RG 122(A)

CHATEAUGUAY AREA, CHATEAUGUAY, HUNTINGDON, BEAUHARNOIS, NAPIERVILLE AND ST-JEAN COUNTIES

Documents complémentaires

Additional Files

Licence

License

Énergie et Ressources naturelles
Québec

QUEBEC DEPARTMENT OF NATURAL RESOURCES

Honorable DANIEL JOHNSON, Minister

PAUL-ÉMILE AUGER, Deputy Minister

GEOLOGICAL EXPLORATION SERVICE

ROBERT BERGERON, Director

GEOLOGICAL REPORT 122

CHÂTEAUGUAY AREA

CHÂTEAUGUAY, HUNTINGDON, BEAUHARNOIS, NAPIERVILLE and ST. JEAN COUNTIES

by

T. H. CLARK

QUEBEC

1966

E R R A T A

G.R. 122

PAGE					
5	par.	2,	line	23 -	"Lingulepis" should read: "Lingulepis minima"
15	"	4,	"	1 -	"necessary" should read: "accessory"
17	"	3,	"	11 -	"arbritarily" should read: "arbitrarily"
18	"	4,	"	7 -	"the south lay" should read: "the east lay"
24	"	1,	"	13 -	"composition, cementation of burial" should read: "deposition, cementation of buried"
28	"	1,	"	3 -	"Ordocivian" should read: "Ordovician"
28	"	4,	"	1 -	"Climatichnites" should read: "Climactichnites"
29	"	2,	"	4 -	"in the assemblages made" should read: "and the assemblages are made"
29	"	4,	"	4 -	"Pyrichnites" should read: "Gyrichnites"
34	"	4,	"	3 -	" - and upper" should read: " - an upper"
35	"	1,	"	8 -	"Hystricurus" should read: "Hystricurus"
39	"	4,	"	5 -	"Whitfieldi" should read: "whitfieldi"
39	"	5,	"	1 -	"cf. L." should read: "cf. L."
40	"	3,	"	4 -	"sp. anna" should read: "cf. H. anna"
41	"	1,	"	5 -	"Cryptozoön" should read: "Cryptozoön sp."
45	"	3,	"	6 -	"to band into" should read: "to bend into"
47	"	5,	"	5 -	"northerly" should read: "northwesterly"
49	Fig.	6A	legend	-	"Read A,B,C,D,E for types from bottom upwards
51	par.	1,	line	12 -	"mouth" should read: "south"
53	"	1,	"	12 -	"depositions" should read: "deposition"
55,	"	1		1 -	"Queenstown" should read: "Queenston"
57	"		"	14	and
62			"	14	"Byrne, E.W." should read: "Byrne, A.W."
61			"	18 -	"Nam." should read: "mem."
62	line 18	col.		2 -	"Hall, E.E." should read: "Hall, James"

CONTENTS

Page

MAP AND ILLUSTRATIONS

Map

Figures

Plates

CHÂTEAUGUAY AREA

Châteauguay, Huntingdon, Beauharnois, Napierville and St-Jean Counties

by

T.H. Clark

INTRODUCTION

REASON FOR UNDERTAKING THIS WORK

With the presentation of this report on the Châteauguay area the geological surveying of the St. Lawrence Lowland of Quebec is completed, save for parts of marginal map-areas. The Lowland, stretching from Quebec City southward and southwestward beyond Montreal to the Ontario and International borders, is an area of sedimentary rocks of considerable economic potential. The shales of the Utica and Lorraine Formations have been used in brick making, and hold a possibility of providing a source of bloatable shale for making light-weight aggregate. The Chazy and Trenton Limestone Formations have provided excellent building stone, and are extensively used today as aggregate, parts being pure enough to qualify as high-calcium chemical raw materials. Part of what has in the past been called the Potsdam sandstone is a valuable source of silica. All of the above rocks, together with the Beekmantown dolomite beds, have provided building stone and road material.

Of great potential importance is the known occurrence in the sedimentary rocks of the Lowland of stores of natural gas, and there is hope that petroleum may also be found. All in all, the natural resources are valuable, and the program of mapping the Lowland, begun by the writer in 1938 and now essentially completed, was conceived as an aid to the more intelligent prospecting for its wealth of rock products. Results obtained throughout the remainder of the Lowland, combined with preliminary conclusions gained from the progress of the present work have contributed to the production of the Department of Natural Resources Geological Map No. 1407 -- "The Geology of the St. Lawrence Lowland," published in 1962, and of Map No. 1500 "The Geology of Quebec, 1965," in preparation.

LOCATION OF THE AREA - GEOGRAPHICAL AND GEOLOGICAL

The Châteauguay map-area is bounded by longitudes 73°30' and 74°00' and by latitude 45°15' and the International boundary with the United States. The latter does not quite correspond to latitude 45°00'. It includes parts of Napierville, Huntingdon, Saint-Jean, Châteauguay and Beauharnois counties.

Topographically, the area consists largely of a nearly flat plain sloping gently to the northeast from about 200 feet above sealevel in the southeast corner to the Beauharnois canal in the northwest corner with an elevation of about 100 feet. This plain is traversed by several streams, of which the Saint-Louis, Châteauguay, Anglais (English) rivers and Norton creek are the most important. The plain gives way along the western half of the southern boundary of the area to Covey hill, with a steep, north-facing slope rising to more than 1,100 feet above sealevel.

Geologically, it is the southernmost part of the St. Lawrence Lowland of Quebec. The dominating structure of the Lowland, the Chambly-Fortierville syncline, passes through Hemmingford and dies out as a recognizable structure at the International border a few miles farther south. Although distribution in neighboring map-areas indicates the possible presence of Chazy beds in the northeast corner, there is no outcrop or evidence of such beds from known well records. Outcrops and well records indicate that the area is underlain by dolomite and sandstone of Cambrian and Ordovician ages.

MEANS OF ACCESS, TRANSPORTATION

Three railroad lines cross this area, all parts of the Canadian National Railways. First, from northwest to east is a part of the line connecting Côteau, Que. to St. Albans, Vt. via Cantic, Que., largely concerned with throughgoing freight, but with four stations for local use. The second line, also concerned with freight, enters the area at Sainte-Martine and runs southwestward to Ormstown. The third line cuts across the eastern portion of the area with its southern termination at Hemmingford, beyond which its earlier extension into the United States has been abandoned. The Beauharnois canal passes across the northwestern corner of the area. The poor coverage of the area by railroads is partly compensated for by a good network of "blacktop" roads.

POPULATION AND OCCUPATIONS

The chief towns and villages in the area are Sainte-Martine (pop. 1436), Ormstown (1348), Howick (566), Saint-Chrysostôme (868), and Hemmingford (679). (Population figures taken from Canadian Official Railway Guide with Airlines, Montreal, June 1960).

The northern and eastern halves, more or less, of the area (mostly plains) are good farm land, and yield mixed crops. Animal husbandry is well established around Howick and Ormstown. The western half of the southwestern quarter, more or less, is stony, quite unfit for large-scale farming, but is excellent location for apple orchards and sugar-maple groves, of which there is an abundance. Between the plains and Covey hill much of the area is underlain by nearly flat-lying sandstone, either exposed or covered by but a few inches of soil, and largely unfit for agriculture.

A few industries, apart from those dependent upon local agriculture, are scattered through the area.

PREVIOUS GEOLOGICAL WORK

Not only has there been no systematic study of the areal geology of this area, but there are very few references to the bedrock geology in geological literature prior to this report. Except for casual references to the presence of Potsdam sandstone in Canada (e.g., Hall, 1859), the earliest record of observations made on this formation in this area is contained in Logan's monumental work -- the Geology of Canada, 1863. He gave details of the distribution and characteristics of the formation on Covey hill and the sloping flats southeast of Ormstown, and estimated its thickness as 540 feet on Covey hill and 700 feet overall (pp.87-89). He recognized that our exposures are part of a band which "sweeps around from Keeseville on the Ausable, a tributary of Lake Champlain, to Alexandria on the St. Lawrence, in Jefferson county." He also commented on the tracks and trails, mentioning Protichnites and Scolithus by name. He recognized that "the upper part of the formation is in general a fine grained, white, silicious sandstone .. and at the summit the sandstone becomes by degrees interstratified with beds of magnesian limestone."

Both in his report on the southwest quarter of the Eastern Townships (1896) and in an extended paper dealing with the Potsdam and Calciferous Formations in Canada (1895), Ells quoted from Logan, but added no new observations on the rocks of this area. His misunderstanding of Logan's section at Covey hill and his correlation of the "Basal conglomerate of the Hemmingford area" (1895, p. 28) with the Georgia slate series of the Appalachian terrane indicate that he had not examined the area closely. His conclusion that the "typical Potsdam sandstone" should be considered Ordovician is not substantiated by the stratigraphic or the paleontological evidences he presented.

Wilson's map of the Valleyfield area to the west (1941), and Clark's map of the Lachine area to the north (1952), provide information concerning neighboring areas. The recently published geological map of New York State (1962) shows the distribution of rock formations in contiguous areas south of the International boundary. Quebec Department of Natural

Resources Map No. 1407 (1962) covering the St. Lawrence Lowland embodies most of the results arrived at during the course of the present work.

References to the glacial geology, particularly of Covey hill, can be found from 1900 onward (see Bibliography).

FIELD WORK AND ACKNOWLEDGMENTS

Field work on the Châteauguay area was begun in 1954 and continued for short seasons in 1955 and 1957. Transportation was achieved by a Department of Mines station wagon. Traverses were carried out by pace-and-compass methods, aided by the use of air photographs. All streams were traversed.

Satisfactory assistance was rendered by Messrs. A.W. Byrne and Léo Héroux during the 1954 season; by St.G. Pouliot and M. Fulton in 1955, and by Claude René, T. Hashimoto, and D. Mather in 1957. As senior assistant in 1955 and 1957, R.S. Dean made outstanding contributions to the work of the party.

GEOLOGY

GENERAL STATEMENT

The oldest rocks of this area (Covey Hill Formation of Upper Cambrian age) occupy practically all of Covey hill and are succeeded to the west, north, and east by irregularly concentric belts of younger and younger rocks of Cambrian and Lower Ordovician ages. Within these latter,in half a dozen places, inliers allow Covey Hill sandstone to show through, indicating its widespread occurrence throughout much of the area.

The beds are all nearly horizontal, dips of 2^{o} being the most common, though dips up to 5^{o} are the rule in a few places. Save for the Havelock and Stockwell faults, no faulting of importance is indicated here, and folds are so flat and open as to be hardly recognizable. The major folds, the Chambly - Fortierville syncline, dominates the eastern third of the area; another fold can be seen between Norton Creek corners and Sainte-Clotilde. Only one small-scale fold is known.

The steep northern and eastern flanks of Covey hill are interpreted as fault-line scarps. Between the Covey Hill beds and those exposed north and east of the hill there is a major unconformity. Another unconformity of considerable import, but far less obvious, separates parts of the Cairnside member of the Châteauguay Formation. Joints are prominent throughout the region, the most common attitude being more or less NW., and vertical. Crossbedding, present throughout practically all the sandstone beds, indicates that the dominant current direction was from west to east.

It is suggested that the Covey Hill beds are an accumulation, along a subsiding seashore, of waste from the New York Adirondacks to the south. Later formations are the result of successive incursions of the sea, in which more and more mature sands were accumulated and, eventually, the carbonates of the March and Beauharnois Formations.

STRATIGRAPHY

Potsdam Group

Historical Review

Since 1838, when Ebenezer Emmons first applied the name Potsdam to basal sandstones resting on the Precambrian and overlain by supposedly Ordovician (Calciferous) beds, both tradition and custom have conspired to perpetuate the term as a formational name referring to all sandstones with the above stratigraphic relationships, and therefore of Cambrian, and presumably of Upper Cambrian, age. One of the first to break with this traditional treatment was H.P. Cushing (1901) who removed the so-called "passage beds," consisting of alternating sandstone and dolomite, from the Potsdam Formation, which he restricted to a coarse, white or buff, gritty sandstone with coarse conglomerate at its base. In 1902 Van Ingen took a big step forward by giving a synoptic view of the stratigraphic development of the "Potsdam" rocks along the northeast margin of the Adirondacks. After recording several sections in various places he concluded that there were three divisions, as follows:

Upper Division. Irregularly laminated sandstone with well-rounded quartz grains, and holding shale and dolomite pebbles. Dolomite in thin beds is intercalated with the sandstone toward the top, which by degrees becomes pure dolomite. Fossils are common in certain layers:

Scolithus linearis	_Hyolithes primordialis_
S. canadensis	_Ophileta compacta_
Obolella prima	_Platyceras sp._
Lingulepis	_Ptychoparia minuta_
Lingulella acuminata	_Conocephalites errucosa_

Middle Division. White, gray, or yellow, well sorted, fine-grained sandstones grains more angular than rounded. Regularly bedded. Ripple-mark and cross-bedding common. Climactichnites sp. common in places.

Lower Division. Red and brown, coarse-grained, poorly sorted sandstone, feldspar present together with a little magnetite. No fossils.

TABLE OF FORMATIONS
and
CORRELATION CHART OF FORMATIONS IN CHÂTEAUGUAY AREA

<table>
<tr><th colspan="4">EARLIER WORK</th><th colspan="9">PRESENT REPORT</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">LOGAN ELLS</th><th rowspan="2" colspan="2">1900 - 1960 AUCT.</th><th rowspan="2">SYSTEM</th><th rowspan="2">SERIES</th><th rowspan="2">STAGE</th><th rowspan="2">GROUP</th><th rowspan="2">FORMATION</th><th rowspan="2">MEMBER</th><th colspan="2">SUGGESTED CORRELATION</th></tr>
<tr><th>LITHIC</th><th>TIME</th></tr>
<tr><td rowspan="5">ORDOVICIAN</td><td rowspan="5">CALCIFEROUS</td><td rowspan="3" colspan="2">BEEKMANTOWN
BEAUHARNOIS
(RAYMOND)</td><td rowspan="3">ORDOVICIAN</td><td rowspan="3">CANADIAN</td><td rowspan="3"></td><td rowspan="3">BEEKMANTOWN</td><td rowspan="3">BEAUHARNOIS</td><td>Saint-Lin
(not exposed)</td><td></td><td rowspan="2">? Bellefonte
Jefferson City</td></tr>
<tr><td>Huntingdon
(Mallet,457')</td><td></td></tr>
<tr><td>Sainte-Clotilde
(Mallet, 221')</td><td>Oxford</td><td>Roubidoux
Gasconade
Tribes Hill
Heuvelton</td></tr>
<tr><td rowspan="2">PASSAGE BEDS</td><td rowspan="2">THERESA
(RAYMOND;
CLARK)
MARCH
(WILSON;
CLARK)
NEPEAN
(WILSON)</td><td rowspan="4">CAMBRIAN</td><td rowspan="4">CROIXAN</td><td rowspan="4">TREMPEALEAUIAN</td><td rowspan="4">POTSDAM</td><td rowspan="2">CHÂTEAUGUAY</td><td>Ruisseau Norton</td><td>March
Theresa</td><td rowspan="2">Little
Falls</td></tr>
<tr><td>Cairnside
500'</td><td>? Keeseville</td></tr>
<tr><td rowspan="2">CAMBRIAN</td><td rowspan="2">POTSDAM</td><td rowspan="2" colspan="2">?KEESEVILLE
POTSDAM</td><td rowspan="2">COVEY HILL</td><td>Rivière aux
Outardes
500'</td><td>?Keeseville</td><td>?Keeseville</td></tr>
<tr><td>Covey Hill
restricted
1500'</td><td>Potsdam</td><td></td></tr>
</table>

It appears that Van Ingen's Lower Division corresponds pretty closely to our Covey Hill Formation; his middle division to our Cairnside member of the Châteauguay Formation; and his Upper Division to our Ruisseau Norton member of the Châteauguay and possibly to part of our Beauharnois Formation.

In 1908, Cushing named the "passage beds" the Theresa Formation, which consists of alternating sandstone and dolomite. Chadwick (1915) divided the Potsdam into an underlying Potsdam sandstone, mostly red, and an upper, white sandstone, using for the latter Emmons' old term Keeseville. In 1920 he suggested that the typical Potsdam and the so-called Keeseville might be separated by an unconformity, and he published a stratigraphic succession as follows:

Higher beds
Theresa mixed beds, dolomite and sandstone
Potsdam (?Keeseville) white sandstone
Typical Potsdam sandstone, red, with conglomerate

Thus there seems to have been a fair amount of agreement as to the lithologic succession, much as given by Chadwick (1920). Further development might have been carried out by amassing more lithologic detail, so that the distribution of formations could have been achieved. Instead, the confusion which had already begun to develop by the beginning of the century as a result of the introduction of biozones in a futile attempt to achieve correlation before the distribution of the lithologic units had been stabilized became greater. However, much good work along these lines was reported by Wheeler (1942) who adduced new evidence to show that the Cambro - Ordovician boundary lies considerably above the typical Theresa, and that the Potsdam, Theresa, Little Falls and Whitehall are all Cambrian. The Tribes Hill, containing the Upper Theresa, now known as the Heuvelton Formation, forms the base of the Ordovician. This important paper was marred by irregularities in the naming of new members of the Tribes Hill Formation, attention to which was later called by Fisher (1955).

In Fisher's paper just referred to, a strong plea is addressed to stratigraphers to attend strictly to the code of the American Commission on Stratigraphic Nomenclature, so as to avoid any further confusion between formations (mappable lithologic units) and biozones which are not in the general sense mappable. Both units contribute to the full understanding of the sedimentary history, but confounding one with the other, or trying to make one do the work of the other, has led, and is still leading, to near chaos in a few regions. In the Châteauguay area the difficulty is minimized by the absence of fossils from the Covey Hill beds, which must, therefore, be mapped solely as a formation. To a lesser degree the same is true of the members of the Châteauguay Formation, and of the Beauharnois Formation. If we are to preserve the term Potsdam, as a formational name it must refer to a lithologically constant, mappable unit. This involves priority in the meanings attached to the term Potsdam. Emmons (1838) originally described the Potsdam sandstone as a red, reddish yellow, gray and grayish white rock consisting of quartz and yellowish feldspar. This comes close to our Covey Hill rock type. There is, however, no evidence yet that proves lithologic continuity between the rock at Potsdam and that at Covey hill. Emmons (1842) mentioned a variety of the Potsdam well developed at Keeseville which is more liké our Châteauguay Formation than it is like the Covey Hill.

Because of the complexities in the local sections of the "Potsdam sandstones" around the Adirondacks, and because of difficulties in correlating this so-called formation from place to place, it seems advisable in our area to drop the name Potsdam as a formational name and to use our own term Covey Hill, with the understanding that in the fullness of time the lithological equivalence of the Potsdam sandstone at Potsdam and the Covey Hill beds may be either established or disproved.

An adequate review of the uses of the term Potsdam, Keeseville, passage beds, and Theresa is given in Wilmarth (1938 pp. 1716-1719).

Covey Hill Formation (Including Rivière aux Outardes Member)

This formation, the oldest in the Châteauguay area, is composed of many varieties of white, gray, or reddish immature orthoquartzite. It underlies all of Covey hill, and outcrops in a few isolated patches to the north. Southward, beyond the International border, it stretches as far as the lower slopes of Lyon mountain in the Adirondacks, composed largely of granite, from the weathered products of which it was probably derived. This is one of the three local formations which were earlier included under the term "Potsdam sandstone."

From Franklin-Centre south and west to the borders of the area a somewhat different type of rock is exposed from that characteristic of the Covey Hill proper. This is well shown along Outardes-Est river and Mitchell brook. It consists of fine- to coarse-grained sandstone, and shows far more of the fine-grained habit than is to be seen anywhere in the Covey Hill proper. Pebble beds are present, but not to the extent seen farther east. Feldspar is nearly absent. Red and brown colors are much rarer. Cross-bedding is common, but, instead of being the deltaic type with relatively flat foreset beds, it here consists of huge swales up to 25 feet across which were washed out of the sand and were subsequently filled (Pl. IB). Ripple-mark, which was not seen anywhere in the Covey Hill proper, is fairly common. Although there is no stratigraphic section involving both these beds and those of the Covey Hill proper, there is no doubt that these lie at the top of the complete Covey Hill section. They present so many differences from the typical Covey Hill lithology that they deserve to be considered as a separate member.

The lack of uniformity in structure in this part of the area prohibits the determination of the thickness of these upper Covey Hill beds, but it is probably several hundred feet.

They are typically exposed in the bed of Outardes-Est river, for 1/4 mile below and 1/2 mile above the bridge on Route 52.

Distribution: Covey hill, 20 miles long north of the international border and from 6 miles wide from north to south at its eastern end to 3 miles wide at the southwestern corner of the area, is occupied exclusively by the Covey Hill Formation. In addition, Covey Hill beds occur in five inliers, the best exposed of which is along the banks of Anglais (English) river below the bridge at Saint-Chrysostôme. A recent deepening of the river exposes a bank about 7 feet high of mostly brown to gray, medium-grained sandstone, with some conglomeratic lenses containing rounded quartz pebbles up to 12 mm. in diameter. Shale flakes up to 4 inches across are common. Crossbedding dips for the most part toward the east. Numerous diastems can be recognized, resulting in fairly smooth continuous surfaces, which, however, do not truncate sand grains. Less than a mile west of this locality there are a few small outcrops of crossbedded white to creamy yellow, medium- to coarse-grained sandstone with some grains up to 5 mm. Pink feldspar is present but rare. These are the characteristics of the lower part of the Cairnside sandstone. And two miles to the northwest there is another small group of outcrops of similar white to creamy yellow, fine- to coarse-grained, crossbedded sandstone with pink to brown laminae in places. In both cases the dips, though low, are toward the outcrop at Saint-Chrysostôme, the beds of which dip to the north, so that an unconformity is indicated on structural as well as stratigraphic grounds.

Farther north, also on Anglais river, immediately above Aubrey, there is a long outcrop of well-cemented greenish gray, fine- to medium-grained sandstone containing red sandstone lenses. Pebbles up to 6 mm. are present. Some of the bedding shows up as low, shallow troughs similar to those which occur commonly in the Rivière aux Outardes member of the Covey Hill Formation. The beds dip to the northwest at 4°. Half a mile to 1 1/2 miles to the east, there is, on ground rising 60 to 75 feet higher than the outcrop in Anglais river, a group of a dozen outcrops of white, fine- to medium-grained, crossbedded sandstone showing no color banding. These characteristics ally these beds with the upper part of the Cairnside member. The dip, where any exists, is 1° to the north-northeast. Again on both structural and stratigraphic grounds an unconformity is indicated.

A third occurrence is also on Anglais river, a mile west of Riverfield. Here, gray, fine- to medium-grained, well-cemented, well-bedded sandstone outcrops rather poorly. Its appearance and characteristics are reminiscent of the Rivière aux Outardes member of the Covey Hill Formation.

The beds dip 3° west. A mile and a half to the south-southeast a group of glassy white to gray sandstone outcrops dipping 2°-3° to the north contain quartz pebbles up to 6 mm. and on one surface there are examples of Arenicolites. The latter alone is sufficient evidence for a post-Covey Hill age, so that the evidence again favors an unconformity between the two exposures.

Farther south two inliers are shown on the map. The evidence for the northern of the two is meagre and the inlier must be considered as a possibility only. However, 2 1/2 miles east of Covey Hill corners there is an outcrop, well exposed on the south side of the road, of a pink to red, feldspar-rich, coarse-grained, locally conglomeratic, crossbedded sandstone. This obviously belongs to the Covey Hill Formation. The dip is 3° to the west. Between this exposure and Covey Hill corners and also south of the road, there is a large group of outcrops of presumably lower Cairnside sandstone consisting of pure white to greenish gray sandstone in places 100% quartz. These beds have a westerly dip of 1°-2°. Although the Covey Hill sandstone of this inlier may belong at the top of the formation as exposed at the summit of Covey hill, there is no possibility of the rest of the formation, including the Rivière aux Outardes member, occurring between the two exposures. Here again stratigraphy and structure combine to indicate an unconformity, and the outcrop, as in the other cases listed above, becomes an inlier.

Composition and Lithology.- Practically every specimen examined was found to be made up of more than 50% quartz grains. In a very few cases feldspar (mostly orthoclase and microcline) approaches 50% in amount, and is nowhere completely absent. Other minerals seen in thin-section are zircon, plagioclase, tourmaline (both pink and green), and, rarely, apatite. Micaceous minerals also occur in the more shaly parts.

Quartz grains commonly show undulating extinction, and some grains are composites of many elongated crystals of strained quartz, the latter indicating a metasedimentary source for at least part of the beds. Feldspar crystals and fragments are commonly altered, probably kaolinized, and many show authigenic enlargement by a K-feldspar resembling adularia, which is itself likewise altered. Authigenic enlargement of feldspar grains occurs in crystallographic continuity with the detrital grains, and usually results in the development of euhedral crystal faces. Tiny crystals of zircon, almost certainly authigenic, were also noted in a few sections.

The Covey Hill Formation is predominantly sandstone, ranging from fine- to commonly coarse-grained (Pl. IC). The latter is in many places conglomeratic with pebbles of quartz up to 1 inch in diameter, and occasionally of feldspar up to 1/2 inch across. Some of the lower beds consist almost wholly of pebbles of quartz and are true conglomerates. More rarely the rock is a siltstone. True shale is virtually absent. Both feldspar and pebbles are commonest in the lowest beds exposed along the northeastern flank of Covey hill. Pebbly sandstones are common over the wide flats north of the Gulf, and in the exposures near Stockwell (Pl. VA,VB). Throughout the western end of Covey hill,pebbles and feldspar occur in nearly every outcrop, but are rarely abundant (see analysis of Covey Hill syncline below).

In color the rock ranges from deep reddish brown through brown and red to pink and buff. Pure white or off-white sandstones are uncommon, but can be seen on the flats north of the Gulf (Plate IIA), and in many places at the western end of the hill. A few developments of greenish gray sandstone occur without, as far as is known, any stratigraphic significance.

The beds at the summit of the hill are the highest stratigraphically on Covey hill proper but the lower, western end of the hill is probably made up of still higher beds.

Succession at East End of Covey Hill.-Because the beds on Covey hill are essentially horizontal a section built from the summit down the steep slope to the north would, if complete, give the stratigraphic succession. However, only scattered outcrops dot the hillside. By drawing a line from the summit northward at about N.15°E., reaching Highway 52, 7,000 feet west of Havelock (Fig.I), and by combining the lithologic characteristics of outcrops close to this line, an approximation to a stratigraphic succession, more than 1,000 feet thick, can be obtained. Such a succession is as follows:

Top. Summit of Covey hill:

Medium-grained sandstone, well cemented, with quartz pebbles and rare shale flakes. Crossbedded.

Brown quartz conglomerate, in part loosely, in part strongly, cemented. Some feldspar. Crossbedded.

Coarse- to medium-grained sandstone with quartz pebbles. Some feldspar and patches of conglomerate.

Brown, coarse-grained sandstone, fairly well cemented. Orthoclase and quartz pebbles present.

Fine- to coarse-grained, loosely cemented, brown sandstone. Quartz pebbles and orthoclase present.

Fine- to coarse-grained, loosely cemented sandstone with a few pebbles.

Medium- to coarse-grained, loosely cemented, white-weathering sandstone. Pebbles and feldspar present.

Coarse-grained sandstone, grading into conglomerate. Orthoclase present.

Medium- to coarse-grained, white, gray, and brownish sandstone. Orthoclase present. Crossbedded.

Coarse-grained sandstone with orthoclase. Quartz conglomerate with orthoclase. Crossbedded.

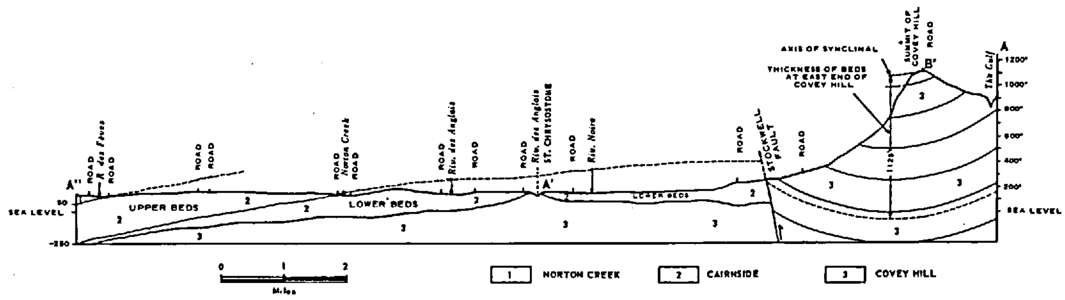


FIGURE 1

CROSS-SECTION ALONG LINE A-B'-A'-A'' TO SHOW A METHOD OF DETERMINING THICKNESS OF POTSDAM FORMATION EXPOSED AT EAST END OF COVEY HILL. THE DIPS ARE CALCULATED TO ACCORD WITH THE VERTICAL EXAGGERATION. BOTH THE LOWER AND THE UPPER PARTS OF THE CAIRNSIDE MEMBER ARE SHOWN TO HAVE A MAXIMUM THICKNESS OF ABOUT 300 FEET EACH.

M.R.N.Q. 1965 G-446

Although the above "section" is taken along a line not perpendicular to the strike of the beds, the dip is so low and the slope of the section line is relatively so steep that it is a fair representative selection of rock types. To generalize, the rock is dominantly sandstone, medium to coarse grained, grading into a quartz-pebble conglomerate. It is mostly off-white, with brownish red the chief exception. Cementation ranges from poor to good. Orthoclase feldspar is present throughout, and is common in some beds. Crossbedding is common. There seems to be little, if any, stratigraphic limitations to the above characteristics.

Shorter Sections.- Elsewhere, 2 miles west-southwest of Maritana, a fine series of outcrops on a hillside provides the following section:

Top of section:	
6 feet	Pink and chalky yellow sandstone. Fine-, medium- and coarse-grained.
1 foot	Greenish gray, well laminated sandstone, with fine magnetite-bearing bands.
4 feet	Missing.
5 "	Red sandstone, becoming pink toward the top. Medium- to fine-grained. Mostly in 1" to 3" beds.
2 "	Alternations of fine-, medium- and coarse-grained off-white sandstone.
1 foot	Medium- to coarse-grained sandstone, gray.
1 "	Fine-grained sandstone, with one bed of 1/4"-1/2" quartz pebbles.
3 feet	Missing.
1 foot	Medium-grained sandstone with fine black laminae.
2 feet	Missing.
1 foot	Fairly coarse-grained gray sandstone. Crossbedded.
1 "	Missing.
2 feet	Very coarse-grained, crossbedded, gray sandstone.
2 "	Missing.
1 foot	Medium-grained gray sandstone.
33 feet	

Again, 1/4 mile south of Highway 52 at Maritana the following sequence — not necessarily continuous — was measured. Each unit of the section represents a step formed by the outcrop of the bed concerned. Little, if any, intervening rock was found. All the sandstone is gray unless otherwise noted.

1'	6"	Loosely cemented conglomeratic sandstone. Crossbedded.
1'	8"	Medium-grained to conglomeratic sandstone. Crossbedded.
1'		Medium-grained to conglomeratic sandstone. Crossbedded.
2'	2"	Conglomeratic sandstone, well cemented.
	6"	Medium-grained sandstone.
3'		Conglomeratic sandstone, strongly crossbedded.
	8"	Medium-grained to conglomeratic sandstone. Crossbedded.
1'	2"	Conglomeratic sandstone.
1'		Conglomeratic sandstone.
	7"	Medium-grained, reddish sandstone with a few pebbles.
1'	8"	Medium-grained, reddish sandstone.
1'	1"	Conglomeratic sandstone. Crossbedded.
	11"	Conglomeratic sandstone.
16'	11"	

Still another section, also measured across a series of steps, 3/4 mile southwest of Maritana and possibly at about the same horizon as the preceding section, is as follows:

1'		Massive, coarse- to medium-grained sandstone.
	10"	Coarse-grained, dull red sandstone.
	6"	Coarse- to medium-grained red sandstone.
1'	4"	Medium-grained, massive gray sandstone with a few pebbles. Well cemented, glassy appearance.
1'	6"	Coarse-grained gray sandstone. Crossbedded.
2'		Coarse-grained gray sandstone. Crossbedded.
2'	6"	Medium-grained pale red sandstone. Crossbedded.
1'	4"	Coarse-grained, conglomeratic sandstone. Crossbedded.
	10"	Coarse-grained white sandstone with a few pebble beds, pebbles up to 5 mm. Crossbedded.
	5"	Medium- to coarse-grained brown sandstone. Crossbedded.
	8"	Very coarse-grained sandstone with abundant pink shaly inclusions.
12'	11"	

A mile and a half east of Franklin-Centre there is an exposure showing seven steps. The section is as follows:

	9"	Coarse-grained sandstone, massive.
	10"	Coarse- to medium-grained, thin-bedded sandstone. Crossbedded.
1'		White, coarse-grained, thin-bedded sandstone with pebbles up to 5 mm. Uppermost 2" brown. Crossbedded.
2'		Coarse-grained, thin-bedded, brown sandstone.
1'	3"	Coarse- to medium-grained, thin-bedded sandstone. Crossbedded.
1'	8"	Conglomerate with quartz pebbles up to 6 mm. Thin-bedded. Crossbedded.
	10"	Very coarse-grained sandstone. Quartz pebbles abundant. Irregular pockmarks on surface.

One and one-half miles southwest of Maritana an outcrop with seven steps gives the following section:

	9"	Coarse- to medium-grained sandstone, followed upward by massive conglomeratic sandstone, the latter not measured.
	10"	Medium-grained sandstone, bedding obscure. Quartz pebbles up to 10 mm. Strongly crossbedded.
	9"	Medium- to coarse-grained, thick-bedded, strongly cemented sandstone. Crossbedded.
	9"	Massive, coarse-grained, homogeneous sandstone.
1'	2"	Medium-grained, massive sandstone. Quartz pebbles up to 5 mm. present. Crossbedded.
	8"	Coarse- to medium-grained, thin-bedded sandstone. Pebbles present. Crossbedded.
1'		Very coarse-grained conglomeratic sandstone, thin-bedded, beds 1" more or less thick. Crossbedded.
5'	11"	

From the above section it is apparent that fine-grained sandstone is practically absent, that pebbles are commonplace, crossbedding is almost ubiquitous, and brownish color, if not the rule, is at least far from unusual.

Information from Thin-sections.- Fifteen thin-sections of Covey Hill sandstones were made and analysed. The many surprising similarities in these sections allow a composite description to be given as follows. In all sections but one the grains were poorly sorted; three sections showed the coarser grains to be angular; three, subangular; and five, rounded. Interstitial minerals between the dominant quartz and feldspar grains include hematite, "limonite," and clay minerals. Quartz grains show some strain effects, some are composite, and in rare cases authigenic overgrowths of quartz occur. The feldspars (2-20%) are made up of kaolinized (?) orthoclase, in part perthitic, and, in part, of fairly fresh microcline. These features are constant throughout all sections. Authigenic overgrowths of orthoclase on orthoclase are rare, and all are developed at the expense of quartz. Very rarely, authigenic zircon crystals, having grown in intergranular spaces, appear completely surrounded by later authigenic quartz. No reaction between the zircon and quartz was noted.

Of the necessary minerals, zircon is the most abundant, and was found in all sections. Tourmaline (both green and brown), muscovite, biotite (mostly altered), and apatite occur in abundance in approximately the order listed.

A few interesting observations follow from the analysis of the mineral occurrences in thin-sections. Hematite was found in all sections but five, and these five occur in line about in the middle of the middle part of the Covey Hill Formation. No particular reason for this arrangement is apparent. The distribution of roundness and angularity of grain shows more angularity in the lower part of the formation and more roundness in the upper part, which is in accord with what might be expected. Authigenic overgrowths are largely confined to the lower part, which might be explained by the greater depth of burial and hence higher temperatures, or by the greater diversity of materials in the lower beds affording more raw material for authigenic overgrowths. In this connection no authigenic overgrowths of feldspar were seen in sections made from beds of the Rivière aux Outardes member or the Covey Hill Formation.

Cementation: The degree of cementation ranges from loose to strong. As with color, cementation changes both from bed to bed and laterally along any particular bed. There is no evidence of any cement other than silica, save for the ferruginous cement in some of the red and brown beds.

Other Inherent Characteristics: Crossbedding of the current type with small cut-and-fill structures is very common practically throughout the formation proper. In most cases the dip of the fill beds is toward the east and southeast, as shown on Figure 7. In the Rivière aux Outardes beds the cut-and-fill units make large swales up to 25 feet across, leaving, in places where the fill beds have been removed by erosion, basins up to 5 feet deep (Pl. IB). Ripple-mark is unknown in the Covey Hill Formation proper, but is present in its Rivière aux Outardes member (Fig. 7). In the few places where noted, the crests, with one exception, strike between north and east. The direction of the currents concerned, where shown, was toward the southeast. No mud-cracks were seen anywhere in the Covey Hill Formation.

Structure: The Covey Hill beds are disposed in a wide-open syncline the axis of which plunges west-southwest. Map 1 shows horizontal beds close to the trace of the axis. Dips are adequately shown on that map, though, so general and irregular is crossbedding, readings on but about one in three exposures should be taken with assurance of regional significance. Trends of elongated outcrops on the northern limb indicate the strike of the beds more reliably than do compass readings (Pl. IC). Elongated north-south outcrops, or strings of outcrops, record small isolated exposures along traverse lines, and have no structural significance. Outcrop pattern on the southern limb is not indicative of structure. A small anticline (Pl. IIC) is probably a drag-fold on the northern limb of the Covey Hill syncline.

Several lithologic characteristics indicate the same fold structure, and provide clues to the stratigraphic succession. The formation can be divided into four stratigraphic zones shown in the following tabulation. Zone IV corresponds to the Rivière aux Outardes member.

Top of the Section

Zone	Dominant Colors	Pebbles	Feldspar	Shale Flakes
IV	White	Uncommon	Uncommon	Unknown
III	White, red	Present	Present	Rare
II	White, red, green	Common	Common	Common
I	White, brown	Common	Abundant	Present

There are reasons to believe that the plunge decreases in intensity toward the west. If this is actually so, then the four zones are of the same order of thickness, and the Rivière aux Outardes member represents about the topmost quarter of the exposed section - a conclusion in harmony with calculations of thickness given above. Because the base of the formation is nowhere seen, any thickness arrived at by measurements of the present exposures must be a minimum.

Thickness.- There is no continuous section of this formation from which reasonably accurate measurements might be made. Its probable thickness can be derived, however, from the exposures of the eastern end of Covey hill where the entire hill is composed of the rocks of this formation. The dips are low, 1° to 2° in general, and on the hillside slope to the north, Covey Hill beds are exposed discontinuously over the surface. From the summit, going in a north-northeasterly direction, the farthest outcrop of the formation is 10,000 feet away, horizontally measured. This farthest bed would be the lowest bed exposed, and the thickness as shown in Figure 1 is 1,125 feet. This is in harmony with thicknesses of similar parts of the "Potsdam" sandstone from the two deep wells drilled at Saint-Timothée (Montréal No. 1 and St. Lawrence River No. 1) where the pebbly, feldspar-bearing coarse sandstones were 1,650 and 1,646 feet thick. An alternative method shown on Fig. 3 gives the thickness of the exposed Covey Hill (restricted) beds as 1,200 feet.

A much less satisfactory method is to use the section exposed along the length of Covey hill from the summit to the southwest corner of the area. Here the differential in elevation is 450 feet, and the length involved, 67,000 feet. The calculated dip along this line is 9 minutes, and the calculated thickness of the Covey Hill Formation down to the lowest bed exposed north of the summit comes to 1,727 feet assuming an average dip of 1° or 2,897 feet using a 2° dip. Because reversals of dip are very common among the exposures along the north slope of the hill the Lower average dip is likely to be closer to the true average than is the higher dip. If so, then roughly 600 feet of the beds along the western end of the hill lies above anything exposed at the eastern end. If we allow, arbritarily, that 100 feet of this 600 feet represents the uppermost part of the Covey Hill Formation (restricted) this gives a maximum thickness for the Rivière aux Outardes member of 500 feet and a maximum figure for the Covey Hill Formation, restricted, of 1,227 feet.

Because the upper contact is an erosional unconformity, and, because the lower contact is not revealed, the calculated thicknesses are probably minima. Because even in the lowest, stratigraphically, beds exposed there are no pebbles composed of other than quartz and more rarely feldspar, and,as few of these are as much as 1 inch in diameter,it is unlikely that the lowest beds of the formation are exposed here.

It is safe to say that the thickness of the entire formation is 1,800 feet, probably 2,000 feet, with a possibility that it is even thicker.

Marine or Non-marine Origin.- There is no compelling evidence to support the view that the Covey Hill beds are of marine origin, save the constant dip of the crossbedding to the east and southeast. With the exception of a few poor burrows of the Scolithus type; but generically unidentifiable, there are no fossils in this formation. The red and brown colors, particularly the former, are good evidence for a non-marine origin, and the abundance of feldspar, still appearing fresh, argues for rapid accumulation. The lack of both vertical and lateral continuity of lithologic expression in most of the beds indicates deposition under strong and irregular current conditions. For instance, in the recent cut along Anglais river at Saint-Chrysostôme, within a vertical distance of 4 feet, several diastems can be counted, the surface of each one showing the results of strong scouring action. It is not impossible that this sandstone is the result of the marine erosion of bajada deposits or of a piedmont slope of waste exposed to the action of east-flowing currents.

The conditions envisioned as obtaining during the deposition of the Covey Hill beds are as follows:- The Adirondack and the Laurentian mountains of that time stood several thousand feet above the local plain, which may or may not have been sealevel, and yielded sediment which was carried downslope by streams and deposited, as indicated above, as confluent alluvial fans,stretching outward from the mountain fronts for perhaps tens of miles. Off to the south lay the sea in which Upper Cambrian, marine, sedimentary rocks were being deposited. An advance of the sea at about the close of Cambrian time allowed the waves to eat into the slightly or semi-consolidated alluvial fans, and at the same time to receive for distribution any further detritus won from the Lyon Mountain massif. With a subsiding shoreline sediments could be accumulated until this subsidence, presumably affecting Lyon mountain also, reduced the gradient of the rivers to such an extent that further contributions of debris were slowed up. If, now, subsidence itself slowed up, strong current action on the shoaling sea floors would result in the large-scale swales characteristic of the Rivière aux Outardes member.

Châteauguay Formation

General Statement

Lying unconformably upon the Covey Hill beds is a series of sandstones and dolomites,here named the Châteauguay Formation, covered disconformably by the dolomite beds of the Beauharnois Formation of Beekmantown age. The Châteauguay Formation is made up of two members, the Cairnside (below) and the Ruisseau Norton. The Cairnside consists of crossbedded orthoquartzite with siliceous cement, thick bedded and poorly provided with fossils in its lower part, and showing abundant trails and tracks, together with Lingulepis acuminata in its upper part. It is well exposed on the flats (Blueberry Plain of Logan) southeast of Cairnside, whence it takes its name, and also to the east of the road from Covey Hill corner southward to the international border. The Ruisseau Norton Formation consists of alternations of calcareous and dolomitic sandstone and dolomite, with every gradation from the one into the other. These beds can be seen at several places along Norton creek. The Cairnside member does not seem to be represented elsewhere. The Ruisseau Norton member is probably the equivalent of the Theresa (restricted) Formation of New York. It is likely that Wilson's March Formation, described below, is the northwestern extension of Ruisseau Norton member in the Châteauguay area. Notes on the use of the names Theresa and March follow. Throughout the formation the sandstone beds are stained light brown in spots and patches probably owing to the weathering of pyrite.

Much confusion has attended the identification of the Theresa Formation in the field. It was early recognized that between the Potsdam sandstone and the overlying dolomite beds (Little Falls, Beauharnois, Tribes Hill, etc.) there existed alternations of sandstone and dolomite similar respectively to the Potsdam and the overlying dolomite formations. It was natural to assume that a gradation by intercalation was represented here and the name "passage beds" was almost universally accepted as an appropriate term for this development up to 1908, when Cushing proposed the term Theresa Formation as a substitute for "passage beds". He fixed the lower boundary at the base of the lowest dolomite bed. This was generally accepted, but in 1911 Ulrich showed that the uppermost part of the Theresa, subsequently named the Heuvelton Formation (Chadwick 1915), was of Lower Ordovician (Tribes Hill) age, whereas the restricted, or typical, Theresa was shown to underlie the Little Falls dolomite of Upper Cambrian age. Although the name Theresa is not used in this report, there is strong probability that the typical Theresa and Ruisseau Norton in the Châteauguay area are parts of a continuous rock-unit, which was, however, probably time-transgressive, so that our northern part of the rock unit may well be younger than that part developed at Theresa, N.Y.

In 1946, a series of passage beds in the vicinity of Ottawa, similar to those in New York State between the "Potsdam" and the Beekmantown dolomite, was named the March Formation by A.E. Wilson. She wrote (p.13): "The March formation consists of alternating gray sandstone and sandy dolomite or blue-gray dolomite, all weathering dark rusty brown. The sand grains are large, generally rounded, and commonly loosely cemented. Some of the thick dolomite beds contain pockets, 1 inch to 3 inches in diameter, filled with large crystals of pink or white calcite. The formation represents a transition from the Nepean sandstone to the Oxford dolomite, the sand content being most evident at the base." Also she wrote (p. 12): "The lower contact is placed arbitrarily at the lowest dolomitic layer." However, "the lower basal dolomitic layer is rarely exposed and the interbedded resistant sandstone layers are widely exposed and resemble the Nepean..... The upper contact of the March is placed arbitrarily above the last occurrence of sand in any quantity." Wilson's March Formation corresponds almost exactly in lithology to our Ruisseau Norton member. Our Cairnside member is not developed in the Ottawa - St. Lawrence lowland, although superficially it appears to resemble Wilson's Nepean sandstone.

Cairnside Member

Distribution and Lithology: The rocks of this member are typically exposed for a few miles southeast of Cairnside corners. The type section is to be seen along the road going southeast from Cairnside (Fig. 2). It is nearly pure orthoquartzite with siliceous, or rarely (in its upper part), dolomitic cement. This is in contrast to the Ruisseau Norton member, in which dolomite and dolomitic orthoquartzite are interbedded in more or less equal amounts. Crossbedding is common but never on so large a scale nor so prevalent as in the Rivière aux Outardes member of the Covey Hill Formation. It is on the whole fairly thin bedded; very few beds reach 2 feet in thickness and most are less than 6 inches. Many of the thicker beds are more resistant to the weather than are thinner bedded parts and so stand out as escarpments, continuous in some places for nearly a mile. This is particularly noticeable on a sloping topographic surface where the harder parts form somewhat steeper slopes than do the intervening beds. This gives an undulating surface across which a road shows a series of step-like changes in slope, as for instance on the southern 2 miles of Highway 40 from Ormstown to Saint-Antoine Abbé, or along Highway 52, 2 miles east of Havelock.

What are probably the lower beds of the Cairnside member occur along, and within a mile to the east of, the road from Covey hill to the International border (Fig. 3). They consist of nearly white orthoquartzites, well,evenly, and thickly bedded, poorly crossbedded, and devoid of visible feldspar (Pl. IA). These beds, so distinct from anything found on Covey hill, have dips for the most part less steep than those prevalent over Covey hill itself, and yet they lie within a quarter of a mile of what are, southwest of Covey Hill corners, some of the stratigraphically lowest

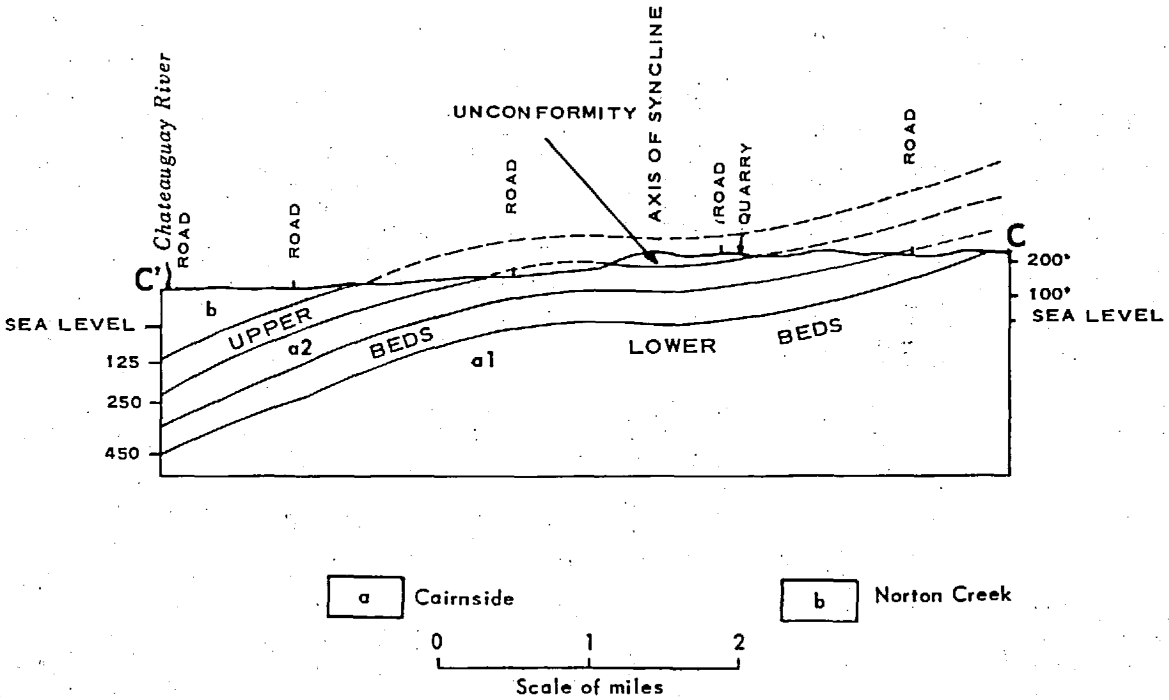


FIGURE 2

SECTION ALONG LINE C-C'. THIS ILLUSTRATES THE STRUCTURE OF THE UPPER PART OF THE CAIRNSIDE MEMBER AT ITS TYPE SECTION.

beds of the Covey Hill Formation, about 500 feet lower than those at the summit of the hill. Such a relationship can best be explained by a fault, of which, however, there is no local corroborative evidence. Nevertheless, on the 1962 New York State map a fault is shown in this position, striking more or less north-south. At its southern end the downdrop is on the west side of the fault, whereas at Covey Hill the downdrop must be on the east.

Thin-sections: Several thin-sections of this sandstone were made. In all cases save one the section consists almost wholly of quartz grains, rounded or subrounded. A few of the quartz grains are composite as if they had been derived from granite or gneiss. In most of the sections the quartz grains are intergrown with sutured contacts. Feldspar is relatively rare, except in one section noted above where, as kaolinized(?) orthoclase and microcline, it makes up 15% of the whole. In one other section microcline amounts to 25%, and in the other sections the feldspars together do not amount to as much as 1%. Orthoclase is usually kaolinized; microcline is fresh or nearly so. Both orthoclase and microcline have authigenic overgrowths of orthoclase, the latter also being kaolinized. Accessory minerals, other than the feldspars, are limonite, zircon, garnet, amphibole, brown and green tourmaline, and muscovite; their abundance is more or less in the order given.

Although the cement is dominantly siliceous, especially in the lower part, carbonate cement is present in some of the upper dolomitic beds. In one case the quartz grains appear to float within the dolomite cement, though no evidence of dolomitic replacement of quartz was noticed.

Internal Unconformity: Seven thousand feet southeast of Cairnside a road goes off to the northeast toward Riverfield. From 1,500 to 3,000 feet along this road, and on both sides of it, quarrying has removed a layer particularly rich in silica, and has exposed the top of the underlying bed. Looked at casually, the upper surface of the lower bed shows shallow depressions 2 to 3 inches across resembling interference ripple-mark (Pl.IIB). However, a close study of these depressions shows that they are actually hollowed out places within a thin-bedded sandstone, the bedding being preserved throughout the ridges separating the hollows which therefore are erosional in origin and cannot be interference ripple-mark (see Fig. 4). Still more remarkable is the nature of the surfaces of the depressions. Some are glass-smooth to the touch, and almost all show that the sand grains have been truncated so that ideally they consist of the lower hemispheres of what might have been originally nearly round grains. Such abrasion could hardly have been achieved by any other agent than wind or ice. Glaciers would not have left the ridges undestroyed, whereas eddies from gentle winds might well have scoured and polished those parts within the depressions. Covering the saucer-like hollows is a discontinuous bed of dark gray, micaceous shale,— paper-thin over most of the surface, but reaching a maximum thickness of 4 inches in the quarry 4 1/2 miles NW. of Hemmingford. This shale has

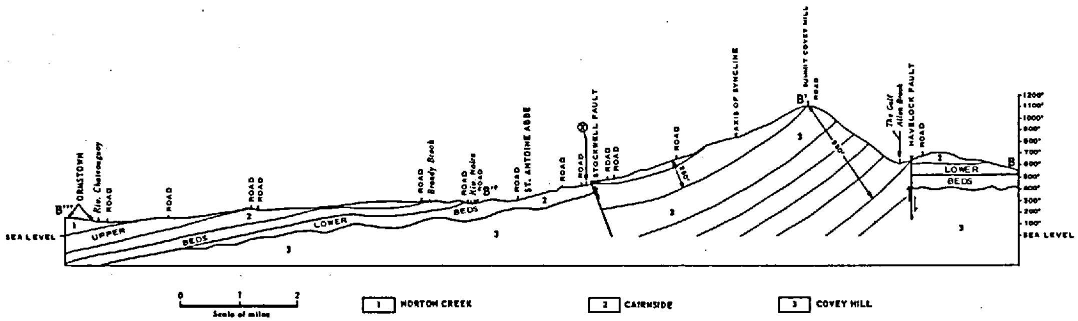


FIGURE 3

CROSS SECTION ALONG LINE B-B'-B''-B'''. NOTE THE HORIZONTAL LOWER CAIRNSIDE BEDS AT B, AND THE GENTLY UNDULATING LOWER AND UPPER CAIRNSIDE BEDS BETWEEN THE STOCKWELL FAULT AND B'''.

facilitated the removal of the overlying bed during the quarrying operations, leaving the underlying surface intact over most of the quarry floor. The shale is composed of dioctahedral illite and K-feldspar (personal communication from R.S. Dean).

Granting that we have here an erosional unconformity involving a wind-polished surface, further conclusions can be developed. Wind would only truncate and polish sand grains that were firmly cemented together, and this in turn implies a fairly deep burial, with the subsequent removal of probably tens or scores of feet of beds, presumably by water action, before the present unconformity could be exposed. Following this exposure a period of stability must have developed allowing the wind to drift very fine sand over the surface, pitting it into its present shape and eddying sand around within the pits to truncate and polish the grains forming the bases of the hollows. This represents a long period of instability encompassing the following stages:

1. Deposition of the overlying Cairnside beds.
2. Cessation of composition, cementation of burial beds.
3. Rise of land, and subaerial erosion down to level of the present unconformity.
4. Stabilization of conditions, with sand drifting over the strongly cemented bed, pitting it through selective action, cause unknown, and truncating the underlying sand grains.

5. Subsequent depression, retaining in all probability the final wind-blown dust film soon covered by pure quartz sands of the upper part of the Cairnside member.

That this is not an isolated peculiarity is proved by the finding of the same unconformity in several localities; in blocks thrown up by the excavation of a stream 1/4 mile southeast of Botreaux; in a newly excavated ditch southeast of the road and about midway between Rivière-des-Fèves and Riverfield; and on the floor of a quarry 1 1/2 miles northwest of Hemmingford.

Relationship to Covey Hill beds.— It appears that subsequent to the formation of the Covey Hill beds an invasion of the sea resulted in the reworking of Covey Hill sediments, yielding reasonably clean sands almost devoid of colored impurities and of feldspar yet still holding here and there a few pebbles. Crossbedding is not strongly developed. The combination of the lack of currents strong enough to develop the swales of the upper Covey Hill (Rivière aux Outardes member) beds, or strong enough to transport abundant pebbles, presumably set the stage for the occupation of the sea floor by bottom dwellers, a few of which left traces in these beds in the form of burrows of the *Arenicolites* type.

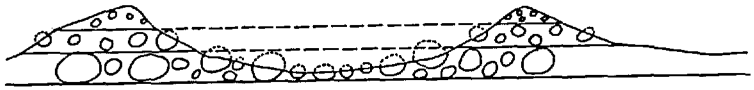


FIGURE 4

Diagrammatic section across one of the depressions on the mid-Cairnside unconformity. Note that the bedding has been eroded to make the hollow, and that the sand grains have been truncated. Vertical exaggeration about 3X; horizontal exaggeration about 2X; sand grains disproportionately large.

D.N.R.Q. 1965 B-846

The fault contact at the east end of Covey hill has already been referred to. Elsewhere, though actual contacts are unknown, the distribution indicates that an unconformity of considerable magnitude separates the two formations. The best evidence for this lies in the inliers of Covey Hill sandstone and conglomerate surrounded by, and presumably earlier covered by, Cairnside beds. At Saint-Chrysostôme the exposures in the river banks are typical lower Covey Hill, with pebbles, shale flakes and pink and green colors, etc. Crossbedding is present but there are no swales such as are so common in the Rivière aux Outardes member. Five other inliers of Covey Hill beds can be seen, the most northwesterly belonging probably to the Rivière aux Outardes member. The southeasternmost is typical Covey Hill similar to the beds close to the summit of the hill, topographically 800 feet higher. In general these Covey Hill beds dip more steeply than do the adjacent Cairnside rocks, which latter give the impression of belonging to a blanket of clean sands spread over the eroded surface of the Covey Hill beds.

Thickness: Lack of a definitive section raises serious difficulties in the way of obtaining the thickness of the Cairnside beds. Southeast of Cairnside the upper beds occur as synclines. An east-west line intersecting the road going SE. from Cairnside, 1 mile from the latter place, is as close to the axis of this fold as we can get. This axis can be traced 2 miles east of the road and 1/2-mile west of it. The complex of Cairnside exposures still farther west does not fit in well with this synclinal pattern. Thicknesses can be measured of the beds underlying the 2 1/4-mile long axis, and also along a line 2 miles long striking S.60°E. from the western end of this axis and ending on a road running NE. in Aubrey. This latter line intersects the lowest beds nearly perpendicularly. Dips of 1° to 2° are the rule, with occasional dips up to 3 1/2°. Assuming dips along the axis of 1° and 2° and the same for the line at S.60°E., the thicknesses can be calculated to be as follows:

	1°	2°	average 1 1/2°±
Along axis	207'	415'	311'
Along 120° line	184'	369'	276'

Somewhat higher dips should be expected on the flanks of the fold, and this could explain the discrepancies in the two calculated thicknesses. An average between the two is probably nearly correct, and consequently a thickness of 300 feet is considered reasonable.

Whether this figure of 300 feet represents the total thickness of the Cairnside member in the vicinity of Cairnside cannot be told. There is no certainty concerning the structure of this member, and, until the structural relationship between the Cairnside syncline and the rest of the outcrops of this member is known, 300 feet is the only figure that deserves serious consideration. It can hardly be less, and it possibly may approach 400 feet. (see Fig. 1, 2).

The exposures southeast of Havelock probably include the basal beds of this member, and give additional information (Fig. 3). If we assume, as is reasonable, that the outcrops along the road south from Covey Hill corners and those south of the road running east from the same place are not separated by faults, are all parts of the same succession, and are essentially horizontal, then a section based on their topographic elevation would be as follows:

725' to 650'	along road south from Covey Hill corners
650' to 575'	No outcrop
575' to 500'	Large outcrop south of east-west road
500' to 450'	No outcrop
<u>450' to 425'</u>	Outcrop south of east-west road.
725' to 425'	Topographic limits to outcrops, equivalent to 300 feet of horizontal strata.

Hence, with complete horizontality the beds exposed in these outcrops would be 300 feet thick. With a constant dip to the southwest, as is indicated, the thickness would increase 130 feet per degree of dip, and a like amount of dip to the northeast would decrease the thickness similarly. The dips are not uniform but all have a westerly or southerly component, with a maximum recorded value of 4°SW. Hence it is reasonable to give at least 300 feet and probably 400 feet as the thickness here. Without doubt there is some overlapping between the Cairnside and the Havelock sections. In the latter, within 50 feet of the top, there are friable beds suggesting the earlier presence of a carbonate cement, and a few hundred feet north of the Covey Hill custom house, at about the top of the section there, one may see Arenicolites, so common in parts of the Cairnside farther to the northwest. What the overlap is cannot be determined, but trails, burrows, and Lingulepis acuminata are abundant towards the base in the Cairnside type area. Since these are scarce or absent in the Havelock section most of the latter probably underlies the Cairnside section, and hence the total maximum thickness would be 800 feet. However, accepting the reasonable figures of 300 feet given for each section above, and allowing an overlap of, say, 100 feet, the combined thickness is probably very close to 500 feet.

In the St. Lawrence River No. 1 well at Saint-Timothée, between what is now recognized as Ruisseau Norton and the typical Potsdam, there are 334 feet (423' to 757' in the log) of white and light gray sandstone devoid of pebbles. This is considered to be the equivalent of the Cairnside member.

Structure: The near horizontality of the beds near Havelock (Pl. IA) and those in the vicinity of Aubrey have already been referred to. Both distribution and attitude aid in determining the course of this band of outcrop as shown on the map. East of the Havelock fault the Cairnside beds occupy a wide exposure within which the dips are either horizontal or have a western component. Such attitudes do not fit in with the obvious (though not necessarily correct) interpretation of the structure as that of an anticline plunging north-northeast, a companion to the Chambly-Fortierville syncline. Probably numerous minor warpings, possibly related to the Havelock fault, have been responsible for this anomalous condition.

West of the Havelock fault almost all of the most northern exposures have horizontal bedding. To the southwest, however, difficulties appear. In two localities the Cairnside beds occur as synclines with very low dips of both bedding and axes, 1^{o} to 2^{o} being the rule. The clusters of exposures near Botreaux and a mile southeast of Ormstown do not show this synclinal tendency. The three folded areas have in common a marked linear limitation of outcrop along their southwestern borders, which limitations are here taken to represent faults. The displacement along the faults is unknown as is also their lateral extent beyond the respective outcrop groups.

Considering the fairly wide exposure of essentially horizontal rock north of Aubrey these synclinal structures within the belt of outcrop of the Cairnside member call for special explanation. Because of sparse exposures, it is unknown whether the synclinal forms also affect the neighboring Cairnside and Ruisseau Norton beds. The axes of the folds, all nearly E.-W., are not in harmony with the regional folds exemplified by the Chambly - Fortierville syncline, the axis of which strikes about 35^{o}. It is possible that they are the result of the uplift along the Stockwell fault, especially if that fault has a steep southerly dip, in which case the rise of Covey hill would crowd the region to the north of it, inducing whatever accommodation was appropriate. Hence, possibly the extent of the Cairnside beds was foreshortened sufficiently by the formation of low warps whose axes would be parallel to the strike of the fault, i.e. nearly E.-W. The beds north of Aubrey were both too far from the fault and also too far to the east to have been affected. The outcrop group at Botreaux may not have been affected because of the lesser disturbance along the fault towards its western end. No ready explanation of the faults bounding the synclines comes to mind. It is not considered that this folding was intense enough to have been influenced by the later folding, probably late Ordovician, when the Chambly - Fortierville fold was initiated. The synclines in question and the Havelock and Stockwell faults belong to an earlier structural episode. The history of sedimentation in the Quebec Lowlands does not have any place for such disruption after the beginning of Beekmantown time.

In summary, the two major faults and the minor crumpling of the Cairnside beds are presumed to have occurred immediately prior to Beekmantown deposition. Thus, the Cambrian - Ordocivian interval would be one of structural instability, with unconformable relationships between the two systems of rocks concerned.

Fossils: In contrast to the lower beds in the Havelock area those of the upper part in the vicinity of Cairnside have fossils in nearly every outcrop. Tracks, trails, and burrows (ichnofossils) and *Lingulepis acuminata* occur in fair abundance.

Lingulepis acuminata has been recorded from beds of known Upper Cambrian and of known Lower Beekmantown ages in northeastern North America. Our specimens are typical in every respect. The most unusual occurrence is 2 miles north-northwest of Saint-Antoine-Abbé, near the end of an abandoned road going northeast from Highway 40 north of Brandy brook. Here a great many specimens were taken both from outcrop and from a pile of moss-covered debris, evidently the refuse left by some early collector. It is interesting to speculate whether or not this collector was Logan, for there is no record of any other having found this fossil hereabout. This species was also found during the course of the current work as follows: - at the type locality; on the southwest side of the road in several outcrops; in woods about 10,000 feet from Cairnside; near the confluence of Brandy brook and Noire (Black) river, where its horizon is approximately the same as that of the "Logan outcrop" given above; in the Beauharnois Formation along L'Acadie river 1/2 mile north of the road corner 2 miles west of Hallerton.

Climatichnites wilsoni: This ladder-like trail, which is so common in the basal Cairnside at Melocheville (Lachine map-area), is nowhere abundantly preserved in the Châteauguay area, but has been seen in a dozen localities.

Protichnites sp.: This track-trail is rare, and, like the preceding, is poorly preserved. It has not been possible to identify the species to which examples from the Châteauguay area belong.

Arenicolites sp.: These U-shaped burrows are exceedingly common in several places, particularly 2 miles east-southeast of Cairnside and 1/2 mile south of Corbin (Pl. VIB,VIC). In both cases burrows of three different sizes occur in the assemblages made up of burrows of the same size. Nowhere was there seen a surface showing the upper apertures of the burrows, but the curved lower parts are very common. The largest of these is also common in the Cairnside sandstone at Buisson Point in the Lachine map-area. In the lower Cairnside beds of the Havelock area this fossil occurs sparingly and only in the topmost beds exposed there.

Several species of *Scolithus* are present in this formation, but they need a careful morphological and ecological study before they can be identified with species already described. Both vertical and inclined types are represented. Some of the vertical tubes are divided vertically by curved structures appearing on the horizontal surface as crescentic diaphragms. They have little if any stratigraphic value, and like most of the previously mentioned ichnofossils are facies fossils.

At several places there can be seen the trail of an animal preserved as an irregularly curved path, some nearly circular with a diameter of a foot or so. If the name is not preoccupied, the writer would propose the name *Pyrichnites* for it (Pl. VIA).

A peculiar track, not elsewhere described, occurs on the surface of sandstone beds 1/2 mile southeast of Botreaux, the only known locality. It consists of a longitudinal series, about an inch wide, of parallel ridges and furrows of approximately equal widths. The ridges are 1/2 - 3/4 inch apart. In a few cases this arrangement of cross-bars occurs in a continuous sunken groove 1 inch wide, 1/4 inch deep and up to 1 foot long. No *Scolithus* was seen in the layer carrying this track, though elsewhere *Scolithus* is abundant. The tracks are aligned N.20°-40°E.

Still another unrecorded type of trail can be seen in the type area 11,000 feet southeast of Cairnside and 2,000 feet north of the road. This trail consists of two parallel, bounding impressed lines about 5 mm. apart, and a row of depressions along the middle line.

Ruisseau Norton Member

Type Section and Lithology: Succeeding the Cairnside member of the Châteauguay Formation is a series of alternating sandstone and dolomite beds, with every gradation between the two extremes. Even where the contacts between sandstone and dolomite are sharp, there is little evidence of contemporary erosion. The type section, one of the most interesting outcrops, can be seen 2 1/2 miles northwest of Hemmingford, where, on a hillside facing the valley of Norton creek,the following section was measured:-

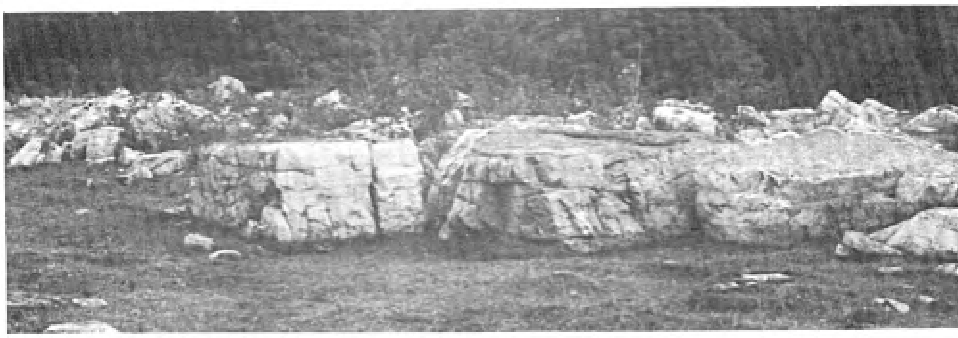
Top of Section

10' - 12'		Upper dolomite: Dense, medium to light gray dolomite, dark buff to dark brown weathering. One unidentifiable inarticulate brachiopod and fragmentary dendroid graptolites were found near the top.
	4'	Upper sandstone: Rarely outcrops and usually found as a band of loose blocks along the base of the upper dolomite.
	13'	Middle dolomite: Upper 5 feet massive; lower 8 feet very finely banded, sandy, light gray weathering; so abundantly supplied in places with sand grains as to be easily mistaken for a sandstone. Branching burrows.
2 1/2' -	3'	Middle sandstone: Sparingly exposed along a flat bench. May possibly grade upward into the middle dolomite.
	6'	Lowest dolomite: Dark brown, lumpy weathering dolomite, interbedded with thin white sandstone layers.
	2 1/2'	Lowest sandstone: Weathers white on outside, but buff to rusty within. Upper 6 inches in places is crowded with vertical Scolithus burrows.
38'	40 1/2'	

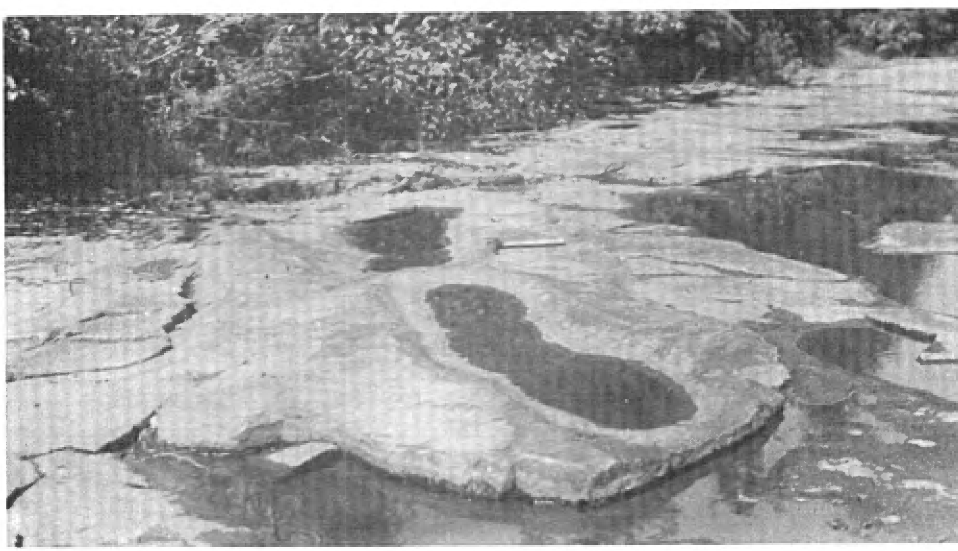
At the exposures along Norton creek where it makes a quarter-mile-long bend to the east, 2 1/2 miles northwest of Hemmingford, the section is as follows:

2'	Coarsely crossbedded sandstone, in places buff weathering.
2'	Irregularly bedded dolomitic sandstone; massive above with many burrows; lower part with few burrows.
2'	Dolomitic sandstone, buff weathering. In part an autobreccia with fragments of dolomitic sandstone.
6"	Solid sandstone bed, coarsely crossbedded.

PLATE I



A.– Cairnside member. Châteauguay Formation. Thick-bedded quartzose sandstone in lower part of member. One mile SE. of Covey Hill corner, looking SE.

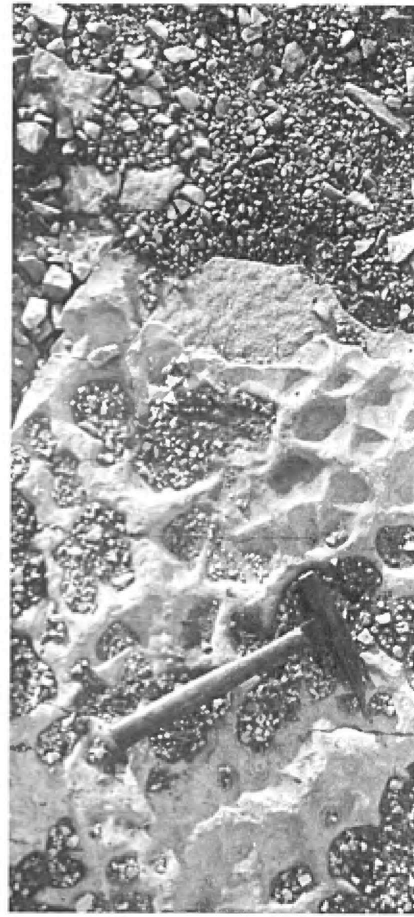


B.– Rivière aux Outardes member, Covey Hill Formation. Large-scale swales characteristic of this member. Rivière aux Outardes, 1 1/2 miles W. of Franklin-Centre, looking N., downstream.

C.– Covey Hill sandstone. One mile SE. of Stockwell, looking S.

PLATE II

A.– Covey Hill Formation. Thin-bedded sandstone forming north wall of Gulf lake at the International boundary.



B.– Cairnside Formation. Looking down at surface of internal unconformity. 1 1/2 miles SE. of Cairnside corner.

C.– Covey Hill Formation. Small anticline in sandstone beds high up on north flank of Covey Hill.

PLATE III

Havelock breccia mound. One mile N. of Covey Hill corner. Looking NE. from highway.

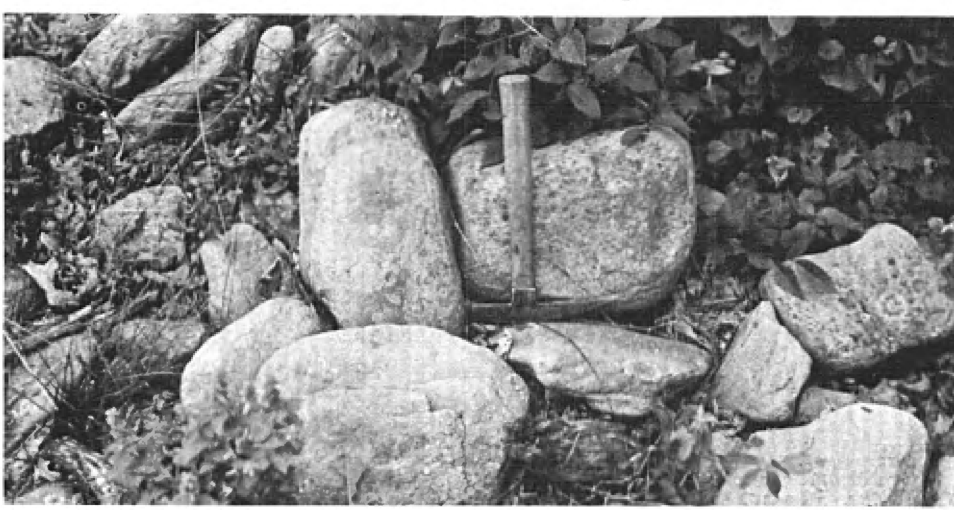
PLATE IV

Havelock breccia. Stratified calcarenite on south side of summit of breccia mound.

PLATE V

A.– Covey Hill sandstone and conglomerate. Note irregularity of bedding. This outcrop was at one time a stack isolated from the "mainland" to the left of the photograph (south, and uphill). Deeper water of the retreating post-glacial sea lay over the lower, right hand side of the photographed area. One mile ESE. of Stockwell. Looking W.

B.– Another view of the stack shown in IV - A. Looking S.

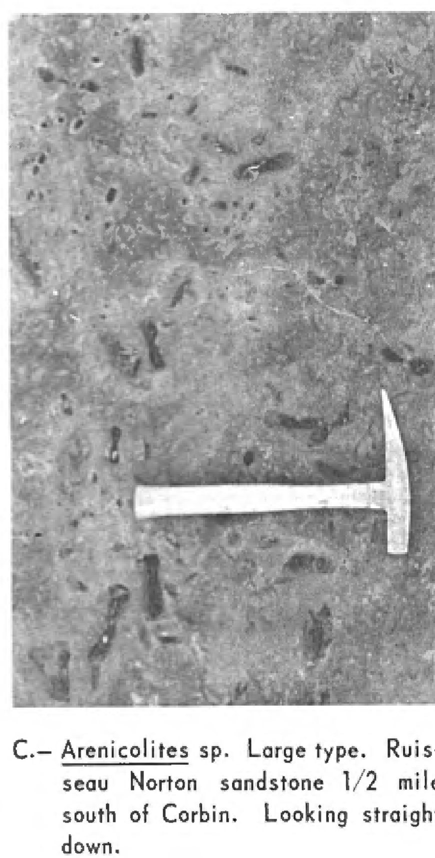


C.– Post-glacial boulders from beach at Stockwell.

PLATE VI

A.— "Gyrichnites". Trails on surface of Ruisseau Norton sandstone. Two miles NNW. of Hemmingford. Looking straight down.

B.— Arenicolites sp. Small type. Ruisseau Norton sandstone 1/2 mile south of Corbin. Looking straight down.



C.— Arenicolites sp. Large type. Ruisseau Norton sandstone 1/2 mile south of Corbin. Looking straight down.

1' -	1'3"	Crossbedded sandstone.
6" -	1'3"	Dolomitic sandstone, buff weathering, irregular in thickness due to irregular lower contact.
1'3" -	2'	Massive sandstone bed.
	2'	No exposures.
	1'	Dolomite in patches, overlying at least 6 inches of sandstone with "Gyrichnites" trails.
	3'	Sandstone with carbonate cement showing only as blocks masking a small escarpment.
	5'	Massive sandstone, non-carbonate cement.
	5'	No exposures.
	5'	Massive sandstone, finely but strongly crossbedded.
30'3" -	32'	

Some 2,000 feet north of the above section and 1,000 feet west of the creek there is an outcrop consisting of beds almost certainly below those just recorded. The section is as follows:

1'3"	Pure, white weathering sandstone.
3'	Buff weathering sandy dolomite.
3'	Buff weathering white sandstone.
6'	Massive sandstone.
13'3"	Total thickness.

In the above, and in fact in the great majority of the exposures of the rocks of this member, the individual beds of sandstone usually make escarpments, whereas the dolomite beds weather back to make terrace floors. The escarpments should theoretically face in the direction opposed to that of the dip of the beds, but a plot of all recorded escarpments does not show such a preference. This is not remarkable in the light of the very low dips of the beds, rarely more than 2°, and in many cases less than 1°. The escarpments thus become topographic rather than structural features.

Distribution and Structure: In outcrops adjoining Norton creek 2 miles or so northwest of Hemmingford, and in the southeast corner of the area, it is obvious either from the pattern of outcrop or from the actual dips and strikes that the exposures are disposed in nearly flat folds (see Map) which, however, do not markedly influence the general trend of the member. In addition to these minor folds, the areal distribution shows two synclinal folds of major importance. First, both the areal distribution and the attitude of the beds in the southwestern corner of the area indicate a synclinal structure, very close to the southwestern end of the Chambly-Fortierville syncline the dominant structural feature of the St. Lawrence Lowland. This fold probably carries on beyond the International border, as is shown on the 1962 New York map, but it is not certain that the rocks of the Châteauguay Formation are involved. Second, the distribution near Norton Creek corner shows the presence there of a smaller and tighter syncline due in part without doubt to complications attending the Havelock fault.

The continuation of the band of outcrop as mapped from Norton Creek corner to the western margin of the area at Ormstown is not subject to outcrop control.

Thickness: No measured section of the whole sedimentary succession attributable to this member can be made. However, its breadth of outcrop is considerably less than that of the upper part of the Cairnside member, the thickness of which was given above as 300-400 feet. Estimates of thickness made upon the basis of breadths of outcrop are admittedly vulnerable. Nevertheless, in the adjoining Lacolle area, Eastern Canada No. 6 well at Saint-Blaise passed through 250 feet of alternating sandstone and the dolomite, and in the St. Lawrence River No. 1 well at Saint-Timothée alternating sandstone and dolomite occurred for 250 feet. In both cases the rocks concerned are now considered to belong to the Ruisseau Norton member. Other logs of wells farther to the northeast show a diminishing thickness for this member. Hence 300 feet does not seem to be out of line as an estimated thickness within this area.

Beekmantown Group

Historical Background

Lying upon the rocks of the Châteauguay Formation is the massive dolomite of the Beauharnois Formation, belonging to the Beekmantown Group. Though neither of these latter terms is new it seems best to give a review of the history of the subdivision of the rocks of the Beekmantown Group.

Following pioneer beginnings by Amos Eaton in 1824 and T.A. Conrad in 1837, the first specific work of any consequence on the Lower Ordovician (Beekmantown) of Northeastern North America was by Lardner Vanuxem (1842) who recognized that the "Calciferous Sandstone" was distinct from his "fucoidal layers." The former would have included the upper Châteauguay beds, and much of the Beauharnois, the remainder of the latter falling into his fucoidal beds. He was the first to illustrate diagnostic fossils of Beekmantown beds -- Orthoceras primigenium, Ophileta complanata, and Ophileta levata.

The extension of these beds into Canada was recognized by Logan (1863, p. 110). "The typical Calciferous sandrock, which succeeds to the Potsdam in New York and the adjacent parts of Canada, consists in the lower part of a dark bluish-gray, crystalline, strongly coherent dolomite or magnesian limestone, weathering yellowish brown, and very often holding small geodes, generally filled with calcareous spar.... The fossils have in most cases disappeared, leaving only their moulds in the rock. The upper part of the formation is in some places a bluish gray calcareous argillite, weathering yellow or brown, and often having a bituminous odor." For the remainder of the nineteenth century little more was done, and Calciferous sandrock remained the accepted name for this development. In 1890, Brainerd and Seely, and also Whitfield, revived interest in the study of the Calciferous and provided a standard of reference for later work in their subdivisions A to E, although the presence of both Cambrian and Ordovician faunas in their section proved to be a cause of much confusion. In 1899, Clarke and Schuchert recognized the necessity of differentiating between the Cambrian and the Ordovician portions of the Calciferous, but unfortunately they chose for the latter the quite inappropriate name Beekmantown. Subdivision of the Beekmantown was begun in New York by Clarke, Cushing, Ulrich, and others, and progressed as new information became available, resulting in formational names such as Hoyt and Little Falls (both now considered Cambrian), Tribes Hill, etc. As far as the present area is concerned these names are of interest only for purposes of correlation.

In Quebec no attempt to subdivide the Beekmantown rocks was made until Raymond (1913) suggested setting apart the lower beds (Passage Beds, auct., in part) which he considered to be reworked Potsdam sands with a carbonate cement, and referred them to the Theresa Formation (Cushing's name for the Passage Beds). The vast remnant bulk of the Beekmantown, well exposed around Montreal, he named the Beauharnois Formation, taking the name from a locality along the old Beauharnois canal, and stating that he considered it "a complete formation, and a great deal remains to be done on its stratigraphy and fauna." Subsequent writers in Quebec followed Raymond's terminology for the beds which overlie the Potsdam and underlie the Chazy, until Wilson (1946), working in the Ottawa - St. Lawrence Lowland, included the Nepean sandstone (previously called Potsdam) within the Beekmantown, and, for the formational names Theresa and Beauharnois, Wilson substituted two new names, March and Oxford respectively. Whether or not further information will allow March to remain as a substitute for Theresa cannot be told at present, but no substantial reason has yet been forthcoming for abandoning

Raymond's name Beauharnois. Because of the lack of distinctive features between the Oxford beds west of the Frontenac axis and the Beauharnois beds east of it, the term "Beauharnois" holding the priority, the name "Oxford" should disappear. According to Wilson "The same formation was called 'Beauharnois' by Raymond (1913, p. 140) who used the name only once." Subdivision of the Beauharnois Formation was first mentioned by Belyea (1952), and was accomplished by Byrne in 1958. The latter recognized three members: a basal Sainte-Clotilde, a middle Huntingdon, and an upper Châteauguay.

Beauharnois Formation

Distribution and Lithology: In the northwestern corner of the area outcrops of pure and of sandy dolomite that differ lithologically and in fossil content from those of the Châteauguay Formation are placed in the lower part of the Beauharnois Dolomite Formation. The Beauharnois occupies a large portion of the area of the St. Lawrence Lowland to the north. At Sainte-Thérèse its thickness, measured from the core of the Mallet well, is 1,060 feet. Because of the near horizontality of the beds in the present area, and the difficulty of deciding on a line along which a measurement might be made, only 200-300 feet can be estimated. However, in all probability the true thickness is much greater.

Within this formation there are many varieties of lithologic expression -- from massive beds to beds composed of laminae 1 mm. or so thick, with or without shaly partings, either type being up to 2 feet thick. Much of the rock is mottled, probably due to imperfections in the dolomitization process. Vugs are present but rare, and are usually filled with white or pink calcite. The color ranges from nearly white to nearly black, with a gray-buff tendency. Sand grains are present in many places, and sandstone beds and sand in the dolomite are common especially in the lower member. Limestone is confined to the lower member.

In many places the dolomite contains beds and masses of breccia. Although of many aspects there seems to be little doubt that these are of contemporaneous or penecontemporaneous origin, and are of a different nature from those described under Structural Geology below. In no case do the breccias conform to the normal pattern of intraformational breccias. They may well be due to disruption consequent upon dolomitization -- small-scale collapse breccias, so to speak. These are common along L'Acadie river between two road bridges 1/2 mile apart and 1 1/2 miles west of Hallerton.

Subdivision: The subdivision of the Beauharnois Formation envisioned by Raymond was first attempted by Belyea (1952, p. 8) who recognized three intergrading parts -- and upper part composed of dark "argillaceous beds, commonly with shale partings, and exhibit all gradations from limestones, dolomites and silty dolomites to dolomitic and limy siltstones."

(ibid., p. 9). The middle division "consists predominantly of clean, crystalline and granular dolomites" (ibid., p. 8) and the "lower part of the Beekmantown consists of interbedded sandstones and dolomites and beds showing all gradations between them. It includes Clark's Theresa (March) formation."

Later, Byrne (1958) recognized and named three subdivisions of the Beauharnois as follows:

Châteauguay member. Dolomite, shaly dolomite, shale and limestone. Fauna characterized by Bathyurus. Mallet well, 317 feet thick.

Huntingdon member. Unfossiliferous, mostly massive dolomite. Mallet well, 457 feet thick.

Sainte-Clotilde member. Dolomite, sandy dolomite, sandstone, and fossiliferous limestone. Fauna characterized by Hystricurus. Mallet well, 221 feet thick.

Because no satisfactory type sections have yet been found for any of these members, the writer adopts the names Sainte-Clotilde and Huntingdon provisionally, and suggests Saint-Lin for the upper member. Only the Sainte-Clotilde and the Huntingdon members are exposed in this area, but it is likely that the Saint-Lin member occurs in the northeast corner beneath the overburden.

Sainte-Clotilde Member

Distribution and Lithology: The beds of this member occur in four parts of the present area. First, in the southeast corner where they wrap around the axis of the Chambly-Fortierville syncline, and lie between a band of Ruisseau Norton beds and the overlying Huntingdon dolomite; second, in very restricted areas near Norton Creek corners, where again they occur close to a synclinal axis; third, they are exposed in the northwest corner of the area north of Ormstown; and fourth, in an outcrop 3 miles northeast of North Georgetown.

Type and Other Sections: The type section for this member is to be found in two quarries 1 1/2 miles west-southwest of Sainte-Clotilde, one north and one south of the railway track. Byrne's type section (1956, p. 47) was taken from the quarry south of the tracks, to which is now added the section in the quarry to the north.

Top of Section:

1'	Limestone, pale blue-gray, sandy, cherty in places. Fossiliferous. Ecculiomphalus intortus, Liomphalus multiseptarius.
1'	Limestone, blue-gray, fine-grained, conglomeratic in places,
1'	Limestone, blue-gray, finely laminated, shaly.
1'6"	Limestone, blue-gray, medium-grained, crystalline, with some large dolomite crystals. Sparingly fossiliferous. Bellefontia, Clarkella, Finkelnburgia, etc.
1'6"	Limestone, blue-gray, very fine-grained crystalline, grading into medium-grained crystalline below, cherty in places. Fossiliferous in upper part. 1/2 inch to 2 inches shale partings.
6'	Limestone, medium-grained crystalline, with dolomite and calcite crystals. Irregularly bedded. Thin shale interbeds.
12'	Total thickness.

North of the track, the section, taken from the quarry wall, is entirely of beds of dolomite, as follows:

Top of Quarry Wall:

1'	Medium-dark gray dense dolomite, with rough weathered surface. Massive, no vugs, no burrows.
1'4"	Buff-gray dense dolomite, obviously bedded, vuggy. Burrows on weathered surfaces.
1'4"	Ditto, bedding seen only on weathered surfaces.
1'6"	Medium gray dense dolomite.
1'	Dark gray dense dolomite, with finely-bedded brecciated fragments in center. Separated from bed above by very irregular surface in detail.
1'5"	Medium gray dense dolomite, very finely bedded. Small pink calcite vugs. Burrows in upper part.
1'4"	Thin bedded, deeply weathered dolomite.
1'6"	Medium gray, fine-grained crystalline dolomite containing blocks up to 6 inches of similar dolomite but finely banded.
1'2"	Medium-gray, very fine-grained crystalline dolomite. Obscure bedding.
1'6"	Dark gray, finely grained crystalline dolomite. Thin bedded.
1'8"	Medium gray, very fine-grained crystalline dolomite. Wavy bedding on weathered surface.
1'	Ditto, but bedding regular.
1'2"	Light gray, very fine-grained crystalline dolomite.
1'10"	Ditto.
1'8"	Medium gray dense dolomite.
1'	Ditto, a few burrows.

1'5"	Light gray-buff dense dolomite finely and irregularly striped with black laminae.
1'2"	Ditto.
1'6"	Light gray, dense dolomite.
1'8"	Upper surface with bosses 5 feet across and 1 foot relief. In between bosses and on upper surfaces of some are patches of <u>Scolithus</u>-bored rock.
1'4"	Gray-blue dense dolomite with small pink calcite vugs.
1'2"	Gray-blue dense dolomite.
1'	Dark gray dense dolomite in 1-inch to 4-inch beds.
	Base of quarry.
30'8"	Total thickness.

A few shorter sections elsewhere are given below to indicate the lack of uniformity of lithology within this formation. About 3 miles west of Hallerton and just west of a railroad track there is an outcrop showing the following sections:

9"	Dolomite, light gray, fine-grained crystalline, very finely banded.
8"	Dolomite, medium gray, sandy, weathering to a rough pitted surface.
1'	Dolomite, light gray, massive, buff weathering.
2'5"	Total thickness.

North of the road, 1 1/2 miles northwest of Hemmingford, there is the following section:

1'0"	-	1'6"	Sedimentary breccia consisting of nearly white, sandy, finely bedded dolomite.
4"	-	6"	As above, but with shale above and below.
3"	-	6"	Dolomite, massive, with pink calcite vug fillings up to 1 inch across.
3"	-	6"	Dolomite, dark gray, mottled.
2'0"	-	2'0"	Dolomite, dark gray, finely banded.
6"		6"	Dolomite, gray, massive.
4'4"	-	5'6"	Total thickness.

At the crossing of L'Acadie river and Highway 52 the following section occurs:

9"	Dolomite, buff, fine-grained, weathering brown. Faint and irregular banding.
6"	Dolomite, gray to buff, fine-grained. Thin wavy irregular shaly bands emphasized by weathering.

1'   Dolomite, dark blue-gray, fine grained. Irregularly banded.
1' 2"   Dolomite, blue-gray with black mottling. A few sand grains toward the top.

3' 5"   Total thickness.

Along the northeast-southwest road parallel to, and 2 miles northwest of, Châteauguay river from Ormstown to Allens Corners several exposures of dolomite can be seen on both sides of the road. These show brown weathering fine-grained, medium to dark blue-gray dolomite with lenses of dolomitic sandstone. In two or three places there are remnants of fossiliferous limestone beds not completely obliterated by the dolomitization. Near the northeast end of this road there is an exposure in a stream below a bridge at the end of a private road where the following section can be seen:

1'   Dolomite, dark blue-gray, very fine grained. Poor molds of fossils are common.
6"   As above, but interbedded with black fissile shale.
5'   Dolomite, dark blue-gray, very fine grained, weathering brown. Faint remanent banding. Vugs present. Freshly broken rock from the ditch contains abundant Lecanospira.

Four miles to the northeast exposures near the road consist of gray sandy dolomite, weathering brown, with interstratified beds of dolomitic sandstone which itself contains lenses of very fine-grained blue-gray dolomite.

Along the nearly dry valley floor of an unnamed stream, probably the abandoned channel of Châteauguay river, 2 miles west of Sainte-Martine, there is a long exposure of calcareous and dolomitic sandstones, replete with irregular and anastomosing burrows, and containing also a few poor examples of Lecanospira. This is interpreted as the most northerly outcrop of the rocks of this member in this area. It may be noted that the rock exposed in Châteauguay river at Sainte-Martine just north of this area probably also belongs here.

Fossils.- At the type locality the following fauna has been identified (Byrne, 1958, p. 55):-

CYSTIDEA

Eocystites primaevus (Billings)

BRACHIOPODA

Lingulella mantelli (Billings)
Clarkella calcifera (Billings)
Finkelnburgia subequiradiata Ulrich and Cooper
F. wemplei (Cleland)
F. sp
Syntrophiopsis landmani Ulrich and Cooper
Diaphelasma sp., cf. D. complanatum Ulrich and Cooper

GASTROPODA

Liomphalus ?multiseptarius (Cleland)
Ecculiomphalus intortus Billings
Archaeophialla antequissina Hissinger

CEPHALOPODA

Cyrtendoceras depressum Ulrich et al.
Endoceras sp.

TRILOBITA

Bellefontia colliana (Raymond)
B. nonius (Walcott)
B. acuminiferentis (Ross)
B. sp.
Isoteloides Whitfieldi (Raymond)
Tsiniania sp.
Xenostegium sp.
Hystricurus sp.

Byrne lists fossils from four other localities as follows:-

BRACHIOPODA	LOCALITIES
Lingula sp. cf. L. quebecensis (Billings)	1
Syntrophinella sp.	1
GASTROPODA	
Lecanospira compacta	1, 4
Ecculiomphalus canadense (Billings)	1
Euomphalopsis involuta (Ulrich and Bridge)	1
Pleurotomaria? sp.	3

TRILOBITA	LOCALITIES
Hillyardia semicylindricum Ross	1
Hystricurus sp.	1
H. conicus	1
H. flectimembrus Ross	3
Bellefontia colliana Raymond	2

1. Float in field 2 miles east of Harrington.
2. Railway line, 500 feet east of Sainte-Clotilde quarry.
3. Boulders in field, 1 mile southwest of Bogtown.
4. Field, 1/2 mile east of road going north from Hemmingford and 2 1/2 miles north of Hemmingford.

In the Redpath Museum, McGill University, there are several specimens, labelled merely "Ormstown", of dark fine-grained, somewhat sandy dolomite, containing the following species:

GASTROPODA

Ecculiomphalus canadense (Billings)
Pleurotomaria calcifera Billings
Lecanospira compacta (Salter)
Hormotoma sp. *anna* Billings
Eccyliopteris disjunctus (Billings)

The position of the exposures near Ormstown, the lithology of the specimens, and the fauna all indicate the Sainte-Clotilde member.

Huntingdon Member

Distribution and Lithology: The only beds referable to this member lie along the axis of the Chambly-Fortierville syncline, northeast of Hemmingford. The lithologic types can be well seen from the following sections:-

From a cut in the north-south railway line 1/4 mile south of Barrington Station -

1' 2"	Dolomite, gray, fine grained, faintly banded.
1'	Dolomite, blue-gray mottled, fine to medium grained.
1' 6"	Dolomite, blue-gray, siliceous, mottled. Thick bedded.
1' 4"	Dolomite, pale buff with calcite-filled vugs. Fragments of brachiopods.
2'	Dolomite, blue-gray, fine grained, weathering buff.
7'	Total thickness.

Outcrop in field 2 miles due east of Barrington:-

4" Dolomite, blue-gray, siliceous. Much calcite present.
9" Dolomite, buff-gray, sandy, Weathers to sandy pitted surface.
4" Dolomite, siliceous, like that of 4" bed above.
1' 6" Dolomite, gray, fine grained, faintly banded.
1' Dolomite, fairly dark gray, slightly mottled, sandy. *Hystricurus*, *Clelandia* present.

Outcrops along L'Acadie river 1 1/2 miles west of Hallerton, north of the east-west road.

3' 6" Dolomite, blue-black, regularly banded with much calcite. Sandy bands regular and conspicuous on weathered surfaces.
4" Dolomite, shaly, thin bedded.
2' Dolomite, irregularly banded and bedded, calcite common. Brecciated in places.

5' 10"

As indicated in the sections given above, there is very little limestone in this member. It is considerably less sandy than the Sainte-Clotilde member, and fossils are rare. Only one identified species is known from this area, and the complete fauna follows:

Cryptozoön
Lingulella mantelli (Billings)
Trilobite fragments (*Hystricurus*, *Clelandia*)
Crinoid columnals.

Thickness: Because no upper contact is known no determination of the thickness of this member can be arrived at. The thickness in the Mallet well is 457 feet.

STRUCTURAL GEOLOGY

STRATIFICATION

Throughout the area dips of less than 2° are the rule. In a few places dips up to 5° are common though of local importance only. In spite of the supposition that, in view of the northeasterly plunge of the folds, there should be a tendency for the beds to dip northerly and easterly this cannot be seen on the dip and strike chart. The reason is that because of the low dips, and the still lower angle of plunge, minor irregularities in either sedimentation or in subsequent disturbances have overlaid the original dip, giving the apparently anomalous pattern seen today.

UNCONFORMITIES

Two interformational unconformities and one intraformational unconformity deserve to be recorded. First, the unconformable relationship between the Covey Hill Formation and the covering Cairnside sandstone is nowhere shown, but is made mandatory by the inliers of Covey Hill beds within the belt of outcrop of the Cairnside member. The best of these occurrences is to be seen along the left bank of Anglais river at Saint-Chrysostôme where recent deepening of the river has exposed a fine section of the Covey Hill beds. These are medium-grained, well cemented, gray to brown sandstones containing some conglomerate lenses with pebbles up to 1/2 inch and shale slabs up to 4 inches long. The dip is, relatively for this area, steeply northwest, whereas the Cairnside beds nearby, consisting of white orthoquartzite, are essentially horizontal. Moreover, the Covey Hill sandstones shown here are not of the Rivière aux Outardes member, and this indicates an eroded thickness of at least 600 feet from the top of the Covey Hill Formation.

The second interformational unconformity lies between the Châteauguay and Beauharnois Formations. The evidence for this is deduced from the inferred geological history of the area. As indicated on Fig.1 and 3, the movement along the Stockwell fault is considered to have been responsible for the minor crumpling of the Cairnside beds southeast of Cairnside, and erosion following the accompanying uplift and preceding the Beauharnois inundation was responsible for the unconformity.

The intraformational unconformity lies within the Cairnside member, and has been described in detail above.

GENERAL DISTRIBUTION OF THE FORMATIONS

The Beauharnois Formation and the Ruisseau Norton member of the Châteauguay Formation conform roughly in attitude, and with them probably goes the upper part of the Cairnside member. If all the formations were conformably assembled, then fold axes, such as the Chambly-Fortierville synclinal axis, would traverse the entire area from northeast to southwest. That they do not do so, with the exception of the Chambly - Fortierville fold, is in itself evidence either of unconformable relationships between the formations or their members, such as the unconformity between the Covey Hill Formation and the Cairnside member of the Châteauguay Formation, or of structural anomalies interfering with such orderly arrangements, e.g., the northward extension of the Havelock fault to cut the Ruisseau Norton syncline, and the east-west Stockwell fault, both of which will be decribed below.

DISLOCATIONS

Joints

These structural features were not everywhere recorded. Enough readings were made, however, to show on the Joint Pattern map (Fig. 5) that there is a dominant system striking between S.45°E. and S.25°E, and that toward the eastern end of Covey Hill this gives way to a system more nearly north-south. Without doubt this change in direction of the joints is a reflection of the influence of the Covey Hill fault. The barely discernible rotation of the joints along the northern base of Covey hill may also be a reflection of the influence of the Stockwell fault. A secondary system striking between N.60°E. and N.70°E. is important in the western part of the area.

Faults

Two major faults interfere with the preservation of the original distribution of the formations. These bound Covey hill on the east and north sides. For neither is there any direct contactual evidence, but their existence is necessitated by the distribution.

Havelock Fault.- That Covey hill is bounded by a fault along its eastern end is indicated by the horizontal propinquity there of basal Covey Hill beds and strata of the Cairnside member of the Châteauguay Formation (Map and Fig. 3). Because the elevation of the lowest Covey Hill beds is about 300 feet, and the elevation of the lowest recognized Cairnside beds is about 425 feet, the displacement indicated is about 125 feet less than the estimated thickness of the Covey Hill Formation (at least 1,800 feet) or at least 1,675 feet (possibly even 2,075 feet). Or, looked at another way, because the elevation of the uppermost recognized Covey Hill beds in the vicinity of the fault is 1,100 feet, and the elevation of the lowest Cairnside beds is 425 feet, the minimum vertical displacement along the fault is about 675 feet. To this should be added (a) the thickness of any Cairnside beds below the 425-foot level, i.e. between the lowest observed Cairnside beds and the underlying Covey Hill Formation, and (b) the thickness of the upper Covey Hill beds once existing above the 1,100-foot elevation of the eastern end of Covey hill. This latter thickness is 602 feet. The vertical displacement becomes, therefore, 675 feet + a (above) + 602 feet, or well over 1,277 feet, possibly as much as 1,500 feet.

Such a fault should be recognizable along its strike to both the north and the south. Southward, one indication is seen on the 8-mile topographic map (OTTAWA-MONTREAL. N.W. 44/76, National Topographic Series, Ottawa) where contours indicate a marked drop in elevation along the east side of a north-south line traceable south from Covey hill for 8 miles. In

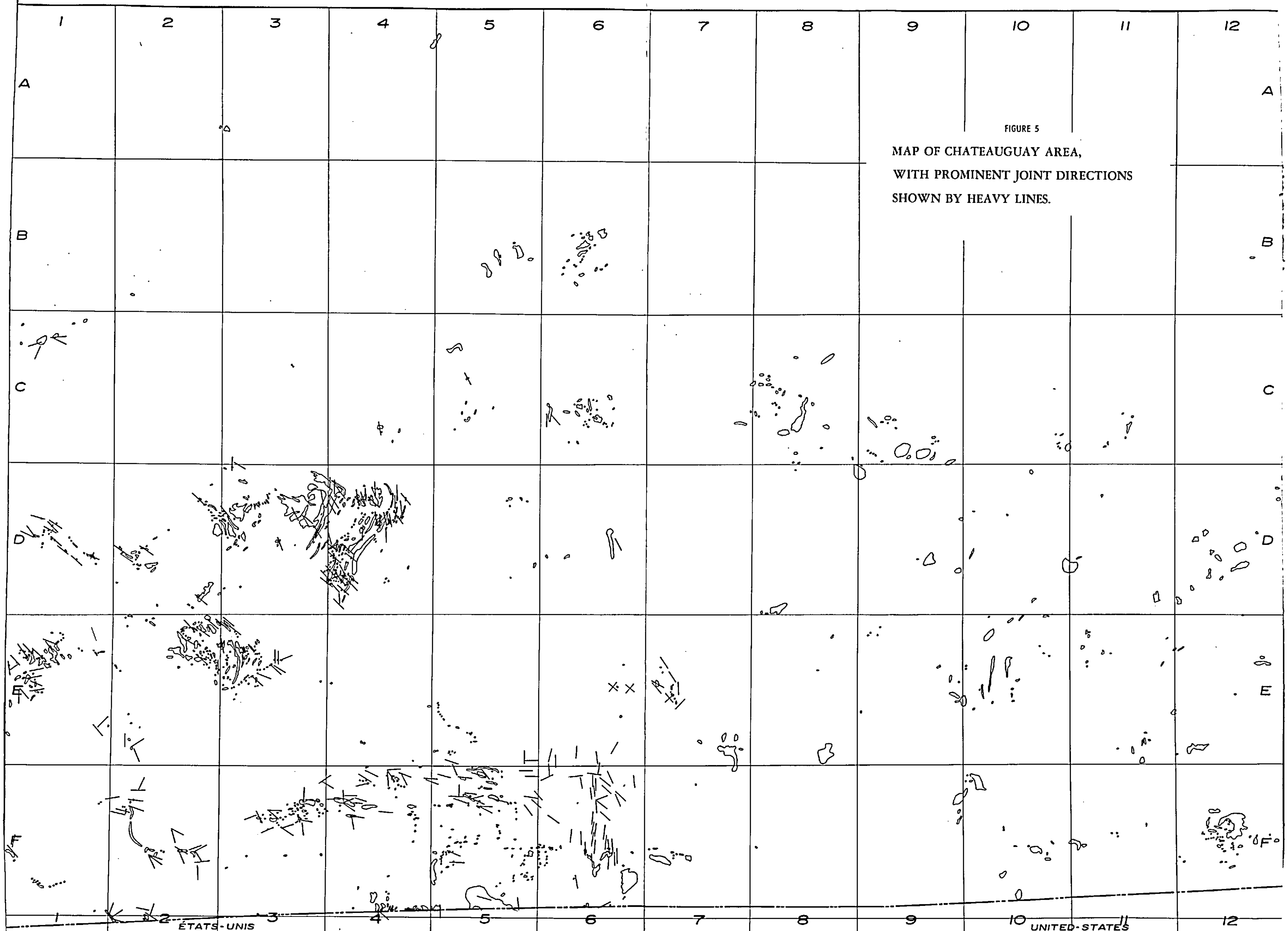


FIGURE 5

MAP OF CHATEAUGUAY AREA, WITH PROMINENT JOINT DIRECTIONS SHOWN BY HEAVY LINES.

addition, on the recent geological map of New York State an outlier of Theresa is shown within the Potsdam with a fault contact along its eastern side. This fault is in line with our Covey Hill break, but in the New York occurrence the movement must have been in the opposite direction. To the north of Covey hill there are complications close to the axis of the Ruisseau Norton syncline which can best be resolved by faulting, one corroborative feature of which is the presence of abundant brecciated exposures thereabouts. Northward beyond this point no evidence for the continuation of the fault is known due to the complete absence of outcrop along the fault line. It lies parallel to the Tracy Brook fault (St. Johns map-area; New York State map), and may be a unit in a fault system related to thrust faulting and subsequent reactions consequent upon the Taconic orogeny.

Thus the Havelock fault is indicated by distribution and dislocation over a length of 20 miles. Moreover, within a half-mile or so of the fault, the joints within the Covey Hill Formation show a marked tendency to become more nearly north and south. This alignment with the strike of the fault is expectable, granting that the forces which caused the dislocation itself were strong enough to fracture the rock at least along the western side of the break. No other cause for the unusual north-south strike of the joints in that vicinity comes to mind.

Stockwell Fault.- The Stockwell fault is of more limited extent, and may even die out within the Châteauguay map-area. As with the Havelock break no direct evidence has been recognized save for a slight tendency for the joints to depart from the normal NW.-SE. direction toward an E.-W. pattern. There are no post-Covey Hill beds in close proximity to, and north of, Covey hill. The Stockwell fault is therefore a hypothetical break, but nonetheless highly probable (see Figs. 1 and 3). The vertical dislocation would be the same as that of the Havelock fault where the two faults meet, decreasing westward possibly to zero within a mile or two of the southwestern corner of this map-area.

In addition to the faults just described are others of slight importance. One and three-quarter miles east of Hemmingford, north of Highway 52, there is an outcrop of dolomite, cutting across which, at 25°, is a nearly vertical fault. Brecciation occurs along the length of the fault as exposed, the blocks in the breccia ranging from an inch up to 2 feet across. Toward the northern end the beds appear to band into a gentle anticline for 10 to 20 feet on either side.

At the type locality for the Ruisseau Norton member of the Beauharnois Formation the succession of sandstone and dolomite shows minor faults in which the beds are displaced no more than 2 feet.

Folds

Chambly-Fortierville Syncline.- Because of the low dips in this area no strong folding can be expected. The most important example is the Fortierville-Chambly syncline so well shown in the southeast corner of the area. The axis of this fold here strikes about N.35°E., a direction quite in harmony with the strike of the remainder of the axis north of this area. Involved in this fold are the Beauharnois Formation and the Ruisseau Norton member of the Châteauguay Formation. Whether or not the Cairnside member of the Châteauguay Formation carries the continuation of the folding south of the international border is not known, but this is probable.

Ruisseau Norton Syncline.- A similar, but smaller fold is seen in the vicinity of Norton Creek corners, where both distributions and attitude of the pre-Beauharnois beds show that the fold here is complicated by faulting that is considered to be the northernmost expression of the Havelock fault. No other folds of regional importance have been recognized, save that this syncline is matched to the east and west by distribution indicating anticlines with axes striking and plunging NNE.

Cairnside and Saint-Antoine-Abbé Folds.- The peculiar distribution of the Cairnside beds between Cairnside and Saint-Antoine-Abbé invites the suggestion that these beds have been folded into synclinal forms. The structures themselves, and the supposed sequence of events, have been discussed in the treatment of the Cairnside member. Briefly, it is considered that prior to Beauharnois deposition the Stockwell fault resulted in compression of the region to the north, distorting the then recently formed Cairnside beds (and possibly also the Ruisseau Norton beds) into low folds just sufficient to accommodate the foreshortening consequent upon the faulting (Fig. 2A). Erosion of this warped terrane preceded Beauharnois deposition. Later folding, close to the Ordovician - Silurian time boundary (probably Taconic) resulted in the distribution seen around the Chambly-Fortierville synclinal axis. The earlier disturbance was not severe enough to cause any essential deviation of the member-boundaries following the Taconic disturbance.

Covey Hill Syncline.- This has already been described under Covey Hill Formation.

BRECCIAS

In addition to the breccia bodies, contemporaneous or penecontemporaneous, that occur in many places throughout the Beauharnois Formation and are usually confined to beds less than 2 feet thick, there are other and much larger breccias. The largest of these is a complex on the east side of the road from Covey Hill corner north to Havelock, called here the Havelock breccia. Some 2 miles north of this, and on the east side of the same north-south road, is a peculiar body here named the Ruisseau Allen ring-breccia. Brecciated masses accompany the Havelock fault at Norton Creek. A small-scale fault breccia body northwest of Hemmingford has been mentioned above.

Breccia presumed to be related to dolomitization

This type of breccia is confined almost solely to the dolomite beds of the Châteauguay and Beauharnois Formations. It includes examples that may be the result of dolomitization, and others that may be of contemporaneous sedimentary origin. In many cases little evidence, and none conclusive, has been found to support either mode of origin.

Along L'Acadie river going downstream (north) from the east-west Hallerton road there are abundant exposures belonging, probably, to the top of the Sainte-Clotilde member of the Châteauguay Formation. For 1/4 mile, dark blue-black dolomite is interstratified with thin sandy lenses. About 500 feet from the bridge over the Hallerton road there is a bed of breccia 30 inches thick consisting of dark blue-black dolomite blocks with considerable calcite and some pyrite. The upper surface of this breccia has poorly preserved gastropods. Similar breccias can be seen for 750 feet downstream. In none is there any evidence of other than a contemporaneous origin of the breccia.

A side road goes west from the main road 1 1/2 miles north of Hemmingford. One mile from the main road there are widespread exposures of dolomite. In an excavation on the edge of the woods to the north the topmost bed exposed is a breccia containing sandy dolomite and dolomitic shale blocks, similar to the rock types in the remainder of the section. This has the characteristics of an intraformational breccia.

Breccias connected with Monteregian activity.- The Havelock and the Ruisseau Allen breccias are probably related to the forces responsible for the Monteregian Hills to the north.

Havelock Breccia.- The distribution of the outcrops of breccia comprising this occurrence is shown on Fig. 6A. In the southern group of exposures the sandstone at the southern end is white to red normal Covey Hill sandstone, coarse grained in places, with small pebbles of quartz common. The strike in general is northerly and the dip is 5°NE. The relatively high dip may possibly represent the drag caused by movement along the Covey Hill fault. Within 50 feet of the northern ends of each of the bands of sandstone there occur breccia bodies containing fragments of light gray weathering, dark gray Trenton Limestone bearing characteristic fossils of the Middle Trenton Montreal Formation such as *Resserella rogata*, Sowerbyella sericea, Platystrophia ?trentonensis, Rafinesquina alternata. The limestone itself is brecciated. In two places the blocks of Trenton limestone were originally large enough to support small-scale quarrying, and pits 10 to 12 feet long and 5 to 6 feet wide and high remain. To the southeast of these pits and to the northeast of the remaining exposure with the Trenton limestone there are exposures of breccias rich in brownish, gray, and white sandstone together with dolomite fragments, all referable to either the Châteauguay or the Beauharnois Formations The northernmost of these outcrops presents an escarpment facing north, and shows a sandstone "dike" cutting across its summit. That this is a diatreme breccia similar to the main mass of the breccia of Sainte-Hélène Island,Montreal, seems reasonable because of, first, the lack of igneous material in the breccia, and,second, the mixture at the present level of fragments of many formations. Between the top of the Covey Hill beds and the base of the Middle Trenton there should lie about 2,000 feet belonging to the Châteauguay Formation and the Beekmantown, Chazy and Black River Groups, and the Lower Trenton limestone.

The northern group of exposures,which can be seen as a hill 60 feet high(not recorded on the topographic map)roughly circular in plan (Pl. III), duplicates the rock types of the southern exposure except that there is no Covey Hill sandstone here. Breccia exposures (Type B, Fig. 6A) consisting of sandstone and/or dolomite fragments are quite comparable to their counterparts in the southern group, though not so strongly cemented. Type C consists of limestone blocks and resembles that of the southern group in all save the size of the blocks, - none larger than 1 foot across have been seen. The most remarkable breccia type is that labelled D (Fig. 6A) which consists of loose friable sandstone (Pl. IV) and fine-grained breccia consisting largely, and in some exposures wholly, of Trenton limestone fragments. These are bedded deposits, nearly horizontal except in one place, possibly a loose block. No bedding can be detected in any of the other exposures in the northern group. If we assume that this breccia mound is also a diatreme, spacially separate from the southern diatreme, it is difficult to imagine how such stratified sand- and grit-sized deposits could originate within a diatreme unless the top of the filled part of the pipe, following the in-fall of the ejectamenta, corresponded with about the present topographic surface. There might then be an opportunity for sorting and sifting the finer constituents within what would almost immediately become a deep water hole. If the Trenton limestone were at the topographic surface at the time of diatreme action that formation would have yielded the largest fragments and many of these, in falling down to the present topographic level, might easily have been triturated to make up the sandy beds now apparent.

Ruisseau Allen Breccia.- One mile north of Havelock, and immediately east of Allen brook there is a remarkable group of exposures consisting of outcrops of sandstone and breccia disposed as shown in Fig. 6B. More or less in the center of the group there are three exposures of white,

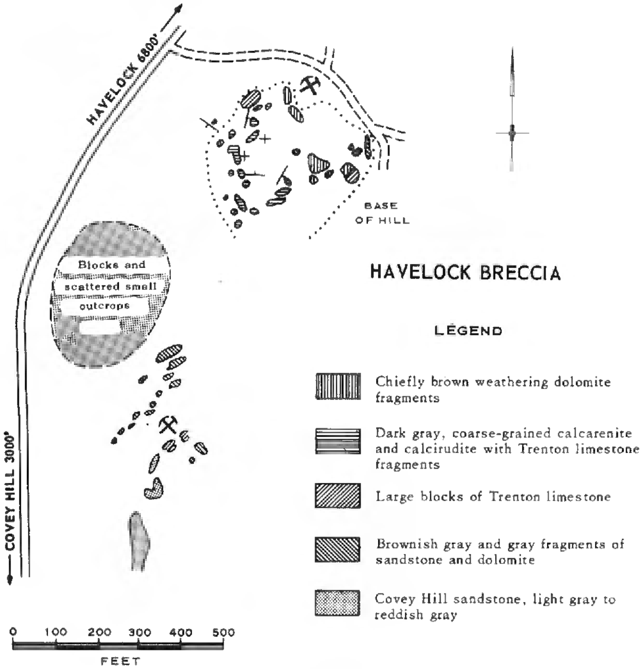


FIGURE 6A

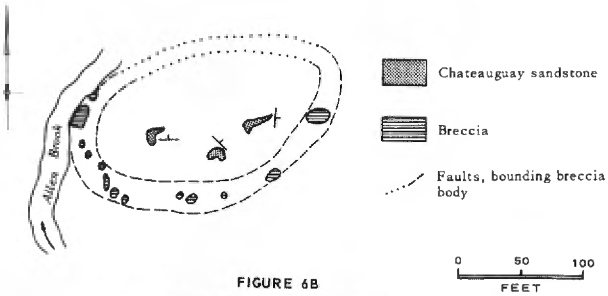


FIGURE 6B

ALLEN BROOK BRECCIA RING

D.N.R.Q. 1965 B-846

fine-grained sandstone, weathering white to light gray, all fairly well consolidated with siliceous cement. No more than 25 inches of bedding is seen in any of these outcrops. Strikes are N.,S.45°E, and E. with dips, respectively, of 5°, 3 1/2°, and 4°, indicating that these are separate blocks and not part of a continuous body of sandstone. Scolithus burrows are present in two of the exposures. These characteristics correspond to those of the upper part of the Cairnside member of the Châteauguay Formation. The local country rock is probably lower Cairnside.

The breccia, of which there are a dozen exposures, is composed largely of fragments of dolomite and impure calcareous sandstone in a sparse matrix consisting of granular quartz and dolomite. The fragments range in size up to 14 inches in diameter. All the larger fragments have rounded edges and corners. The sandstone fragments all appear to have a calcareous cement which allies them to the Cairnside or Ruisseau Norton members.

Although the ring is incomplete it does not take much imagination to conclude that it may once have been complete. Whether this be so or not it seems probable that this is an expression of an abortive diatreme action which did not result in a cleared-out pipe as in the northern Havelock mound, but instead represents the upward limit of gas-fluxing dislocation at the time of cessation of the deep-seated igneous activity responsible for these disruptions.

Fault Breccia

In many localities it is virtually impossible to decide upon the origin of some of the breccia bodies. In one or two places the close association of breccia with faults indicates a genetic relation. One relatively insignificant example has already been described above in connection with the fault 1 3/4 miles east of Hemmingford. Two outcrops 1 mile southeast of Norton Creek corners belong here. One was revealed by the excavation of Norton creek about 1,000 to 1,250 feet upstream from the highway bridge.

The second can be seen in a small quarry immediately adjacent to and north of the east-west road south of the creek. In the river outcrop the brecciation is accompanied by slickensides, and the rock types are sandstone and dolomite. The quarry exposure shows on the northern wall a clean-cut boundary between breccia containing blocks of dolomite and dolomitic sandstone and the undisturbed essentially horizontally bedded dolomite. Nearby exposures to the south and west have localized breccia developments that are certainly not restricted to any bedding unit, and may well be due to minor adjustments to the Covey Hill fault.

Halfway along the road from Covey Hill to the international border the road shows numerous cuts in the lower part of the Cairnside sandstone. Several of the roadside exposures consist in part of breccia not apparently related to bedding. These may well be side effects of the Covey Hill fault. Four thousand feet south of Covey hill and 200 to 300 feet west of the road there is a wide and low mound of brecciated rock which, too, may well be due to the Covey Hill fault, although the evidence here is very inconclusive.

GEOLOGIC HISTORY

The first event recorded in the local rocks, as here interpreted, was the accumulation of debris from the Adirondack mountains to the south, possibly in the form of widespread alluvial fans stretching out tens of miles to the north of the mountains. Assuming that the granite of the Adirondack massif had undergone a long period of weathering there would be available an enormous amount of detritus rich in quartz and feldspar later to be deposited very irregularly in nearly horizontal beds with crossbedding common. The red color, the abundance of feldspar, and the lack of fossils are conditions corroborative of the idea that these beds might have been accumulated subaerially. It is, however, difficult to understand how crossbedding should show almost uniformly easterly dips (Fig. 7) if the sands had been derived from the mouth and had been carried by essentially northflowing streams. This may be an insuperable difficulty, but one could invent a lake into which the debris was poured and in which prevailing winds would produce a current system flowing from west to east. The same result could easily be achieved if the debris were deposited into the sea so rapidly that elimination of the red color and most of the feldspar was not achieved. Later work will doubtless shed more light upon this problem. It is here considered that the spread of alluvial fans, modified or not by marine action, was great enough to cover all of the present area, and that enough of the debris had been accumulated to allow the next step to take place.

Following this a sea advanced from around the Adirondack massif from the southeast and possibly also from the southwest. This marked locally the beginning of sedimentation related to the Appalachian geosyncline, the features of which had been in existence a few score of miles to the east since the beginning of the Cambrian period. In Upper Cambrian time the spread of the sea beyond the narrow limits of the Lower and Middle Cambrian brought the shoreline to this area. The first efforts of the sea seem to have been expended upon the mass of debris in the modified alluvial fans. As the strand moved southward most of the impurities of the sands would have been eliminated, albeit irregularly, resulting in quartz-dominant sands and gravels, most of the feldspar having been ground away and the iron-bearing coloring matter reduced to colorless iron salts. As the littoral progressed toward the highlands of the Adirondacks cleaner and cleaner sands would be deposited here while only less mature sands and gravels would still be delivered and deposited farther south. These reworked sands formed the

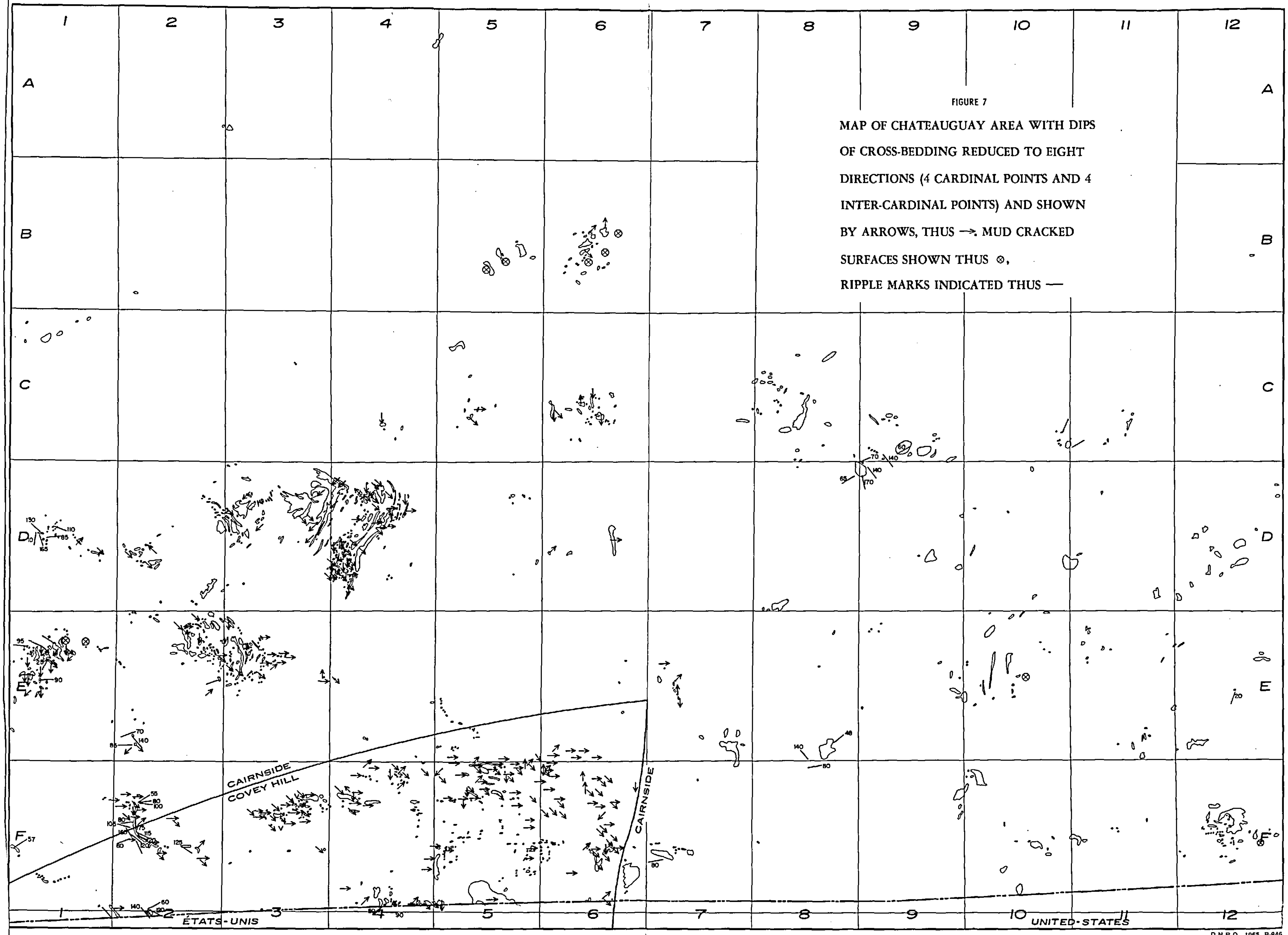


FIGURE 7

MAP OF CHATEAUGUAY AREA WITH DIPS OF CROSS-BEDDING REDUCED TO EIGHT DIRECTIONS (4 CARDINAL POINTS AND 4 INTER-CARDINAL POINTS) AND SHOWN BY ARROWS, THUS —>. MUD CRACKED SURFACES SHOWN THUS ⊗. RIPPLE MARKS INDICATED THUS —

lower part of the Cairnside member of the Châteauguay Formation, and were deposited unconformably upon the eroded surfaces of the Covey Hill beds, until a retreat of the sea, still in late Cambrian time, laid bare the sands which then covered all of the present area north of Covey hill, and in all probability all of the pre-faulting Covey Hill region too.

A readvance of the sea occurred without great time lapse. The evidence for this break is not altogether convincing, but nevertheless cogent. The lowest beds of the upper part of the Cairnside member of the Châteauguay Formation as exposed near Cairnside contain pebbles of quartz and are richer in feldspar than are the beds above them. No actual contact is known. Moreover, the lower beds are practically devoid of fossils but the upper Cairnside sea abounded in animals which left tracks, trails and burrows behind, and also in the brachiopod Lingulepis. How much of the lower beds were removed and how long a time interval elapsed present insurmountable problems. The advance of the sea reworked the already cleaned sands so as to reduce them to an almost pure quartz content, and to bring in a fauna as indicated above. That there were interruptions in depositions is shown by a remarkable unconformity within the Cairnside member, the latest phase of the attendant erosion having been achieved by wind which whipped sand around the area with two results -- first, a large quantity of pure quartz sand scattered over the area in the form possibly of dunes, and, second, wherever bedrock appeared its surface was scoured by drifting sand. As the sea advanced the quartz sand was spread out as a pure quartz deposit available for exploitation as a high silica deposit. The Cairnside sea was quiet enough for the fauna already listed to exist in. It was not a well populated sea, partly because of the lack of food in the quartz sand bottom and partly because the shifting sands made it difficult for normal benthonic animals to get a foothold. By this time the Lyon Mountain massif was probably largely inundated, so that coarse or mixed debris was no longer being produced in quantity. The widespread sea, with its southern shore line now far distant, promoted the deposition of carbonates, whether organic or chemical we do not know, and this provided much of the cement for the upper part of the Cairnside beds, and here and there in a few favorable locations, allowed the accumulation of enough carbonate to form dolomitic sandstones or even sandy dolomites. These varieties are rare in the Cairnside member, but remnants of them occur locally in the upper part. Ultimately, with no observed break in sedimentation, carbonate deposition became persistent enough so that separate beds of dolomite could be formed, perhaps originally as widespread lenses of limestone, contained within the normal Cairnside sandstone type. With the alternation of more or less equally developed dolomite and sandstone beds Ruisseau Norton sedimentation followed that of the Cairnside member.

According to the correlation of the members of the Châteauguay Formation and of the following Beauharnois Formation a considerable time gap must have occurred between the deposition of the beds of the two formations. No contacts are known but a withdrawal and later advance of the sea are regarded as practically certain.

It was during this interval that the Havelock and Stockwell faulting occurred, contributing to the driving off of the sea northward, with minor crumpling of both Cairnside and Ruisseau Norton beds, setting the stage for the later steep fault-line scarps bounding Covey hill on both the north and east sides.

With the partial erosion of the uplifted Châteauguay strata and subsequent advance of the sea to an extent probably greater than that during Châteauguay time, Sainte-Clotilde carbonate deposition was initiated with or without sands that were derived in part from the erosion of Ruisseau Norton and earlier beds or possibly delivered to the sea by winds. This condition, with a general lessening of the sand contribution, lasted throughout the time taken for the deposition of the Beauharnois Formation. Dolomitization was widespread on this sea-floor, but here and there, particularly at the beginning of Sainte-Clotilde time, limestone beds were preserved as such, and in favorable conditions (as shown in the Sainte-Clotilde quarry), contain a fairly abundant record of the marine life of the time. Sainte-Clotilde and Huntingdon beds are the last direct record in this area of local sedimentation,

It should be emphasized that save for the interruption caused in large part by the uplift of the Precambrian massif to the south, there were only temporary interferences with the orderly advance of the sea over this part of Quebec.

Hence the sandstones and lesser dolomites of the Châteauguay Formation are lithologically essentially similar to the dolomites and lesser sandstones of the Beauharnois Formation. The change from arenaceous to carbonate deposition, though progressive, was by no means orderly.

That deposition persisted throughout the remainder of the Ordovician period is most likely. Although no outcrop of Chazy rocks occurs here, distribution of the formation in the neighboring Lachine, Saint-Jean, and Lacolle map-areas shows that the Chazy sea doubtless occupied all of this territory with the formation of rock types similar to those characterizing the neighboring areas. The same may be said of Black River and Trenton rocks, though the presence of larger blocks of Trenton limestone in the Havelock breccia is direct proof of a once continuous cover of Trenton limestone over this region. Utica, Lorraine, and Richmond sediments were probably deposited here, perhaps not to the same thicknesses as occur farther north in the St. Lawrence Lowland. The non-marine Richmond (Queenstown)Formation was in all probability the last of the sedimentary formations deposited here.

The Taconic orogeny, which threw the Appalachian geosynclinal rocks into a mountain range, was responsible for the weak folding that pervades all but the southeastern part of the area. It is not known whether or not further sedimentation followed, as all traces were subsequently removed.

The next event took place during the Cretaceous period, when in response to the surge of magma in depth — farther north to form the Monteregian Hills — abortive attempts to break through resulted in the Havelock and Ruisseau Allen breccias, the former of which is interpreted as a diatreme which broke through to the surface without, however, any accompanying release of magma to form a volcano.

The long subaerial erosion which probably started in Middle Paleozoic time, persisted with, as far as is known, no interruption until the beginning of the Pleistocene epoch, during which successive glaciation, covering the northern half of the continent, affected this area in many ways. Much of the accumulated soil was removed, many of the rock outcrops were modified by glacial erosion, and events occurring subsequent to glaciation record the occupation of this area by first a freshwater lake receiving the water from the melting Wisconsin ice sheet. One of the rivers carrying the meltwater was responsible for carving the remarkable chasm on Covey hill known as the Gulf (Pl. IIA). This was succeeded by the occupation of the area by the Champlain sea, the retreat of which during the last few thousand years left the countryside as we see it today.

ECONOMIC GEOLOGY

Local rocks have been used for building stone, for road material, and recently as a source of high-silica rock. Sand and gravel of good to poor quality abound in the southern half of the area.

Building Stone

In a few localities, the dolomite beds of the Beauharnois Formation have been quarried on a very small scale for the production of stone for houses. No large-scale quarrying has been undertaken for this purpose. The sandstone has been little used, largely because of the difficulty of obtaining even roughly squared blocks. Logan (1863, p. 88,89) mentions the possibility of obtaining flagstones, stones for furnace hearths, and stone for glass-making from what is here called the Cairnside member.

Flagstones

During 1962 Les Carrières Saint-Chrysostôme opened a quarry, 1 1/4 miles southeast of Covey Hill corner, in the lower part of the Cairnside Formation for the production of sandstone slabs. Most of the product is sent to Montreal.

Road Material

A quarry at the road corner 1 1/2 miles southeast of Cairnside has been developed in the Cairnside sandstone for the purpose of providing road material. The sandstone is well cemented, hard, and should stand up well as aggregate material in both bituminous and concrete roads. Quarries in the Sainte-Clotilde limestone and dolomite 1 1/4 miles south of Norton Creek corners, on both sides of the railway, were used to provide road material and railroad ballast, but have not been used for more than a decade.

High-silica Sandstone

Increasing use of sandstone rating 99% or more SiO_2 in the production of ferro-silicon by St. Lawrence Alloys Company at Melocheville, and in other operations, has been the cause of considerable exploration for such rock. This kind of sandstone is confined almost exclusively to the Cairnside member. The richest rock lies just above the wind-swept unconformity described above. Quarrying in this horizon has been carried on by Electric Reduction Company, Montreal, 1/4 mile northeast of the four corners 1 1/2 miles southeast of Cairnside. On both sides of the road acceptable stone was taken out down to the unconformity, below which the quality was not acceptable. About 6 feet above the unconformity dolomitic cement and remnants of dolomitic beds raise the magnesium content above the tolerable limit, but for road material and concrete aggregate the stone is excellent.

A second quarry, a mile southeast of Holton station, was opened half a dozen years ago by Radius Exploration Ltd. in the Cairnside member, but at that locality the unconformity could not be recognized. The quarry operated for a year or two, but is now closed.

A third quarry, 4 1/2 miles northwest of Hemmingford, was opened and operated by E. Montpetit et Fils, Ltée, of Melocheville, Que. in the Cairnside member just above the unconformity. As in the case of the first-mentioned quarry above, no quarrying was done below the unconformity. There has been no activity since 1960.

In all these cases, though high-silica rock is available, transportation costs and competition with vein (pegmatite) quartz are said to be responsible for the disuse of these quarries.

Sand and Gravel

Sand and gravel pits are numerous along the northern slope of Covey hill, but large-scale excavation has been attempted in only one place. A mile west of Saint-Antoine-Abbé, Marcil Machabé operates a large pit, the products of which are presently used for the production of aggregate for light-weight concrete. North of Saint-Antoine-Abbé, in an area of dune sand, a small-scale operation supplies high-quartz sand to customers in Montreal.

BIBLIOGRAPHY

BARIL, R. AND MAILLOUX, A. (1950) - Etude Pédologique des sols du Comté de Châteauguay; Que. Dept. Agriculture Tech. Bull. No. 2

BELYEA, H.R. (1952) - Deep Wells and Subsurface Stratigraphy of Part of the St. Lawrence Lowlands, Quebec; Canada Geol. Survey Bull. 22.

BILLINGS, E. (1856) - Fossils of the Potsdam Sandstone; Sea Weeds, Shells, and Footprints on the Rock at Beauharnois; Can. Nat. 1, pp. 32-39.

BILLINGS, E. (1860) - Additional Note on the Potsdam Fossils; Am. Jour. Sci. (2) 30, pp. 242-243, 337-338.

BRAINERD, E. and SEELY, H. M. (1890) - The Calciferous Formation in the Champlain Valley; Geol. Soc. Amer. Bull. 1, pp. 501-513.

BYRNE, E.W. (1958) - Stratigraphy and Paleontology of the Beekmantown Group in the St. Lawrence Lowlands, Quebec; Unpublished Ph. D. thesis, McGill University.

Canadian Official Railway Guide with Airlines (June 1960). International Railway Publishing Company Limited, Montreal.

CHADWICK, G.H. (1915) - Post-Ordovician Deformation in the Saint-Lawrence Valley, N.Y.; Geol. Soc. Amer. Bull. 26, pp. 115, 287-294.

CHADWICK, G.H. (1920) - The Paleozoic Rocks of the Canton Quadrangle; N.Y. State Mus., Bull. 217, 218.

CLARK, T.H. (1934) - Structure and Stratigraphy of Southern Quebec; Geol. Soc. Amer. Bull., Vol. 45, No. 1, pp. 1-20.

CLARK, T.H. (1944) - Stratigraphy and Structure in the Vicinity of Montreal; Royal Soc. Canada Trans., 3rd Ser., Vol. 38, pp. 23-33.

CLARK, T.H. (1944) - Unfolded Rocks of the Lowlands; In Dresser and Denis, pp. 250-288.

CLARK, T.H. (1947) - Summary Report on the St. Lawrence Lowlands South of the St. Lawrence River (Quebec); Que. Dept. Mines Prelim. Rpt. 204, 18 p.

CLARK, T.H. (1952) - Montreal Area - Lachine and Laval Map-areas; Que. Dept. Mines, Geol. Rpt. 46, 159 p.

CLARK, T.H. (1955) - St. Jean - Beloeil Area; Que. Dept. Mines, Geol. Rpt. 66, 83 p.

CLARK, T.H. (1956) - Oil and Gas in the St. Lawrence Lowland of Quebec; Canadian Min. Metall. Bull. No. 531, pp. 480-484.

CLARK, T.H. (1962) - Ordovician Stratigraphy, St. Lawrence Lowlands North of Montreal; New England Intercoll. Geol. Congr. 1962, Montreal. Guide Book, pp. 53-60 (1962). Also Geol. Assoc. Can. 16th Ann. Meeting Montreal. Guide Book pp. 53-60. (1963).

CLARK, T.H. (1962) - Breccia Localities; New England Intercoll. Congr. 1962, Montreal. Guide Book, pp. 95-104. Also Geol. Assoc. Can. 16th Ann. Meeting, Montreal (1963). Guide Book, pp. 95-104.

CLARKE, J.M. and SCHUCHERT, C. (1899) - The Nomenclature of the New York Series of Geological Formations; Science, n.s. p. 10, pp. 874-876.

CONRAD, T.A. (1837) - First Annual Report on the Geological Survey of the Third District of the State of New York; N.Y. Geol. Surv. Ann. Rpt. 1, pp. 155-186.

COOKE, H.C. (1955) - An Early Paleozoic Orogeny in the Eastern Townships of Quebec; Geol. Assoc. Canada Proc., Vol. 7, Pt. 1, pp. 113-121.

CUSHING, H.P. (1908) - Lower Portion of the Paleozoic Section in Northwestern New York; Geol. Soc. Amer. Bull.19, pp. 155-176.

DAWSON, J.W. (1890) - On Burrows and Tracks of Invertebrate Animals in Paleozoic Rocks, and Other Markings; Geol. Soc. London, Quart. Journ. 16, pp. 595-617.

DEBLOIS, R. (1959) - Data on Wells Drilled for Gas and Petroleum in the St. Lawrence Lowlands Area; Que. Dept. Mines Publ. S-49, 119 p.

DRESSER, J.A. and DENIS, T.C. (1944) - Geology of Quebec; Que. Dept. Mines, Geol. Rpt. 20, Vol. 2

EATON, A. (1824) - A Geological and Agricultural Survey of the District Adjoining the Erie Canal in the State of New York; 163 p. Albany.

ELLS, R.W. (1895) - The Potsdam and Calciferous Formations of Quebec and Eastern Ontario; Roy. Soc. Canada Proc. Tr. 12, iv. pp. 21-30.

ELLS, R.W. (1896) - Report on a Portion of the Province of Quebec. Comprised in the Southwest Sheet of the Eastern Townships' map (Montreal Sheet); Can. Geol. Surv. Ann. Rpt. 7, pp. 31-92.

ELSON, J.A. (1962) - Pleistocene Geology between Montreal and Covey Hill; New England Intercoll. Congr. 1962, Montreal. Guide Book pp. 61-66. Also Geol. Assoc. Can. 16th Ann. Meeting (1963), Montreal. Guide Book pp. 61-66.

EMMONS, E. (1838) - Report on the Second Geological District of the State of New York; N.Y. Geol. Surv. Rpt. 2, pp. 185-252.

EMMONS, E. (1842) - Geology of New York. Pt. 2, Comprising the Survey of the Second Geological District; 437 p., Albany.

FISHER, D.W. (1955) - Time Span of the Theresa and Potsdam Formations in the Region Peripheral to the Adirondack Mountains, New York (abs.); Geol. Soc. Amer. Bull., Vol. 66, No. 12, Pt. 2; pp. 158-159.

FISHER, D.W. et al. (1961) - Adirondack Sheet. Geological Map of New York; N.Y. Geol. Survey.

GOLDTHWAIT, J.W., KEELE, J. and JOHNSON, W.A. (1913) - Pleistocene - Montreal, Covey Hill and Ottawa. Excursions in the Neighbourhood of Montreal and Ottawa; Internat. Geol. Congr. XII, Canada. Guide Book No. 3, pp. 117-135.

GOLDTHWAIT, J.W. (1914) - Marine Submergence at Montreal, Covey Hill and Rigaud Mountain; Geol. Surv. Canada, Summ. Rpt. 1913, p. 211.

JACKSON, G.D. (1955) - A Petrographic Study of Part of the Potsdam Sandstone Core from the Mallet Well, Ste-Thérèse, Quebec (abs.); Canadian Min. Jour., Vol. 76, No. 10, p. 96.

LOGAN, W.E. (1849) - On the Geology of the Country on the South Side of the St. Lawrence from Montreal and Lake Châmplain to the Chaudière River, Quebec; Can. Geol. Surv. Rpt. Prog. 1847-48, pp. 5-92.

LOGAN, W.E. (1851) - On the Occurrence of a Track and Footprints of an Animal in the Potsdam Sandstone of Lower Canada; Geol. Soc. London, Quart. Journ. 7, pp. 247-250.

LOGAN, W.E. (1852) - On the Footprints Occurring in the Potsdam Sandstone of Canada; Geol. Soc. London, Quart. Journ., 8, pp. 199-213.

LOGAN, W.E. (1860) - On the Track of an Animal Lately Found in the Potsdam Formation; Can. Nat. 5, pp. 279-285.

LOGAN, W.E. (1863) - Report on the Geology of Canada; Can. Geol. Surv. Rpt. Prog. to 1863, pp. 87-96.

MAILLOUX, A. and GODBOUT, G. (1954) - Etude Pédologique des sols des Comtés de Huntingdon et Beauharnois; Que. Dept. Agriculture, Tech. Bull. No. 4.

McGERRIGLE, H.W. (1938) - Châteauguay Valley, Southern Quebec (abs,) Geol. Soc. Amer. Bull. 49, p. 1937.

OWEN, R. (1852) - Description of the Impressions and Footprints of the Protichnites from the Potsdam Sandstone of Canada, Geol. Soc. London, Quart. Journ. 8, pp. 214-225.

RAYMOND, P.-E. (1913) - Ordovician, Montreal and Ottawa: Excursions in the Neighbourhood of Montreal and Ottawa. Excursions A6, A7, A8, A10, All. Internat. Geol. Cong. XII, Canada, Guide Book No. 3, pp. 137-160.

Excursion in Eastern Quebec and the Maritime Provinces (Part I); Internat. Geol. Cong. XII, Canada, Guide Book No. 1 Quebec and Vicinity, pp. 25-48.

ULRICH, E.O. (1911) - Revision of the Paleozoic Systems; Geol. Soc. Amer. Bull. 22, pp. 281-680

VAN INGEN, G. (1902) - The Potsdam Sandstone of the Lake Champlain Basin...; N.Y. State Mus. Bull. 52,pp.529-545.

VANUXEM, L. (1942) - Geology of New York, Part III... Comprising the Survey of the Third Geological District; Albany.

WHEELER, R.R. (1942) - Cambrian-Ordovician Boundary in the Adirondack - Border Region; Amer. Jour. Sci., Vol. 240, No.7, pp. 518-524.

WILMARTH, M.G. (1938) - Lexicon of Geologic Names of the United States (includes references to geologic names in Canada); U.S. Geol. Survey Bull. 896, Parts I, II.

WILSON, A.E. (1937) - Erosional Intervals Indicated by Contacts in the Vicinity of Ottawa, Ontario; Roy. Soc. Canada, Trans. (3), Vol. 31, sec. 4, pp. 45-60.

WILSON, A.E. (1941) - Valleyfield Map; Can. Geol. Surv.
(1946) - Geology of the Ottawa - St. Lawrence Lowland, Ontario and Quebec; Canada Geol. Surv. Nam.241.

In addition the following unpublished theses in the Redpath Library, McGill University, have been drawn upon:-

BYRNE, A.W. (1958,Ph.D.) - The Stratigraphy and Paleontology of the Beekmantown Group in the St. Lawrence Lowlands, Quebec.

DEAN, R.S. (1962,Ph.D.) - A Study of the St. Lawrence Lowland Shales.

JACKSON, G.D. (1955,Ph.D.) - A Petrographic Study of Part of the Potsdam Drill Core from Mallet Well, Ste. Thérèse, Quebec.

ALPHABETICAL INDEX