitized Limestone in fault breccia zone Fig. 15.

The dolomite crystals in this rock are strongly colored, idiomorphic, and fairly large, being up to 1.5mm. in diameter. They show a strong similarity in their size, habit, and color, to the dolomite crystals in 11.E.5. They are usually closely crowded together, but in places they enclose patches of a fine grained calcite rock, with anhedra averaging 0.02mm. in diameter. This apparently represents the original rock which has been preserved from dolomitization, and is very similar to the undolomitized parts of 11.E.5. The whole rock has been subsequently shattered, and the cracks filled with coarsely crystalline calcite. No evidence was seen in the thin sections to show that the dolomitization also took place after brecciation, although the preservation of patches of calcite mudstone amongst such coarse dolomite crystals indicates that such may have been the case.

Morgan Corners Dolomite.

Slides 23-25; 12.D.30; 12.E.3
Figures 16 and 17.

This formation consists of fine grained dolomite-rocks. The crystals usually have a strong brown color, indicating the presence of ferrous carbonate in appreciable quantity. Dark, carbonaceous, impurities are frequently present, but have been pushed aside during the crystallization of the dolomite, so that they now fill the spaces between the rhombs.

Slides 23 and 25. Dolomite-rock. Figure 16. This rock is moderately fine-grained (average diameter 0.1 - 0.2mm.), and still retains traces of bedding, marked by variations in the quantity of black, carbonaceous matter and slight variations in grain size. Where there is an abundance of carbonaceous matter, the dolomite crystals stand out as very sharply defined rhombohedra.

12.D.30.(A) and Slide 24. Coarse Dolomite-rock. Fig. 17.

These are gray, sugary-textured rocks, consisting of large, closely packed crystals, with an average diameter of 0.5mm. The rock has very little visible impurity. The crystals, most of which show rhombohedral outlines, are brown in color, and show a slight tendency towards zoning, probably due to varying quantities of ferrous carbonate in solid solution.

12.D.30.(B) Calcite Mudstone. Patches of this rock are found within the grey crystalline dolomite-rock described above. It has a slightly larger grain size than the typical calcite mudstones, and there is a sufficient variation in texture to give a suggestion of bedding. Streaks of comparatively coarse calcite also run parallel with the bedding.

It seems possible that these patches of limestone are remnants of an original limestone formation which has largely been altered to produce the dolomite-rock in which they are now enclosed.

12.E.3. Dolomite-rock and Dolomitic Limestone. The rough weathering type consists of irregular patches of moderately fine-grained dolomite and calcite, the irregular weathering being no doubt due to the differential solution of these two minerals. The smooth weathering type is homogeneous and even grained, and appears to consist of fairly pure dolomite, with traces of secondary calcite in the joints only. A thin section shows a mosaic of somewhat pale and unusually clear dolomite crystals. The average diameter of the crystals is 0.08mm.

Hastings Creek Limestone

Slide 11.F.4.

This division consists of an interbedded series of

limestones, shaly limestones and dolomite-rocks. The specimen examined is a very fine-grained limestone, with the clear patches of larger calcite crystals which are characteristic of the finest grained limestones. The rock also contains detrital fragments of quartz and muscovite, and very rarely, a grain or two of microcline. Thus detrital foldspar makes its first appearance in this division, though in the specimen examined, it is by no means abundant.

Luke Hill Limestone

Slide 12.D.33.

To this division belong the ochreous-weathering, somewhat calcareous siltstones immediately above the unconformity For the first time, abundant feldspar is found amongst the detrital grains; the polished, spherical quartz grains characteristic of the beds below, are absent. This change in the composition of the sediment suggests that the material was now being derived more directly from crystalline rocks, and not from pre-existing, unmetamorphosed sediments, as presumably was the case with the underlying formations.

In thin section, the rock consists of angular and partly rounded quartz grains, with a varying amount of calcareous cement. Amongst the quartz grains are a few grains of microcline and plagioclase (oligoclase), usually a little better rounded

than the quartz grains. Along restricted planes of the rock are minute crystals which appear to be hematite, possibly pseudomorphs after pyrite. The same planes also show a sprinkling of zircon grains, extremely conspicuous because of their high refractive index, and a few chips of tourmaline, with a pleochroism from colorless to deep green. Rutile is also to be seen, but in much smaller quantities than either zircon or tourmaline.

Solomons Corners Limestone.

Slides 12.D.55 (A and B)
Figure 18.

Nodular limestone is the principal lithological type in this division, but there are also a few dolomite beds. Slide A shows a fine grained limestone, containing dark, carbonaceous streaks. The limestone is crossed by zones of shearing, along which the carbonaceous matter is concentrated, and the calcite is recrystallized into larger grains. Bordering the shear planes are belts of calcite and silica in parallel intergrowth. Most of the detrital grains appear to be of quartz, but there are also a few grains of plagioclase feldspar. Slide B is a fine grained calcareous sandstone with angular quartz and small flakes of white mica.

St. Armand Limestone.

Slides 12.D.49; 12.D.51 (A-C).
Figures 19 and 20.

This formation is mainly limestone, shaly at the top, and interbedded with dolomite at the base.

12.D.49. Calcite Mudstone. Figure 19. The hand specimens include samples of a gray calcite mudstone, and of a somewhat coarser limestone. Thin sections of the rock show it to be made up of small, well defined grains of carbonate, averaging 0.01 mm. in diameter. The texture of this fine grained rock is very even, but differs from that of the calcite mudstones of the Central and Southern Appalachians in the slightly larger diameter of the grains. The fine grained matrix encloses patches of coarser crystals, which have no well defined boundaries, and may well be the results of recrystallization rather than the infilling of shrinkage spaces. No fossils were found in the specimens examined.

Limestones of this texture (that is, consisting of closely packed anhedra of 0.01 mm. diameter) are found so frequently, and in such large quantities, in some of the older limestones, that Daly has argued that such a persistent texture must be significant of special conditions of deposition, and suggests that these limestones were formed as chemical precipitates.

12.D.51. Calcite Mudstone. Figure 20. Hand specimens show a calcite mudstone with strings of quartz crystals. There are occasional patches of the fine-grained, even matrix of 12.D.49, but all the sections agree in showing the bulk of the rock to be of rather uneven grain, with anhedra averaging 0.03 mm. in diameter. Traces of bedding are recognisable in thin sections of this rock, picked out by variations in the coarseness of the crystals.

Sediments filling "Potholes" in the St. Armand Limestone.

The unconformity above the Solomons Corners is characterised by an irregular and "potholed" erosion surface. The "potholes" are filled with a rather variable mixture of shells, fragments of calcite mudstone, and sometimes a little siliceous sand.

Slide A (fig. 21) shows a matrix of calcite and small detrital quartz grains, enclosing fragments of calcite mudstone and numerous fossils. The interior hollows of the fossil shells are filled with coarse calcite crystals; the tests themselves have been but slightly altered, though their thickness has, in some cases been increased by the growth of a layer of calcite crystals on the surface of the shell. Patches of the rock are dolomitized, and are full of small, clear, rhombs; these are rather inconspicuous amongst the small calcite crystals and quartz grains which make up the normal rock, but where they have been oxidized, they become at once noticeable, for they are sharply zoned with ferrous carbonate, which on weathering produces prominent bands of bright yellow, opaque limonite, concentric with the outline of the crystal.

Slide B (fig. 22). Consists of fragments of calcite mudstone and fossils, set in a matrix of clear calcite, free from non-calcareous minerals. The fossils are entirely re-crystallized, and the fragments of calcite mudstone appear to be slightly altered to coarser crystals round the edges.

Corey Limestone.

Slides 12.D.14 and 12.D.17.

The rocks of this formation are for the most part massive, light colored limestones. A few horizons have scattered sand grains.

12.D.14. Calcarenyte. This is a dark, fine grained limestone, with cylindrical bodies of coarse calcite, reminiscent

of some parts of the Lowville. Thin sections reveal small ovoid, even textured patches, 0.15mm. in diameter, made up of anhedra of calcite (0.01mm. in diameter); they are embedded in a more coarsely and irregularly crystallized matrix. It seems probable that the rock originated as a calcarenyte, with sand grains of calcite mudstone which have later suffered partial recrystallization. The rock is slightly dolomitized, the mineral occurring as zoned rhombohedra, and is related to a few thin cracks running through the limestone.

12.D.17. Calcarenyte. In hand specimens, this is a gray limestone, with quartz grains weathering out conspicuously at the surface. In thin sections the rock is seen to be a calcarenyte with considerably larger grains than 12.D.14, some of the grains being as much as 1.0mm. in longest diameter. The quartz grains reach a similar size; they are all intensely corroded, and many are surrounded by a radial fringe of calcite crystals. Fragments of fossils ar present, replaced by coarse calcite crystals.

Mystic Conglomerate.

Slides 12.C.30 and 12.C.45.

The following are lithological descriptions of boulders from the Mystic limestone conglomerate.

12.C.30. consists of a heterogeneous matrix, mainly dolomite, enclosing abundant isolated, well formed rhombohedra of dolomite, and numerous quartz grains. Most of the rhombs are dark centered, apparently due to the concentration of dark colored impurities.

12.C.45(A) is a dove-colored, fine grained limestone, intersected by irregular patches of larger crystals similar to those found in calcite mudstones. Parts of the rock show dark, oval shadows (in thin sections), strongly suggestive of a calcarenyte which has undergone recrystallization. The rock shows a considerable resemblance, in the finer details of its lithology, to the specimens from the Corey.

12.C.45(B) has a dirty calcareous matrix, enclosing dolomite rhombs and quartz grains. The grain size is slightly smaller than that of 12.C.30, but otherwise the two rocks are very much alike.

Horizon Uncertain.

(193). Calcarenyte. Figures 24-26. This rock consists of detrital grains of calcite mudstone, set in a matrix of more coarsely crystalline calcite. The "sand" grains are from 1.5mm.-3.0mm. in diameter, most of them being approximately 2.0mm. They are all extremely well rounded; the larger grains tend to be somewhat flattened, the smaller ones more nearly spherical. In its texture and structure this rock is strikingly reminiscent of the calcareous and dolomitic sandstones of the Cambrian, and of Rock River and Strites Pond. If this rock is a marine sediment it would seem that here, also, wind rounded sand grains have been blown into a sea under which lime-ooze was accumulating.

The detrital grains consist of an extremely finely crystalline, nearly opaque, ground mass, which is, in fact, a typical calcite mudstone. In this are embedded crystals of feldspar and quartz, which do not occur in the coarse matrix. They are quite clearly authigenic crystals which had already grown in the calcite mudstone before it was broken down by mechanical erosion to form carbonate-sand. The parent limestone of these sand grains does not appear to be represented amongst the rest of the specimens examined, for although authigenic feldspar has been noticed amongst them, no limestone enclosing similarly developed quartz crystals has been found. The feldspars are clear, rarely twinned, and have a refractive index agreeing with albite. They show sharp boundaries against the enclosing calcite. Similar crystals are known to occur in certain calcite mudstone formations; for example, in the Valentine formation of Central Pennsylvania. The quartz is in rather larger crystals, showing hexagonal sections; usually they are clear at the margins, and full of calcite grains inside, sometimes with a zonary arrangement, so that the crystal consists of several concentric shells of clear quartz, separated by partially silicified limestone.

The rock as a whole is intersected by a large number of parallel cracks, along some of which recrystallisation has taken place, giving the rock a deceptive appearance of being veined by secondary calcite.

This specimen is a critical one in the interpretation of the calcarenytes of the limestone formations under discussion. Not only does it provide an example of a limestone-sandstone with detrital grains entirely untouched by recrystallization, but the presence of authigenic feldspar and quartz in the sand grains, but not in the matrix, shows that the limestone from which the sand grains were derived had been lithified and somewhat altered internally before it was ground up to produce loose sand.

(198) Calcarenyte. Figure 27. This is another calcite sandstone, with detrital grains ranging from 0.5mm.-5.0mm. in maximum diameter. The rock consists of calcite mudstone grains embedded in coarser calcite crystals. Most of the grains are enclosed in one or two (rarely more) concentric layers of calcite, resembling the coats of an oolite grain. Outside these concentric coats, each grain is covered by a fringe of prism-shaped crystals of calcite, arranged at right angles to the surface of the grain, and the interstices are filled with clear, coarse, calcite crystals. The whole arrangement rather suggests that the spaces between the grains were originally open pores with no matrix in them, and that they were subsequently filled by calcite precipitated from infiltering water. Such structures are found in modern wind blown limestone sands where cementation by percolating water has had a chance to take place.

Some of the sand grains are compound, being themselves fragments of a pre-existing calcarenyte. In the earlier calcarenyte, however, the detrital limestone grains were embedded in a matrix of calcite mudstone resembling that of the grains themselves; thus the processes which formed the calcarenyte as we now find it, are not merely a repetition of those which produced the earlier calcarenyte which is now only found as small detrital grains, and the differences are sufficiently marked to suggest that one may have been deposited and cemented subaqueously, the other subaerially.

Detrital quartz grains, 0.1mm.-0.4mm., more or less well rounded, are frequently found enclosed in simple calcite mudstone grains; so that the limestone from which the sand grains of this specimen were derived, must have contained beds of (1) simple, pure calcite mudstone, (2) calcite mudstone with abundance of quartz sand, and (3) calcarenytic limestone. This is an association of limestones which might well be found amongst the members of the Strites Pond.