MEMOIR 257

GEOLOGY OF A SOUTHWESTERN PART OF THE EASTERN TOWNSHIPS OF QUEBEC

BY

H. C. COOKE

GEOLOGICAL SURVEY
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PREFACE

More than 100 years have elapsed since Sir William Logan, first Director of the Geological Survey of Canada, commenced geological work in the Eastern Townships of Quebec with the examination, in 1842, of a copper prospect at Carbuncle Mountain in Orford map-area. Since that time, Sir William and many other geologists have contributed at intervals to the many problems—stratigraphic, structural, economic, and physiographic—that studies of this interesting region have revealed, problems that only yet are in process of solution.

The present report deals with a southwestern part of the Eastern Townships. It is based largely on the results of six consecutive seasons' field work by the author, commencing in 1943. Earlier work by the author in adjoining areas to the north and by Drs. J. W. Ambrose and Y. O. Fortier of the Geological Survey in the Memphremagog and Orford quadrangles has afforded material contribution. The report is concerned mainly with the complex structural and stratigraphic relations of a succession of sedimentary and volcanic groups ranging in age from Cambrian or older to Devonian or later, and with the characteristic lithology of these rocks. Attention is also paid to associated intrusive bodies, which range in composition from ultrabasic to granitic, and to which certain metalliferous deposits are directly and others less certainly related. Included in the report are special chapters on structural and economic geology, the latter containing brief descriptions of a variety of metalliferous and industrial mineral deposits.

Although, as the report shows, many problems remain unsolved, Dr. Cooke's retirement from the Survey staff, early in 1949, makes it seem desirable to place on record the mass of facts he has accumulated. With these as a basis, future workers may more readily envisage the problems that remain and direct their efforts toward their solution.

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Chief Geologist, Geological Survey of Canada

OTTAWA, September 20, 1949

Geology of a Southwestern Part of the Eastern Townships of Quebec

CHAPTER I

INTRODUCTION

GENERAL STATEMENT

The area herein described extends northeasterly for some 65 miles from the International Boundary near Lake Memphremagog, and comprises roughly 2,200 square miles. It includes five 15- by 30-minute map-areas, the Memphremagog, Orford, Sherbrooke, Dudswell, and Scotstown, together with the eastern half of Richmond map-area (Figure 1). Each of these

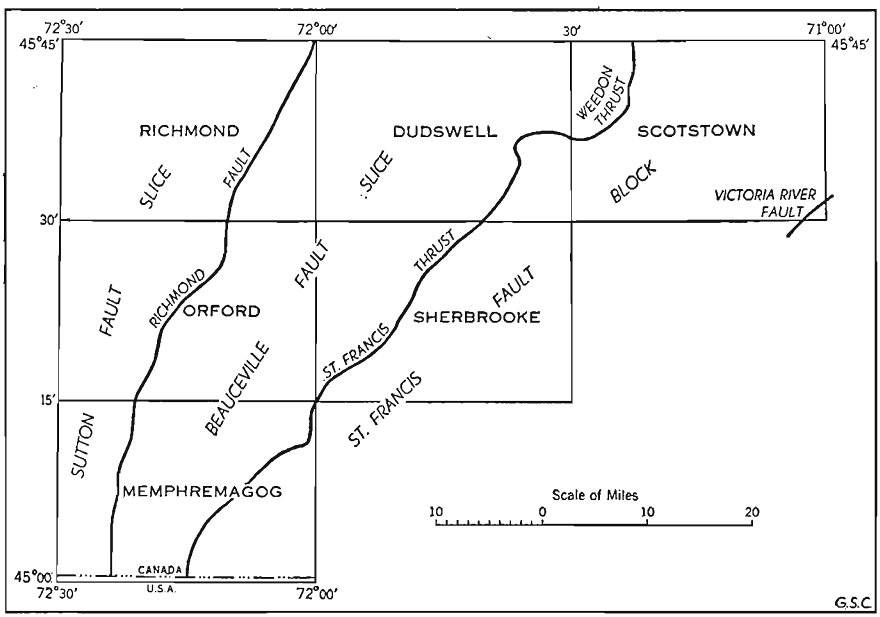

Figure 1. Index map of map-areas described, showing the larger faults and fault blocks.

has been mapped separately on a scale of 1 inch to 1 mile, and it is expected that these maps will be made available, though they do not accompany this report. In their place is a map on a scale of 1 inch to 2 miles, on which the geology of the various map-areas is compiled.

The writer carried on field work in this region from 1943 to 1948, inclusive. He was efficiently assisted in 1943 by Kenneth C. Rose; in 1944, by Kenneth C. Rose, Keith Bell, and Frank Anderson; in 1945, by Keith Bell and Peter Aikens; in 1946, by Frank Anderson and Jorma Killiokoski; in 1947, by John MacDougall and B. M. Veilleux; and in 1948, by B. M. Veilleux and Parker Pitts.

St. Francis River drains nearly all of the area, through several large tributaries. The most important are Salmon River in Scotstown area, Eaton River, which enters the St. Francis at East Angus, and Massawippi and Magog Rivers on the south, which drain Massawippi and Memphremagog Lakes. All these streams are very rapid, and can be navigated only for short stretches by small boats or canoes. Outside the St. Francis basin, a few creeks in the southeast corner of Scotstown map-area run to Lake Megantic and thence to Chaudière River; and about one-quarter of Dudswell map-area drains north and northeast to Nicolet River. Missisquoi River, in the western part of Memphremagog map-area, crosses the International Boundary to drain southwest to Lake Champlain.

The southern part of the area contains several large lakes, formed by the blocking of preglacial drainage channels by glacial drift. These are becoming increasingly utilized as holiday resorts in the summer, both by local residents and by foreign tourists.

Sherbrooke, the largest city of the Eastern Townships, with a population of about 36,000 according to the census of 1941, is served by lines of the Canadian Pacific, Canadian National, and Quebec Central Railways. From it, most of the larger centres of the region may be reached by one or other of these lines, for the precise distribution of which the reader is referred to the accompanying map. In addition, excellent cement highways connect the city with Montreal on the west and with Quebec to the north, both via Richmond to the northwest and Thetford Mines on the northeast. Similar highways lead south through Lennoxville and North Hatley, and east to Sawyerville. The remainder of the district is traversed by a network of roads, many of which are either hard-surfaced or well-gravelled highways; by them all parts of it may readily be reached.

The principal industry of the district is farming. The country is now moderately thickly settled, and most of the arable land is cleared. In general the soils are light, with much sand and gravel, so that large areas are left in pasture. The remaining parts seem well fitted for the growth of potatoes and other root crops, together with hay and a little corn. Dairy farming, in fact, seems to be one of the main sources of income. In the spring, however, large quantities of maple syrup and maple sugar add appreciably to that income.

Next to farming lumbering is of importance. Much hardwood and softwood lumber was cut during the last war, both for export and domestic consumption; and the domestic demand is still great. Articles of woodenware are manufactured at Scotstown, Waterville, and other places. Wood for pulp is cut in large quantities, and supplies mills at East Angus and Windsor Mills. Charcoal is made in kilns at Weedon.

At Magog and Sherbrooke, falls on Magog River have been harnessed to yield important amounts of electric power, and for that reason large industrial plants have been established there. The power at Magog is sufficient to supply only one large plant of the Dominion Textile Company, but at Sherbrooke there are not only hosiery and textile plants but several establishments manufacturing structural steel, mining machinery, machinery for use in paper mills, and other steel products.

PREVIOUS WORK

Geological work in this district began more than 100 years ago, when Sir William Logan in 1842 examined a copper prospect at Carbuncle Mountain, Orford map-area; and the copper deposits of the region drew much attention to it for many years thereafter. After some 20 years of mapping and study, Logan assigned to the Quebec group all the pre-Silurian rocks lying between Logan's line, the fault extending from Lake Champlain to Quebec, and the fault called the St. Francis thrust in this report. The rocks lying east of his Quebec group, herein termed the St. Francis group, he considered to be Silurian. The Quebec group, a convenient term including a great variety of faulted, folded, and more or less metamorphosed strata, together with others now recognized as of intrusive and extrusive origin, he considered to be of Calciferous and Chazy age.

After the Geology of Canada (1863) had been published, differences of opinion arose between Sir William Logan and his collaborator, Sterry Hunt, regarding the structure, and, consequently, the succession of strata, of the Quebec group. In an effort to arrive at the truth, Logan's successor, A. R. C. Selwyn, spent three seasons in the field examining the data, and in 1882 announced that in his opinion Hunt was correct. Sutton Mountains, which Logan had regarded as a syncline including, in spite of their metamorphosed condition, some of the youngest rocks of the group, Selwyn considered as the central anticline of the system, and its rocks the oldest of the group, pre-dating the fossiliferous Cambrian and other rocks on its flanks. The Sutton schists, he also stated, are separated from the rocks of the Quebec group to the east by a great fault along the valley of Missisquoi River. These views, with minor modifications, are still held today.

In 1885, R. W. Ells was entrusted with the work of remapping the Eastern Townships on a scale of 1 inch to 4 miles, a task that required six field seasons, up to 1890 inclusive. The result of this work was the publication of five reports and four geological sheets. Although considerable detailed work has since been done, there are still areas of some size for which these are the only maps.

In 1888, Ells discarded the name "Quebec group" because of "the curious anomaly it presents of one single group name which comprises rocks ranging from what has now been determined to be as old as the Huronian to the upper part of the Cambro-Silurian (Ordovician)". The term has not been used since.

Beginning in 1895, R. Chalmers spent three field seasons on the examination of the superficial deposits of the Eastern Townships, and the gold-bearing gravels of the Chaudière and other streams. Many of his results, particularly those demonstrating the post-glacial faulting of the region, are of much interest.

In 1901, J. A. Dresser commenced the examination of the copper deposits of the region, and demonstrated that they are all associated with volcanic rocks. He also did much work on the petrography of the

Monteregian Hills, and investigated in detail the serpentines of the Eastern Townships, with their associated asbestos and chromite deposits. He was the first to recognize the presence of a conglomerate at the base of the Ordovician rocks of the area, and to suggest that it probably indicates an important unconformity.

In 1911, Robert Harvie entered the field to continue the work begun by Dresser, and by 1913 had mapped a considerable part of Memphremagog area. He demonstrated, by finding fossils, that the rocks around Lake Memphremagog, later termed by Fortier the Glenbrooke group, are largely of Silurian age, though the upper horizons are Lower Devonian. He also considered that the gabbro of the region is pre-Glenbrooke.

During the field season of 1914, and a part of that of 1913, Dr. J. A. Bancroft re-examined the various copper deposits of the Eastern Townships on behalf of the Quebec Department of Mines.

In 1923, F. A. Kerr spent one field season mapping the district east of Lake Memphremagog. His results are on file with the Geological Survey of Canada, and have proved useful in subsequent investigations of that area.

In 1931, T. H. Clark and H. W. Fairbairn studied the west half of the Memphremagog quadrangle, and have published several short papers on the results. They apply the name "Bolton lava" to the large lava masses of Owl Head, Hogsback, and other "mountains" of the area, conclude that these lavas lie unconformably upon the eroded edges of the Ordovician and older rocks, and tentatively suggest Silurian age for them.

In 1931, also, F. R. Burton, on behalf of the Quebec Bureau of Mines, studied the granite bodies of the region to determine their composition and assess their commercial possibilities.

In 1941, G. Vibert Douglas examined the Eustis mine, and his results were published by the Quebec Bureau of Mines.

In 1935, J. W. Laverdiere mapped a small area, mainly underlain by Devonian limestones, near the village of Marbleton.

In 1941-3, J. W. Ambrose mapped the west and east halves of the Memphremagog quadrangle, and published preliminary maps of them. He drew no boundary, on these maps, between the Ordovician and Cambrian (?) beds distinguished by earlier writers, and concluded, in opposition to Clark, that the Bolton lavas are interbedded conformably with the Ordovician strata.

During the field seasons 1942-4, Y. O. Fortier mapped the eastern two-thirds of the Orford quadrangle, and published a preliminary map of it. He had been assistant to Ambrose in 1942, and followed him in his treatment of the relations mentioned above.

In 1945, J. E. Hawley and associates published a paper describing the Aldermac mine a few miles northeast of Sherbrooke.

FIELD WORK OF THE WRITER

During the years 1930-35 inclusive, the writer mapped the Thetford and Disraeli map-areas, and a part of the east half of Warwick map-area. During 1943-6 inclusive, this work was continued southeast to cover the Scotstown, Dudswell, and Sherbrooke map-areas, and the east half of Richmond map-area. This work tied on to the west and north sides of

Orford area, previously mapped by Fortier; and as the Memphremagog map-area, lying to the south of Orford area, had also been mapped by J. W. Ambrose, it seemed to complete the mapping of a block about 100 miles long and ranging from 25 to 50 miles in width, which extends northeast from the International Boundary at Lake Memphremagog.

Unfortunately, the correlation of the writer's work with that of Fortier and Ambrose was unsatisfactory. Neither Fortier nor Ambrose, as already mentioned, had laid down the boundary between the Cambrian (?) and Ordovician formations, the position of which was shown on the sheets to the northeast. The writer was, therefore, instructed to re-examine the Orford and Memphremagog quadrangles and lay down, if possible, the position of this boundary; and also to study the question of the true stratigraphic position of the Bolton lavas, about which Ambrose and Clark had disagreed. The field seasons of 1947-48 were devoted to this work; and the western third of the Orford sheet was also mapped.

The results of this study were somewhat startling. In addition to securing satisfactory evidence on the problems envisaged at the beginning, indubitable evidence was obtained, during September 1947, that a series exists in the district the existence of which had never been suspected. This series, which has been named the Sherbrooke group, is probably of Silurian age; but its beds, for lack of evidence to justify their separation, had previously been mapped with those of the Ordovician Beauceville group. The recognition of the Sherbrooke as a separate group has not only made it possible to recognize many previously unsuspected faults, but has necessitated important revisions of the writer's previously published maps of Sherbrooke and Dudswell areas. These revisions have been made on the map accompanying this report.

The writer's work on the Memphremagog and Orford map-areas was, perforce, concentrated on certain sections, owing to the size and complexity of the region, and the limited time at his disposal. In Memphremagog map-area, the section between Missisquoi Valley on the west and the Massawippi-Fitch Bay Valley on the east was examined in detail, except the area of Devonian strata around Lake Memphremagog, a proper study of which could occupy a field season in itself. This work was devoted mainly to differentiating the Caldwell and Beauceville rocks and establishing their contacts; to determining the relations of the Bolton lavas; and to mapping and studying the rocks of the Sherbrooke group. To the study of the rocks east of the Massawippi-Fitch Bay Valley only a couple of weeks were given, sufficient to confirm the previous mapping of J. W. Ambrose; and no examination was made of the Sutton Mountain area, west of Missisquoi Valley. The mapping of Sutton Mountains is taken from the work of T. H. Clark and J. W. Ambrose.

In Orford map-area, again, the writer's attention was chiefly given to the separation of the Caldwell and Beauceville rocks, the study of the Bolton lavas, and of the Sherbrooke group. Sufficient time was not available for a thorough re-examination of the rough, hilly area east of Brompton Lake, so that the mapping of this section is still unsatisfactory. Similarly, only a few traverses could be made across Baldface, Orford, and Chagnon Mountains, and the separation of the Bolton lavas and later gabbros there must be regarded as a preliminary effort only. For the mapping of the

Sutton schist area west of the Missisquoi-Bowker Lake Valley, only some 3 weeks at the end of the 1948 field season were available; much detail is, therefore, unavoidably lacking from this part of the map.

PHYSICAL FEATURES

Southwestern Quebec includes parts of two physiographic provinces, the St. Lawrence Lowland and the Appalachian Upland. The former, which lies northwest and outside of the area under consideration, is a flat plain underlain by soft Palæozoic strata with very low dips. Near the St. Lawrence this plain is about 200 feet above sea-level, but it rises inland at the rate of some 5 or 6 feet to the mile. Its southeastern border has a height of 450 to 500 feet above sea-level.

From this southeastern border there rises, in places rather abruptly, a chain of hills that extends northeast from the International Boundary into Gaspe. In contrast with the undeformed strata of the plain, these hills are underlain by intensely deformed and metamorphosed beds, folded into overturned and in many places recumbent folds, and converted into mica and chlorite schists with a general northeasterly strike. Part of this chain of hills appears on the western side of Memphremagog and Orford map-areas, and is known as the Sutton Range. Its southward extension into Vermont is the Green Mountains. On the northeast the elevation of the range decreases from about 2,500 feet to a series of isolated summits some 1,400 feet high near Danville, where they rise only 600 to 700 feet above the surrounding plain. Northeast of Danville the range rises again to the Notre Dame Mountains. In Thetford area summits attain a maximum height of about 2,000 feet, and the ridge is some 12 miles wide; it is underlain by the same intensely deformed strata that are found in the Sutton Range. Still farther northeast, in Gaspe, the ridge attains its maximum height of about 4,200 feet above sea-level. It is there termed the Shickshock Mountains. These are not underlain by the intensely deformed schists found farther southeast, but by moderately closely folded sedimentary and volcanic rocks.

East of the Sutton Range, between it and the New Hampshire-Maine boundary, lies a maturely dissected plateau with maximum elevations of 1,100 to 1,300 feet above sea-level. Its southeastern boundary is the Lake Megantic range of hills, which lies mainly in the United States where it is known as the White Mountains. This maturely dissected plateau, or upland, is about 25 miles wide at the International Boundary, but widens to about 50 miles around Thetford Mines. It has been carved on moderately soft Cambrian (?), Ordovician, and Siluro-Devonian sedimentary rocks, which have been closely folded and somewhat metamorphosed, but are not converted into schists. The fold axes, and the beds generally, strike about northeast. This plateau is the northern extension of what N. M. Fenneman has termed the New England upland.

The upland is broken by hills that rise above it, in places as much as 1,000 to 1,200 feet. Within the area under discussion, these hilly areas include all the sections underlain by the Bolton lavas and their associated intrusives, such as Owl Head, Pevee, Sugarloaf, Orford, and the other mountains that lie between Lake Memphremagog and Missisquoi River Valleys; the hilly areas underlain by periodotite between Webster and

Brompton Lakes; the Stoke Mountain ridge and its southern extension to Bunker Hill; and the rugged areas underlain by granite in Scotstown map-area.

The region is drained by streams that, although well adjusted to the structure as a rule on the interior upland, eventually turn northwest to cut at right angles across the ridge that lies between the upland and the St. Lawrence Lowland. St. Francis River is the principal example within the area under discussion. Missisquoi River turns, on the south side of the International Boundary, to cross the rock structures and run west into Lake Champlain. Other examples, northeast of this area, are Nicolet, Becancour, Beaurivage, and Chaudière Rivers.

As, normally, stream valleys become entrenched along zones of relatively easy erosion, such as beds of soft sedimentary rock, fault zones, or even joints, and thereby tend to parallel the bedding of the rocks rather than cross it, this anomalous behaviour deserves attention. It might be possible, of course, that cross-faults are present, permitting valleys to form at right angles to the major structure; but although at low water outcrops can be studied in places across almost the full width of the St. Francis—as for instance at Windsor Mills and Bromptonville—no evidence of faulting was found after careful search; nor do the beds crossing the river appear to be displaced, except around Sherbrooke itself.

With the possibility of cross-faulting thus eliminated, two possibilities remain. One is that the northwest-flowing streams may be "antecedent", that is, they may have established their present courses prior to the uplift of the region to its present position, and maintained them, by erosion, against that uplift. The other possibility is that these stream valleys were developed after uplift. According to this idea, streams on the upland, after uplift, must have reached the sea through courses much longer than at present, and, hence, could deepen their valleys slowly, as with little fall per mile velocities must have been slight. On the other hand, streams flowing down the northwestern slope of Sutton Ridge and across the St. Lawrence Lowland had a short and rapid course to sea-level, hence would erode their valleys rapidly and lengthen them by headward erosion. As these valleys were thus lengthened in southeasterly directions, they would eventually reach the northeast-trending valleys of the slower flowing streams of the upland. Where this happened, the headwaters of the older stream would be diverted into the new valley, giving it greater volume and correspondingly increased powers of erosion. This process is known as piracy.

It is difficult, without detailed physiographic study, to determine which of these alternatives is correct. In general, two types of data may be sought. (1) Do remnants of an original, roughly plain-like surface still exist? As the rocks are all folded, such a surface must have been one of erosion, developed before the latest uplift. (2) On such a surface there must have been many streams with well-developed valleys, and these, presumably, would persist at least during the earlier stages of uplift. If the stream were unable to maintain its valley against the uplift, or if for any other cause, such as piracy, the stream forsook its course, the valley would still remain, mute evidence of the stream's former presence. Such valleys are termed wind gaps.

In the area under consideration, there are no recognizable remnants of an original plain-like surface. If such a surface once existed, erosion has now obliterated most traces of it. Farther to the northeast, in Thetford area, the writer believed that the reasonably level-crested ridge of Notre Dame Range, now roughly 2,100 feet above sea-level, probably represents such a surface, though now somewhat warped and eroded (22, p. 9)[1]. Still farther northeast, in Gaspe, the continuation of the range is characterized by wide, flat-topped summits.[2]

As regards wind gaps, the most striking example is found in Orford map-area, where a strong, low-level valley, comparable in width and depth to that of the St. Francis, cuts directly across the Sutton Range and the hills of Bolton lava lying east of it. It may readily be studied, as it is followed, for practically all its length, by the highway from Magog that leads west to Montreal. Y. O. Fortier, who studied the area in 1942-4, was the first, so far as the writer is aware, to call attention to this striking feature. In his unpublished report, on file in the library of the Geological Survey of Canada, he describes "a marked alinement of small streams and gaps in an east-west direction. These are, Magog River between Lake Magog and Lake Memphremagog; the lower part of Castle Brook and its western branch, which penetrates into the gap between the high peaks of Orford and Chagnon Mountains; the streams flowing from Orford Lake and Eastray Lake into Missisquoi River; two small streams flowing east and west into a south-flowing stream near South Stukely; and, finally, another stream flowing westward from Frost village toward Waterloo. The divide in the deep Orford-Chagnon gap is 950 feet above the sea, the highest point in the Eastman-Waterloo pass .... It must be concluded that this is the vestige of an ancient transverse stream that antedated the formation of the ranges".

Although admittedly sketchy, the evidence seems to suggest that the region was formerly a surface of fairly low relief, which was uplifted to its present position in later Tertiary, perhaps about mid-Pliocene, time. The fairly steep faces that separate, in places, the Sutton Range from the St. Lawrence Lowland suggest that the uplift may have been accompanied by some faulting. Several major streams were able to maintain themselves against the uplift, by the speed with which they could erode their valleys. Through these main channels the drainage from the interior escaped.

After uplift, the softer rocks of what is now the interior upland would be destroyed by erosion faster than the harder strata of the present Sutton Range. Thus, gradually, the Sutton area would take shape as a range of hills, with the area behind it forming a basin with lower elevations.

We may conceive of the area after uplift, therefore, as drained by deep transverse valleys, down which the waters from each side poured. These waters would rapidly develop valleys of their own; and such valleys would deepen most rapidly on zones of easy erosion, such as faults, beds of soft shale or limestone, and the like. Thus, rapidly, a drainage system would develop paralleling the northeast strike of the strata, the situation now existing on the interior plateau. Some of these valleys may, of course, have been in existence before uplift, and would naturally now be larger

[1] Numbers in parentheses refer to Bibliography, page 10.

[2] Alcock, F. J., Mount Albert Map-area, Quebec; Geol. Surv., Canada, Mem. 144, pp. 11-15 (1926).

than those that did not begin development until after uplift. This may explain the unusual size of a few valleys, such as that of Lake Memphremagog, though their size may equally be due to glacial gouging during Pleistocene time.

As the transverse streams were undoubtedly of different sizes, as at present, the larger ones would deepen their valleys much faster than the smaller; and their tributaries, with a steep gradient, would lengthen headward rapidly. Eventually such valleys might intersect the valleys of the smaller transverse streams and steal their headwaters. Thus Missisquoi River, developed along an easily eroded fault zone, appears to have worked back far enough to reach and cut off the stream that formerly followed the wind gap of the Magog-Montreal highway.

When dissection of the surface of the region was approaching the stage of early maturity, with the development of broad valleys with fairly well-graded bottoms, and the original surface had been lowered by some hundreds of feet, further normal development was interrupted by the onset of the Glacial period. The disappearance of the ice left the valleys locally choked with drift, and the remaining surface covered with the stony, gravelly soils that characterize the region. In most of the valleys, the amount of filling was insufficient to force the streams into new courses; consequently, such valleys were once more occupied by streams that have, in most cases, been able to remove enough of the drift to reach bedrock in part of their courses, though immense amounts piled along the sides still remain. In other places, particularly in Orford and Memphremagog map-areas, the amounts of drift deposited were sufficient to choke the valleys locally. In such instances, water accumulated in the unfilled parts to form long narrow lakes; and in many places the accumulated water was forced to escape, not down the original valley, but over the lowest part of the rim to enter some other valley. Thus the water from Lakes Memphremagog and Magog does not drain northward along the original valleys, but crosses the surface northwestward to where, at Rock Forest, it drops into a small, preglacial valley that is now the lower part of Magog River. Similarly, Bowker and Mud Lakes do not drain through their original valleys, but their waters have been forced to find devious outlets across the divide into the old Brompton Lake Valley.

Since the country was opened to settlement, about 1800 A.D., most of the lower parts of the country have been cleared of forest and fitted for agriculture, in spite of the relatively unpromising nature of the stony, gravelly soils. The incredible labour required to do this is evidenced by the immense piles of glacial boulders that have everywhere been gathered together to dot the fields or, more commonly, to constitute the boundary fences. In these areas it is, of course, easy to spot and to examine all the outcrops of the underlying rock, but such outcrops constitute less than 1 per cent of the total surface. It may readily be understood, therefore, that in this region of closely folded, greatly faulted rocks, such a condition is not favourable to accurate geological work. In some areas, indeed, drift seems to have been piled deep against some barrier to the south, such as Mount Megantic at the south side of Scotstown map-area, or Bear and Hawk Mountains at the south side of Memphremagog map-area; and in these places no outcrops whatever are visible within areas of several square miles. Again, certain rocks that weather readily, such as the various slate formations or the limestones of the St. Francis and Lake Aylmer groups, outcrop very poorly, and may display perhaps one outcrop or less to a square mile.

The hills of the region generally provide more abundant outcrops, but as most of them are masses of intrusive or extrusive rock, their examination adds little to our knowledge of the structure. Many of them, moreover, are most difficult of access. Lumbering operations during the war years have left large areas masses of slash, now thickly matted with underbrush laced together with the thorny stems of thimble-berry and wild raspberry.

These conditions may explain, in part, the reasons why repeated attempts have been made to unravel the geological history of the Memphremagog and Orford map-areas, with only partial success. In these areas the geological history and structure are the most complex of the Eastern Townships, and difficulties in determining them are enhanced by the rugged terrain and abundant drift. The writer, in dealing with them, had the advantages of having studied the country to the northeast, where the relations are less complicated and the country more accessible, and believes that he has correctly determined the major units of the geological succession. Whether individual outcrops are everywhere correctly assigned to their proper classification is, however, a matter on which question may arise.

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CHAPTER II

GENERAL GEOLOGY

GENERAL STATEMENT

Study of the considerable areas of the Eastern Townships that now have been examined by T. H. Clark and the writer has disclosed the fact that the region is broken into segments by great through-going faults, most of them overthrusts from the southeast. Between one fault block and another the stratigraphic successions are commonly so different as to suggest that deposition must have taken place in basins quite isolated from one another, and, therefore, that the overthrusts that brought them into contact must be measured in miles. Though there is some evidence that part of this faulting took place during the Taconic orogeny of late Ordovician time, by far the greater part occurred during the Acadian disturbance in the Devonian period.

Within the area under discussion, the most important of these faults divides the rocks of the St. Francis group from those to the west, and is here termed the St. Francis thrust. From Fitch Bay, Lake Memphremagog, it extends northeast through Lake Massawippi and down Massawippi River to Lennoxville. Thence it continues along the St. Francis Valley to a point about 2 miles below East Angus. There the stream swings to the east, but the fault continues straight northeast along the southeast flank of the Stoke Hills. In the 4 or 5 miles beyond the north end of the hills, outcrops are so poor that uncertainty exists about the position of the fault, but it is believed to swing east to become the strong fault, named by F. R. Burton (12) the Weedon thrust, that bounds the southeast side of the Lake Aylmer group in Disraeli map-area.

The St. Francis fault slice occupies the southeast part of Scotstown, Sherbrooke, and Memphremagog map-areas. In Scotstown area its southeastern boundary was found to be another great fault that cuts across the extreme southeastern corner of the area, so that the slice here has a width of 18 miles; but the writer has had no opportunity to follow this boundary farther to study the rocks beyond it.

As the descriptions will show, the St. Francis group of rocks has no resemblance, in petrography or succession, to the rocks west of the fault. Only because the fault seems undoubtedly to be a thrust from the southeast is it concluded that the group must be older than the rocks northwest of the fault.

A second great fault follows Missisquoi Valley, Bowker and Mud Lakes, and the valleys of Salmon and Steele Brooks, thus extending northeast from the International Boundary a distance of at least 50 miles. Its possible extension into Warwick map-area has not yet been determined. The width of this fault block, which may be termed the Beauceville block from the series most largely developed in it, ranges from 8 miles at its southern end to 24 miles at the northern. The rocks northwest of this fault block are considered older than those within it, so that this block is a down-dropped segment or graben.

Within these major fault blocks, smaller faults are numerous, though many are still large. Thus, within the Beauceville block, a large fault followed for 24 miles constitutes the western boundary of the principal band of the Sherbrooke group. Another large fault or group of faults underlies Lake Magog, but its extension north and south is lost beneath thick deposits of drift. Within the other blocks evidence of complex faulting has been found in places, but for the most part lack of suitable horizon markers prevents their recognition.

The rocks of the St. Francis fault slice, within the area studied, consist wholly of the St. Francis group of sediments, with some masses of intrusive granite and, at the southern side of Sherbrooke map-area, some small remnants of the Sherbrooke group. The St. Francis group appears, on scanty fossil evidence, to be of Middle Ordovician age; it comprises a thick succession of impure limestones in the lower horizons, overlain by thick-bedded quartzites and sandstones. Neither the base nor the top is known. The prevailing strike is northeast; within most of the fault slice the beds face southeast, but over large areas they are overturned so as to dip northwest at steep angles.

The Beauceville fault slice comprises rocks ranging from Cambrian (?) to Lower Devonian age. The Cambrian (?) strata, so classified merely because they lie uncomformably below Ordovician beds, are mainly grey quartzites with some grey slate and, in Memphremagog and Richmond areas, some black limestone. Interstratified with these sedimentary beds are various lavas ranging in composition from basalt to rhyolite. The more basic lavas are usually highly altered, many of them converted into masses of ferruginous carbonate, or chlorite. The quartzites are very firmly cemented, apparently by the secondary development in them of needles of mica; this renders them exceedingly hard and tough, a property often useful for identification. The Cambrian (?) strata, here termed the Caldwell group, were folded and eroded before deposition of the succeeding Beauceville group. The lower beds pass into schists, but the metamorphism has not been precisely dated.

The Beauceville group overlies the Caldwell group with structural and erosional unconformity. At its base is a conglomerate made up of pebbles of slate, mainly, with some of quartzite; but subsequent deformation has commonly sheared out the slate pebbles, so that only the quartzite pebbles remain in a slate matrix. This conglomerate was recognized many years ago by J. A. Dresser (37, 40) and named by him the Magog conglomerate. In some places it is not more than a few inches thick, with small pebbles; but commonly it is thick enough to yield outcrops up to 100 feet or even several hundred feet wide. The conglomerate is overlain by a thick formation of black slate, mainly. In places this has been found to lie in narrow steep folds, but mostly it is too poorly exposed for any continuous determination of the structure. One section, described later, seems to indicate that near the base the formation consists of alternating beds of black slate and brownish silt, but that toward the top the silty beds become more siliceous, eventually passing into beds of impure quartzite. Characteristically the rocks have a thin uniform banding. In the lower section the slate bands average about an inch in width, the silt bands somewhat less. In the upper section the bands are wider, up to about 2 inches. Fossils found abundantly in the bed of Castle Brook, a mile or so northwest of the north end of Lake Memphremagog, indicate the formation to be of Ordovician age, probably lower to middle Trenton.

Toward the end of the Ordovician period came the great mountain-building movement known as the Taconic. The Caldwell and Beauceville beds were closely folded into near-vertical positions, and some of the great faults already described were initiated. During this movement, intrusion occurred of the masses of peridotite found in the western part of the Beauceville fault slice. A long period of erosion followed, lasting throughout whatever may have remained of the Ordovician period, and a considerable part of the Silurian. While, during this time, the Taconic mountains were being cut away, no recognizable deposits were laid down within the region under discussion.

Toward the middle, probably, of the Silurian period, part at least of the surface had been lowered to a point where deposition could once more begin, possibly in intermontane valleys. The rocks deposited were those of a series never previously recognized in this region; to them the writer has given the name Sherbrooke group. At the base these rocks are mainly grits, passing in places into conglomerates. The grits range in composition, in different areas, from coarse quartzites to rocks containing relatively little quartz, but all are characterized by rather poor cementation, so that they crumble or break off easily under the hammer. Above the thick basal grits and conglomerates is a thick succession of well-banded slates. In general appearance these are very similar to the Beauceville slates, but differ from them in that alternate bands are of dark grey and light grey slate, instead of dark grey to black slate and brownish silt. In Sherbrooke and Dudswell map-areas large masses of rhyolite are believed to form part of the Sherbrooke group.

Isolated patches of Sherbrooke rocks are found throughout the area between Lake Memphremagog, Lake Magog, and Lake Massawippi, but the main occurrence is a long band extending from a point some 2 miles northeast of Lake Magog beyond the north end of the Dudswell map-area. Some small remnants are also present south of Sawyerville in Sherbrooke map-area. The Sherbrooke rocks, where contacts are not faulted, rest with great structural unconformity on the Caldwell, Beauceville, and St. Francis groups, and are overlain with no angular unconformity by the Lake Aylmer beds of Lower Devonian age.

It would seem that, eventually, uplift put an end to deposition in the Sherbrooke basin; and after an interval of erosion, later in the Silurian, deposition was renewed in a basin west of it. The area now lies along the west side of Lake Memphremagog. The rocks deposited were a thick succession of limy slates, with a rather thin band of conglomerate at the base. They are known as the lower part of the Glenbrooke group. After an interval of emergence, submergence of this trough took place once more, in Lower Devonian time, and the limestones and limy slates of the Lake Memphremagog basin were laid down. These are known as the upper part of the Glenbrooke group. This nomenclature is far from satisfactory, but it will require careful stratigraphic study to trace the line of separation between the lower and upper parts of the group. No one studying the area has yet attempted it.

About the time that the Glenbrooke trough was submerged for the second time, submergence also took place of areas farther northeast, and in this trough rocks of the Lake Aylmer group were laid down. These consist of a locally thick conglomerate at the base, overlain by impure limestones, some very pure limestones, and a little slate. The fossil contents of the limestone beds date them as about the same age (Helderberg) as the limestones of the upper part of the Glenbrooke group.

The next episode of which we have record is the Acadian mountain-building movement of later Devonian time. In it, the Devonian and Silurian strata were folded into near-vertical positions in many parts of the area, but the folds in general were broad, so that large areas occupying the crests of anticlines or troughs of synclines have relatively low dips or lie almost flat. Most of the faults of the region were formed at this time, and movement was renewed along older faults. During this orogeny, many of the granites of the region were injected.

Following a long period of erosion, during which a well-developed hill and valley topography was developed, there ensued an interval of great volcanic activity, when the Bolton lavas were extruded. These seem to have covered an area at least 30 miles long and 6 miles wide, west of Lake Memphremagog, to a thickness of many hundreds of feet; their remnants now form some of the most prominent and picturesque hills of that district. It is believed, however, that the volcanic area was much larger, as lavas with somewhat similar composition and relations are found both east of Lake Memphremagog and as far west as Waterloo.

At a somewhat later date, the lavas were intruded locally by gabbros, and some folding took place. The time of this folding is unknown, but was probably during the final stages of the Acadian orogeny.

The final episode recorded by the consolidated rocks is the intrusion of dykes of camptonite, essexite, and related rocks. As these everywhere have east to southeast strikes, at right angles to the trend of the older structures, it is probable that their intrusion took place in post-Palæozoic time after the pressures from the southeast had finally subsided. From a study of the pleochroic haloes, F. F. Osborne has advanced the suggestion that they may be as late as Tertiary.

In Pleistocene time ice-sheets covered the region, and in disappearing left a succession of moraines, eskers, kames, and lake and stream deposits. The study of these deposits would be a complex problem in itself, and has not been attempted.

The Sutton fault slice lies west of the Beauceville slice, and is separated from it by the great fault along Missisquoi Valley, Bowker Lake, The Gulf, and the valleys of Salmon and Steele Brooks.

According to Clark (16) the west side of the Sutton slice is the Brome thrust, a through-going fault in Sutton map-area (directly west of Memphremagog map-area) that he traced as far as the south side of Brome Lake. Clark states that "the recognition of the fault is based on: (a) the abrupt change from unmetamorphosed sediments on the west to low-grade metamorphics on the east; and (b) the otherwise unaccountable reduction of the Oak Hill series from 3,000 feet to 300 feet. There is, moreover, an east-facing escarpment along the trace of the fault." Projected northward, this fault should enter the southwest corner of Orford map-area. It was not recognized there definitely, but may occupy a strong through-going valley that runs from Brome Lake just west of South Stukely, and thence northeast along Black River.

Nevertheless, although this valley may be developed upon an important fault, the writer does not feel that it is the continuation of the Brome thrust. The rocks west of the valley are not unmetamorphosed sediments, as Clark describes, but schists that differ from those east of the valley only in that they are interbedded with considerable amounts of hard, fairly pure quartzite. It seems more likely that the Brome thrust swings somewhat to the north, to lie in the still unmapped area west of Orford map-area, but final decision on the problem must await further work.

On this assumption, the rocks of the Sutton slice include all those west of the Missisquoi fault, in Memphremagog, Orford, and the east half of Richmond map-areas. They consist mainly of schists that are the metamorphosed equivalents of quartzites, slates, and sediments of intermediate composition, together with some basic lavas now converted to chlorite schists. West of Black River Valley, in Orford area, considerable masses of hard quartzite are interbanded with the schists. At South Stukely a band of white crystalline limestone is sandwiched between two bands of chloritic lava, and has been traced southwest for 1 mile and northeast for 5 miles. Quarries have been opened on it in three places, for extraction of limestone and marble. In Black River Valley, and again to the east of Richmond, a black, finely crystalline limestone outcrops in a few places.

Overlying the schists and quartzites with great structural unconformity is a band of lavas that extends through the northwest corner of Orford map-area and is on strike with similar bands in the mapped part of Richmond area to the northeast, and Sutton map-area to the southwest (mapped by T. H. Clark). These lavas are mainly basaltic in composition and are now converted into masses of chlorite; but in the central part of Orford area, toward the middle of the lava band, there is also a considerable development of more acidic types, mainly trachytes with a little rhyolite. In Sutton map-area, Clark (13) terms the lavas, which are apparently a continuation of the band in Orford map-area, the Tibbet Hill schist, and has concluded that they underlie the Lower Cambrian beds of the adjoining Oak Hill fault slice, hence may be Precambrian.

On the west side of the lava band, a considerable width of soft slaty rocks appears. Close examination of unusually clean outcrops has made it evident that these were also lavas, though now converted completely into aggregates of secondary minerals.

Northwest of the lavas, in Richmond map-area, beds of slate and some possible tuffs may overlie the lavas, according to the scanty evidence available. In other places, both in Richmond and Orford map-areas, beds of coarse quartzite underlie the lavas, apparently with conformity; and in the extreme northwest corner of Orford map-area, in an area thickly covered with drift, there are three outcrops of sedimentary rocks unlike anything seen elsewhere. The writer considers it useless to attempt to place any of these beds in the geologic column until further work in adjacent areas has been done. They are, accordingly, indicated on the accompanying map as of unknown age.

The known succession, as outlined above, is summarized in the following table.

TABLE OF FORMATIONS

Period or epoch	Formation	Lithology
Quaternary		Boulder clay, eskers, kames, varved clays, stream deposits
	Unconformity	
Tertiary (?)		Camptonite and essexite dykes and related rocks
	Faulting: possibly some folding	
Devonian or later	Bolton group	Gabbro Andesites, trachytes, rhyolites, slates Granite, quartz diorite
	Folding: intense faulting	
Lower Devonian	Lake Aylmer group	Conglomerate, limestone, slate, rhyolite
Upper Silurian and Lower Devonian	Glenbrooke group	Conglomerate, limy slate, limestone
Silurian	Sherbrooke group	Conglomerate, grit, quartzite, slate, rhyolite; andesite and basalt
Post-Ordovician		Granite? Peridotite, pyroxenite; gabbro
	Intense folding: some faulting	
Ordovician	Beauceville group	Conglomerate, black slate, minor quartzite
	St. Francis group	Impure limestone, limy slate, quartzite, black slate
	Folding	
Cambrian (?)	Caldwell group	Massive grey quartzites, with some grey slate; basalts, trachytes, rhyolites, tuffs; schists

CAMBRIAN (?)

CALDWELL GROUP

General Statement

Rocks considered to be part of the Caldwell group are found in the Beauceville and Sutton fault slices, but not as yet in the St. Francis fault slice. In the Sutton fault slice they are mainly sericite and chlorite schists, with some massive quartzite and basic lava. These rocks have been called, by earlier writers, the Sutton schists or Sutton Mountain schists; but as equally schistose types are found in places outside of Sutton Mountains they are here termed simply schists. The map shows the schists of Sutton Mountains ending abruptly, on the east, against the Missisquoi fault; but such mapping is an oversimplification of the actual relations. The rocks just east of the fault are almost as schistose as those west of it; and the schistosity dies out gradually, eastward, throughout a belt half a mile to a mile wide. This lack of any sharp break between schistose and non-schistose types makes it necessary to include the schists in the Caldwell group.

In the Caldwell group are placed all rocks that lie below the basal conglomerate of the Beauceville group; and these display considerable lithologic variation from place to place. Near the Missisquoi fault in Memphremagog and Orford map-areas they are mainly grey quartzites of varying degrees of purity, with some grey slate, some basic lava, and a little trachyte. In Richmond and Dudswell map-areas the amount of trachyte is very large, and some rhyolite appears. On the west side of Lake Massawippi there are many thin flows of rhyolite, only a few of which have been mapped, considerable black slate studded with large metacrysts of iron carbonate, and some beds carrying more or less carbonate of lime, as well as the usual grey quartzites.

Schists

The largest area of schists is found in the Sutton Mountains west of Missisquoi Valley and its northward continuation, here considered a fault line. A second body, much smaller, occupies the east side of Magog Lake and across to Massawippi Lake. The mapping, now completed except for a short gap in Warwick map-area, indicates that the main body of schist is, as previously supposed, continuous into the Bennett schist of Thetford map-area.

Like the Bennett, the schists are filled with veins of quartz. Most of them are very narrow, one-fortieth to three-fortieth inch wide, and fill spaces between the leaves of schist, but many are larger, and may cut across the schistosity. In places veins several feet wide are found. In Thetford district some evidence was obtained that quartz was injected during the Taconic orogeny that closed the Ordovician period, but it is not improbable that several ages of quartz are represented.

The principal rocks of the mountains are sericitic schists that exhibit all gradations into massive beds of quartzite. It is obvious, from the relations, that the schists have formed by the shearing of quartzites of varying degrees of purity. Very pure, white quartzite has been little affected by the shearing movements, but the less pure varieties have been converted into schists.

The principal minerals of the schist are quartz, sericite, and chlorite, with the chlorite usually in minor amount. The mica and chlorite are intergrown, and enclose lens-like aggregates of quartz grains. Characteristic accessory minerals include magnetite and ilmenite, titanite, and minute needles of rutile, epidote, apatite, and carbonates. Some specimens carry small brown tourmalines, minute pink garnets, or green biotite and hornblende.

In the axial part of the Sutton Mountain range alteration becomes more extreme, and over large areas the schist becomes gneissoid. This can be seen well in Glen Sutton Valley between Dunkin and Highwater, along Bolton Pass near Sallys Pond, and on Bolton Mountain, the bare ridge northeast of Bolton Glen. In these rocks, large metacrysts of oligoclase feldspar are numerous, some of which have replaced parts of the schist, whereas others, in growing, have pushed aside the schist lamellæ. Small grains of orthoclase also appear in these gneissoid rocks.

Graphitic bands, usually small, are fairly common, both in the ordinary schists and in the more gneissoid varieties. They have a characteristic steel-grey to lead-grey lustre.

Phyllites, second in amount to the sericite schists, appear to have been formed by the shearing of slaty or shaly beds, and are, accordingly, darker than the sericite bands with which they are interbedded. Most of them are minutely crumpled and folded, and in places have a finely banded appearance due to the presence of quartz layers up to one-sixteenth inch in thickness. Contacts with the sericite schists are generally gradational. The minerals present are the same as those of the sericite schists, but the proportion of chlorite is greater.

Chlorite schists are interbedded with the sericite schists in many parts of the belt, and may form bands up to 100 feet or more in width and traceable for a few hundred feet. In thin section these rocks are seen to be mainly composed of chlorite, with scattered grains of quartz and albite and some magnetite. Some actinolite appears to have formed during a fairly late stage of the metamorphism. In Thetford district, and also in Richmond map-area, it was proved that such schists pass into basic lava flows where metamorphism is less intense. It is, therefore, probable that these bands likewise are sheared lavas or basic tuffs.

The chloritized lavas interbanded with the mica schists are very similar petrographically to the lavas near Waterloo, but are generally readily distinguished from them by: (a) their more intense shearing, and especially by the fact that the schist planes have been crinkled and drag-folded in the same way as the planes of the surrounding mica schist; the Waterloo lavas, on the other hand, where schistose, have straight, flat shear planes; (b) the older chlorite schist in most places carries numerous quartz veinlets introduced between the schist lamellæ; the Waterloo lava, on the other hand, contains no quartz whatever except at its contacts with mica schist, or in a few places where some large veins have cut it.

In a few places in Memphremagog map-area, according to T. H. Clark (unpublished manuscript), limy beds have been found interbedded with the mica schists and phyllites. The purer types are creamy white to brown crystalline limestones, but varieties that carried some clay may be schistose. Calcite and dolomite are the principal constituents, with some quartz, albite, and oligoclase. Streaks of green fuchsite and talc have been noted in hand specimens, and pyrite, chlorite, apatite, and graphite are accessory. These beds are apt to be much fractured and filled with veins of quartz and chlorite.

A strong band of crystalline limestone or marble begins a mile or so southwest of South Stukely, and can be traced by scattered outcrops for some 6 miles to the northeast. Outcrops of limestone near Racine village, just north of the north boundary of Orford map-area, lie about on the projected strike of the band, and may represent its continuation. In the northern outskirts of South Stukely, two bands of the limestone are visible, separated by 1,000 feet of basic lava; but elsewhere only one band is exposed. It is everywhere closely associated with basic lava, here considered to be, probably, contemporaneous with the surrounding schists; in several places the basic lava appears on both sides of the limestone band. However, the straightness of the lava-limestone band, in view of the intensely drag-folded character of the schists, particularly to the east, arouses considerable doubt as to the accuracy of the correlation (with the schists).

The limestone band has been quarried in three places, and there can be seen to have widths of about 250 feet. Part of the limestone band is fairly pure lime carbonate, about 90 per cent $CaCO_3$, but other parts are high in magnesia, and may approach dolomite in composition. Veins of quartz cut the carbonate along the edges of the band.

Black, finely crystalline limestone was found in two places in the valley of Black River, 1 mile southeast of Rochelle, the other at the road crossing 2½ miles north of Lawrenceville. A detailed traverse of the valley might reveal the presence of others. The outcrops are isolated from other rocks, so that the relations are indeterminable, but presumably they are interbanded with the schists. The northern of these outcrops is about 700 feet wide.

A similar black limestone was found by Dresser (35) to underlie, presumably, an area nearly a mile wide just east of Richmond. The area is heavily drift covered, so that only scattered outcrops are visible. To the north, the band narrows rapidly and was not found again, and to the south it disappears under heavy drift. In this area schists appear nearby on both sides of the band, so that presumably it is interbedded with them. A second limy band mentioned by Dresser is only a few feet wide, and is definitely interbanded with the schists.

On the west side of Black River Valley, considerable widths of unsheared or slightly sheared quartzites are interbanded with more schistose strata. On the west side of the band of Waterloo lavas the beds are even less deformed, and rather coarse quartzites appear. They still, however, definitely underlie the lavas. One thin section of this quartzite showed nothing but grains of quartz up to 2 mm. or even larger, cemented by thin films (0·01 to 0·2 mm.) of small quartz grains and flakes of white mica. The fabric of the rock, with the minute amount of matrix enclosing most irregular grains with apparently granulated edges, suggests crushed quartz rather than a normal sediment. Only the entire lack of strain shadows, and the appearance in the outcrop, are against such an interpretation.

The band of schist between Magog and Massawippi Lakes appears to be an upthrust block, or horst, lying between the Magog and Massawippi faults. For the entire distance from the south end of Magog Lake to the north end of Massawippi Lake, the rocks are converted into schists, and the schist planes are intensely twisted and drag-folded. Road cuts and outcrops west of the road about 1½ miles north of Katevale, and also on the hill just east of Katevale, display these folds especially well. South of Katevale the influence of the Magog Lake fault does not seem to have been as great, and intense shearing gradually becomes confined to the neighbourhood of the Massawippi fault; away from it, the strata become more massive and normal bedding reappears.

Relations to the Caldwell Group. Sections across Missisquoi Valley display a gradual passage from the unsheared quartzites and slates of the Caldwell group into beds that are more and more sheared, culminating in the highly sheared and drag-folded schists of Sutton Mountains. The change does not take place at the Missisquoi Valley fault; on the contrary, west of the supposed fault in the northern part of Orford map-area there is a width of about a mile of relatively massive quartzite; and east of the fault, around Eastman and southward, the quartzites are highly sheared and drag-folded, exactly like the schists of Sutton Mountains.

It may be concluded, therefore, that the schists are merely the more highly sheared, lower part of the Caldwell group. This, also, was the conclusion reached in Thetford region, with regard to the Bennett schists.

Internal Structural Relations. If the above conclusion is correct, it follows that the structure of the Sutton Mountain area must be anticlinal; because these basal beds are followed on the east by the higher, unsheared beds of the Caldwell group, and these are overlain successively by the Beauceville beds of Ordovician age, and the Glenbrooke beds of Siluro-Devonian age.

This conclusion receives some support from the observed structure of the rocks themselves. Although prevailingly schists, there are some beds of massive quartzite, and in these the bedding appears to be always parallel with the cleavage. Also, phyllites and chlorite schists were formerly beds of slaty rocks and basic lavas; their strike and dip must, therefore, give the attitude of the former beds, and this again parallels the schistosity. Consequently, the conclusion seems justified that the schistosity everywhere parallels the original bedding.

On this basis, it is concluded that the structure of the schist is that of an anticline. According to T. H. Clark, the crest of the anticline crosses the International Boundary near the southwest corner of the Memphremagog area, runs somewhat east of north through Sutton Mountain, passes about a mile east of Sallys Pond, and follows a course roughly north 30 degrees east to pass just west of Eastray station on the Canadian Pacific railway from Magog to Montreal.

In most places along this axis the beds lie nearly horizontal, with a gentle plunge, usually, about 10 degrees to the northeast. In some, however, the dips or plunges become very steep, and the structure is difficult to determine. Fairly detailed examination will be required before the structure is thoroughly understood.

The crest of the anticline has a width, in most places, of about a mile, beyond which distance the dips become permanently southeast or northwest, as the case may be. Dips are steeper on the southeast side of the anticline, which, accordingly, has a narrower outcrop than the other. Toward the southern border of Memphremagog map-area, where there has been less disturbance of the major structure than farther north; dips average about 60 degrees on the southeast flank of the anticline, and about 45 degrees on the northwest.

Drag-folds, large and small, are numerous on the flanks of the major anticline. Commonly they are overturned or recumbent, so that the axial planes on opposite sides of the main crest converge upwards. Thus the anticline falls into the class of abnormal anticlines.

Quartzite

In the neighbourhood of Missisquoi Valley and its northward extension through Bowker Lake, the schists pass by a gradual decrease in schistosity into the massive grey quartzites and interbedded grey slates of the Caldwell group. On account of this gradual change no precise boundary can be drawn between the two groups of rocks; that shown on the map is merely an approximation.

The quartzites are characteristically massive grey to light grey rocks, with occasional creamy white or reddish varieties. The purer types consist mostly of quartz, others carry much feldspar, and some contain no more than 20 per cent of quartz. The quartz and feldspar grains, commonly of various sizes up to 1 mm., lie in a matrix of small grains of the same minerals together with much sericite and chlorite. The quartz grains are rarely well rounded; they tend rather to be subangular, and many of them have sharp angles and even concave sides. The feldspar seems fairly fresh, though part of it is altered to carbonate. Most of it is plagioclase with an occasional grain of microcline. Altogether, the material seems to have accumulated fairly rapidly, rather than to have been subjected to long wear. Apatite, ilmenite, zircon, tourmaline, and garnet have been noted as accessory minerals.

Besides the grey quartzites, occasional beds of very dark, almost black quartzites are found in places. The dark colour is due to the presence of some unidentified black material, possibly carbon, in the matrix surrounding the quartz grains.

The Caldwell quartzites are exceedingly hard and tough as a rule, with secondary sericite apparently acting as a binding agent.

On the west side of the Missisquoi fault, the quartzites continue northward into Richmond map-area in a band about $\frac{1}{2}$ to $\frac{3}{4}$ mile wide south of Kingsbury. Westward, it grades again into schist. North of Kingsbury, rhyolite occupies the position of the quartzite band, but near the north side of the map-area some quartzite appears on the west side of the rhyolite. On the east side of the fault, the only quartzite in Richmond map-area is found in a few irregular areas surrounded by Beauceville strata. Others are found in the northwest corner of Dudswell area and in a small, rudely triangular wedge along its north boundary. Thin sections show the composition to be similar to that of Orford map-area.

The quartzite beds above described have a general northerly strike in Memphremagog area, swinging to northeast in Orford and Richmond map-areas. They maintain near-vertical dips, and face east or southeast. Along the west boundary of Dudswell map-area this general strike is disturbed by numerous great drag-folds several hundred feet across, which indicate strong horizontal movement of the southeast side to the southwest, *after* the strata had been folded into their present near-vertical positions. In these drag-folds, the beds, where they strike southeast, tend to have low northeasterly dips. If the eastward swing of the Caldwell-Beauceville contact, which is found just north of the boundary between Dudswell and Warwick map-areas, is due to folding, it would account for these drag-folds. This point, however, still remains to be investigated. The Beauceville strata in contact with the drag-folded Caldwell beds do not display any similar structures, thus suggesting that the drag-folds were produced by some pre-Beauceville movement.

In Memphremagog and Orford map-areas, other bodies of quartzite appear in the anticlinal area that lies between the two synclines of the Glenbrooke group, and in its northward continuation. Most of these are rather small masses, surrounded by younger rocks. In almost all instances, however, they were definitely identified by finding them in contact with the basal conglomerate of the Beauceville group.

Slates

Thin beds of grey slate are commonly interbedded with the Caldwell quartzites, and the cleavage-bedding relations they display are most useful for making structure determinations. Locally the slates become dark grey to black, and may be difficult to distinguish, in isolated outcrops, from Beauceville slates.

Northwest of the south end of Massawippi Lake considerable thicknesses of black slate contain numerous rusty metacrysts of iron carbonate, up to $\frac{1}{4}$ inch in diameter, which give them a striking appearance. Near the mouth of the creek flowing through McConnell, they can be seen interbedded with the hard quartzites of the Caldwell group.

Limestone

Little limestone has been found in the Caldwell group, aside from the bands in Sutton Mountains, already described. However, some dark grey limestone was found in the area northwest of the south end of Massawippi Lake, specifically about 1 mile south of McConnell, and also in lot 7, rge. IX, Hatley tp. Under the microscope, these rocks are seen to consist of 80 to 95 per cent of carbonate, presumably calcite as effervescence with dilute acid is vigorous; the remainder is mainly grains of quartz, with an occasional grain of feldspar. These have irregular shapes, and some have obviously suffered granulation. Some of the quartz also appears to have been replaced by carbonate. The dark colour is due to the presence of much very fine-grained black material, presumably ferruginous or graphitic.

In lot 9, rge. VII, Hatley tp., a bed identified as limestone because of its effervescence with dilute acid, proved, when examined in thin section, to contain some 40 per cent quartz and 20 per cent plagioclase grains. Cementing these grains was a mixture of mica and carbonate, presumably calcite, and some of the fine-grained blackish material above mentioned. The quartz grains are more or less granulated, and seem to have been partly replaced by the mica-calcite groundmass.

The composition of these limestones, so similar to the impure limestones of the St. Francis group, and their position just west of the St. Francis fault, suggest that they may be erosion remnants of the St. Francis fault block that, as will be shown, was thrust over the Beauceville block from the east.

Trachytes

Trachytes occupy the southwest part of Dudswell map-area, and extend southwest for some miles into Richmond and Orford map-areas. The flows are a few inches to a few feet in thickness, and are interbedded here and there with small amounts of fine to coarse tuffs of similar composition. The flows are everywhere very fine grained and hard, and range in colour from light to dark grey. Most varieties are characterized, in hand specimen, by the presence of needles of biotite about 0·3 mm. long. Some varieties contain numerous small white lumps that suggest amygdule fillings or phenocrysts, but the microscope shows them to be aggregates of zoisite or clinozoisite grains.

Under the microscope, the average grain is seen to be 0·01 to 0·02 mm. Some sections contain little phenocrysts, up to 0·05 mm. in diameter, of fresh oligoclase feldspar, with an occasional phenocryst of quartz. The groundmass is fresh oligoclase in very small grains, accompanied by much very pale green chlorite and a few shreds of white mica. The origin of the zoisite or clinozoisite present in many flows is not known. It does not appear to have originated from the alteration of phenocrysts or amygdules. The possibility was considered that it might be altered trachyte glass, but one flow 25 inches thick on the northern outskirts of Windsor Mills was found to contain a much higher concentration of zoisite in the lower parts than in the uppermost. As glass would normally be found at the upper surface where cooling was most rapid, the hypothesis that the zoisite is altered glass is, therefore, difficult to maintain.

Interbanded with the flows are a few beds of very similar appearance, except that they are slightly coarser in grain. They might easily pass unobserved, and in fact specimens of them were collected as representing slightly thicker flows. The microscope shows them to be crystal tuffs, made of sharp-angled fragments or shards of feldspar of all sizes up to 0·7 mm., with 2 or 3 per cent of quartz. Present also are many fragments of the trachyte, some of them several millimetres long. The feldspar fragments are much altered to aggregates of white mica. The groundmass is a fine-grained mixture of fresh feldspar grains, pale green chlorite, some white mica, and a little zoisite.

On the northern outskirts of Windsor Mills an interesting bed of tuff, 6 feet or more in thickness, is interbedded with the lavas. It contains very numerous black fragments, up to ½ inch long, in a grey matrix of fine to medium grain. The black fragments look like slate, but many of them have a hardness of about 4. Their grain is too fine to be resolved by the microscope. Possibly they are altered glass. The matrix in which they lie has a composition much like the tuffs described in the preceding paragraph.

In Dudswell map-area, no place was found where the trachytes are in contact with other members of the Caldwell group. In Richmond map-area, in lot 4, rge. XIV, Cleveland tp., a band of the lava that strikes north 35 degrees east, dips vertically, and faces southeast is overlain by some 200 feet of slates and then by greenish grey quartzite. The section suggests a conformable relationship, but does not prove it definitely as the outcrops, though numerous, are not continuous. Finally, however, in 1947, several places were found east of Bowker Lake in Orford map-area where the trachytes lie in conformable contact with Caldwell quartzites; and, like the quartzites, are unconformably overlain by the Beauceville conglomerate and have yielded pebbles to it. These discoveries thus definitely establish the fact that the trachytes are part of the Caldwell group.

In several places between Fraser and Bowker Lakes, the trachytes lie fairly close to small bodies of reddish or purplish slate. The writer is inclined to look on these as genetically associated with the trachytes. They may have been fine tuffs, or possibly are ordinary slates coloured by iron-bearing volcanic waters.

Basic Lavas

Lavas formerly about the composition of basalt or andesite form a long narrow band that extends almost due south from Eastman to the vicinity of Mansonville. Around Trousers Lake, the band appears to have been faulted about half a mile to the west, and the supposed break has been the locus for intrusions of quartz diorite and peridotite.

From Eastman south for about 10 miles, the lava band is narrow, ranging in width from 500 to 800 feet, and may, it is thought, consist of a single flow. At a point about 5½ miles north of Mansonville, however, the width increases rapidly where two bands of lava come together, each of which has a maximum exposed width of about 2,000 feet.

In hand specimen, these lavas resemble altered andesites, but in thin section they are seen to be completely altered to chlorite and other secondary minerals.

Careful search was made for contacts with the Caldwell quartzites, and eventually one was found in the valley of a small creek in lot 4, rge. VII, Bolton tp. At this point the lava lies with perfect conformity upon the well-bedded quartzites of the Caldwell group. Better evidence of conformity is, however, to be seen in the perfect parallelism that the flow maintains with the quartzites throughout a distance of more than 10 miles.

In the small anticlinal areas of the Caldwell group found between the two synclines of the Glenbrooke group, basic lava bands are not uncommon. One, 2½ miles long, lies to the west of Sargent Bay; another, 1½ miles long, to the south of the mouth of the bay.

Rhyolites

In Richmond map-area, from the north side of the sheet southwest to a point about 2 miles southwest of St. Francis River, the schists are overlain directly on the southeast by a band of rhyolites about 3,300 feet wide. Sharp contacts were found in three places northwest of New London, and at each the contact appears conformable and non-faulted. The schists strike north 30 degrees east, dip 45 to 60 degrees southeast, and drag-folds indicate that the top is to the southeast. The rhyolites are a succession of porphyritic flows ranging from 2 to 20 feet in thickness; their strike and dip are parallel with those of the schists, and changes in the grain size, mainly of the phenocrysts, within individual flows indicate that they also face southeast. These apparently conformable relations justify the inclusion of this rhyolite with the Caldwell group. The southeast contact of the rhyolite band is the fault along the valley of Steele Brook.

The rhyolites are grey to dark grey rocks made up of 20 to 30 per cent of phenocrysts in a greenish grey matrix. In a few flows, the phenocrysts are all of quartz, but generally feldspar phenocrysts equal or exceed the quartz phenocrysts in numbers. The feldspar is oligoclase, and fairly fresh; in some flows it grades to albite-oligoclase, in others to andesine. All the 'phenocrysts' are broken fragments, with sharp angles and irregular shapes. In one section that displays a pronounced directed texture, the quartz 'phenocrysts' are long narrow shards that parallel it. The writer considers that the phenocrysts were broken, in all probability, by flow movements while the mass was still semi-fluid, as only this one section displays a directed texture, and none of the phenocrysts show the 'tails' characteristically found when a crystal has been partly fragmented in a consolidated rock.

In the areas of Caldwell rocks lying northwest of the Massawippi-Fitch Bay fault, there are rather numerous bodies of rhyolite, most of them small and not mapped separately from the interbedded sediments. One of the largest is a lens-shaped body, some 2,000 feet across where widest, which crosses the boundary between Orford and Memphremagog map-areas. Another of considerable size occupies the northeast end of Bunker Hill. Still others, probably though not certainly Caldwell, are found about 2 miles north of Magoon Point. They are fine-grained, non-porphyritic, hard, light grey, massive rocks that usually weather to white or very light grey tints. The last-mentioned occurrences display brecciated textures, and are probably flow breccias.

Structure

That part of the Caldwell group lying east and west of Missisquoi Valley and its northward continuation through Bowker Lake and Salmon and Steele Brooks has steep eastward dips and faces toward the east or southeast. Between the two synclines of the Glenbrooke group, an anticline of older rocks extends north-northeast through Little Brompton Lake, presumably to join the main anticline of the Caldwell group near the northern edge of Orford map-area. Along the crest of this anticline several areas of Caldwell rocks appear, emerging from beneath strata of the Beauceville group. Some of them seem due to anticlinal cross-folding; others may be caused by faulting. All are poorly exposed, so that their individual structures have not been determined, and even the reasons for their appearance are determinable in only a few instances.

The area of Caldwell beds and schists between Massawippi and Magog Lakes seems to have been an upfaulted block. The schists close to the Massawippi-St. Francis fault dip east, in many places, as near Lennoxville, at angles of 45 to 50 degrees, and are closely drag-folded and minutely crumpled. The drag-folds plunge northeast at low angles, such as 10 to 15 degrees, and thus indicate upward movement of the southeast side, with some movement of that side toward the northeast. The writer considers that they have most probably been produced by the movement of the overriding block of St. Francis rocks from the southeast. The relations will be discussed in more detail in the section devoted to faulting.

The Caldwell rocks appear to have been folded to some extent before the Beauceville group was deposited. Evidence to this effect will be given in the section describing the relations of the Beauceville to the Caldwell.

Age

In the succeeding section, dealing with the Beauceville group, it will be shown that the Caldwell beds suffered folding and erosion before the Beauceville was deposited, and that the Beauceville is of Middle Ordovician age. An interval of considerable length must, therefore, have intervened between the end of the Caldwell deposition and the beginning of that of the Beauceville. As both Ordovician and Cambrian periods were very long, however, it seems unlikely that the interval was long enough to cover all of Cambrian and the lower half of the Ordovician; to the writer, therefore, it seems likely that the Caldwell strata are of Cambrian age. Admittedly, however, this inference is unsupported by any fossil evidence.

It is now recognized that a general epeirogenic uplift of the eastern part of North America took place in early Ordovician time, at the end of the Beekmantown epoch. Possibly the forces causing uplift may have caused folding locally, resulting in the rise of a short range of hills or mountains in Memphremagog, Orford, and Dudswell map-areas. Outside of these areas, as noted in an earlier report (22), Beauceville and Caldwell strata are closely parallel, and the unconformity between them is erosional only.

ORDOVICIAN

The Ordovician rocks of the region include the St. Francis group, which occupies the St. Francis fault block in the southeast part of the mapped area; and the Beauceville group, found in the Beauceville fault block. The two are quite different in composition and succession, and no relationship between them has been proved. The very scanty fossil evidence available suggests that the St. Francis group is slightly the older.

ST. FRANCIS GROUP

Lithology

The base of the St. Francis group is not known, as it is everywhere in faulted contact with other rocks. The oldest known beds are dark impure limestones and limy slates; these are overlain by a thick succession of quartzites with some thick beds of black slate. Two or three thin beds of conglomerate are interbedded with the limestones in road cuts about a mile south of the Lennoxville golf club.

The limestone member is everywhere poorly exposed, presumably because the carbonates dissolve quickly on weathering. On outcrops, the limy beds are characterized by the presence of a soft brownish gossan, in places 2 or 3 inches thick. It consists, presumably, of the insoluble impurities remaining after surface waters have dissolved the carbonates.

In Scotstown area the limy beds have an outcrop width of 1½ miles; in Sherbrooke area, more than 6 or 7 miles; and in Memphremagog area, more than 10 miles. Presumably this variation is due to the boundary fault crosscutting the bedding so as to pass from lower into higher horizons. In Memphremagog area structure determinations near the fault were numerous enough to show that the fault there does transect the bedding at angles of 15 to 20 degrees; but north of Massawippi Lake the fault swings to a closer parallelism with the bedding.

In Scotstown map-area the limestone member is exposed mainly on Fisher Hill and vicinity; southwest of the hill it is wholly concealed by drift, and its extent is inferred from its occurrence in Sherbrooke and Dudswell map-areas. In Dudswell map-area, it appears only in a half dozen outcrops. In Sherbrooke map-area, it is somewhat better exposed, particularly in stream valleys and road cuts, but otherwise exposures are not plentiful. In Memphremagog map-area, exposures are locally good, but there are large areas with few or none.

In road cuts due south of Lennoxville golf club, three beds of conglomerate are interstratified with the impure limestones. The most northerly is about 3,700 feet away, the others farther south at intervals of about 250 feet. They are 4 feet, 6 inches, and 6 feet thick respectively, strike northeasterly, and dip about 60 degrees southeast. All have the same composition, and are rather badly sheared so that the pebbles are drawn into flattened shapes. As nearly as can be learned from inspection, most of the pebbles are of rhyolite, some with quartz phenocrysts up to 1 mm. in diameter. A smaller number are of more basic lava, such as basic dacite or acidic andesite. One is of coarse white granite, and a small one appeared to be a pebble of blackish chert.

Two analyses of the limestones given by M. F. Goudge (42, p. 241) from quarries near Ayers Cliff and North Hatley respectively, are as follows:

	Ayers Cliff	North Hatley
SiO_2	40·36	43·06
Fe_2O_3	1·39	1·12
Al_2O_3	1·93	2·21
$Ca_3(PO_4)_2$	0·17	0·15
$CaCO_3$	51·41	49·21
$MgCO_3$	3·70	3·01
S	0·25	0·10

The contact of the limestone member of the St. Francis group with the overlying quartzite-slate member was found only in the bed of Salmon River, south of Fisher Hill, Scotstown map-area. It is exposed on the bank of a rapid about $\frac{3}{4}$ mile east of the bridge across the river. There, the most northerly beds are limestones and limy quartzites or slates, interbanded with true slates and quartzites. A measured 10-foot section showed an aggregate amount of 40 inches of the limy beds, 44 inches of slate and silt, and 26 inches of quartzite. There were two gaps aggregating 11 inches where the beds are deeply weathered, and are hence probably either limestone or slate. The limy beds thus constitute about 35 per cent of the whole.

Above this point the limestones become rapidly more siliceous, and give way to quartzites of varying degrees of purity; the proportion of slate also decreases. Three hundred and fifty feet above the measured section described, a 27-foot section shows 25 feet of quartzite and only 2 feet of slate, with no limestone.

In Sherbrooke map-area no contact of the two members was found. From the mapping it appears to bevel across the general strike at a small angle, suggesting either that the contact is a fault, or that there is some step-faulting. In Memphremagog map-area the contact appears to lie close to the extreme southeast corner, and, if so, is probably not as sharp as in Scotstown map-area. Exposures there are very poor, but from Rock Island eastward they consist mainly of slate with limestone interbeds and a few beds of near-quartzite, whereas west of that point they are mainly the impure limestone.

The quartzite-slate member of the St. Francis group outcrops in Scotstown map-area across a width of $17\frac{1}{2}$ miles; in Sherbrooke map-area a width of 12 miles is exposed, and the formation continues eastward into La Patrie map-area. The quartzites are made up of 50 to 60 per cent of quartz, with varying percentages of feldspar, mica, and chlorite. The present grain size ranges in different beds from 0·1 to 0·4 mm., but much crushing and recrystallization has taken place. Crossbedding is common, and may be used for structure determination where clean polished surfaces can be found. The quartzite beds range in thickness from a fraction of an inch to several feet, but a common thickness is a couple of feet. Slate beds ranging in width from a fraction of an inch to 4 or 5 inches may separate the quartzite beds, and the cleavage-bedding relations they display are particularly useful for determining the local structure.

The quartzites, with minor amounts of slate, underlie a belt in Scotstown map-area some 4 or 5 miles wide, directly southeast of the limy beds of the group. Southeast of them in turn the rocks become dark siliceous greywackes, with much larger proportions of slates and brownish silty argillites. These softer beds are rather poorly exposed; individual beds range in thickness from 3 or 4 inches to 15 feet, so that their aspect is entirely unlike the 'striped slates' of the Beauceville group. In Sherbrooke map-area this more slaty member was not recognized; possibly it lies to the east, or possibly lithological changes may take place along the strike. In Memphremagog map-area, as described, the full width of exposure of the group seems to fall within the limestone member.

Structure

In Memphremagog map-area, where the limestone member of the St. Francis group is both widest and best exposed, all the exposures on which structure was determined face toward the southeast, except a very few where drag-folding had taken place. Such drag-folds, however, were never more than a few hundred feet across the strike.

In Sherbrooke area, the beds of the quartzite member also face fairly uniformly southeast. In a few places, drag-folds were found in which the beds face northwest, but in every case it was found that such folds have amplitudes of a few hundred feet only, and that across them the beds resume their original attitude and face southeast. The anticlinal crest of one of these drag-folds can be observed in the bed of Eaton River at Lake Mills; the almost horizontal crest of the fold was utilized as part of the foundation for a stone dam.

In the overlying slate-greywacke member in Scotstown area, such observations as were obtained showed that the beds also face southeast; but such observations on small and scattered outcrops cannot be considered to have any general application. Similar slaty rocks of the Beauceville group were found, where outcrops are good, to lie in a succession of very narrow folds; it is not unlikely that the St. Francis slates have been similarly plicated.

In Memphremagog area, the St. Francis limestone and slate beds across the full width of 10 miles are overturned, and now dip northwest at angles of 50 to 70 degrees. Only within a rather small area near the mouth of Fitch Bay is this not the case; there dips, where determined, are vertical or nearly so (Figure 2). In Sherbrooke map-area, overturned strata are met with across a width of about 10 miles, measured from the southeast corner; the northwestern boundary of the overturned strata has swung to the east, out of the limestone beds altogether and into the overlying quartzites. In Scotstown map-area the strata across a width of about 3 miles east of Scotstown and 4 miles west of it are overturned in a narrow band that extends about 1½ miles from the south boundary of the area. Overturning may extend still farther east, but all outcrops are there hidden by thick drift. North of the area mentioned, no further overturning was observed.

Thickness

It is obvious from the width of the area over which the St. Francis group outcrops, and the uniformity of the observed structure, that the thickness must be very great. It can readily be estimated that if beds are not repeated by faulting, some 40,000 to 50,000 feet of strata must be present. No estimate can have much value, however, as strike faults have been found numerous in the region wherever the presence of horizon markers enables them to be recognized; hence, they may be presumed to be equally common in this section. Further, neither the top nor the bottom of the group is known.

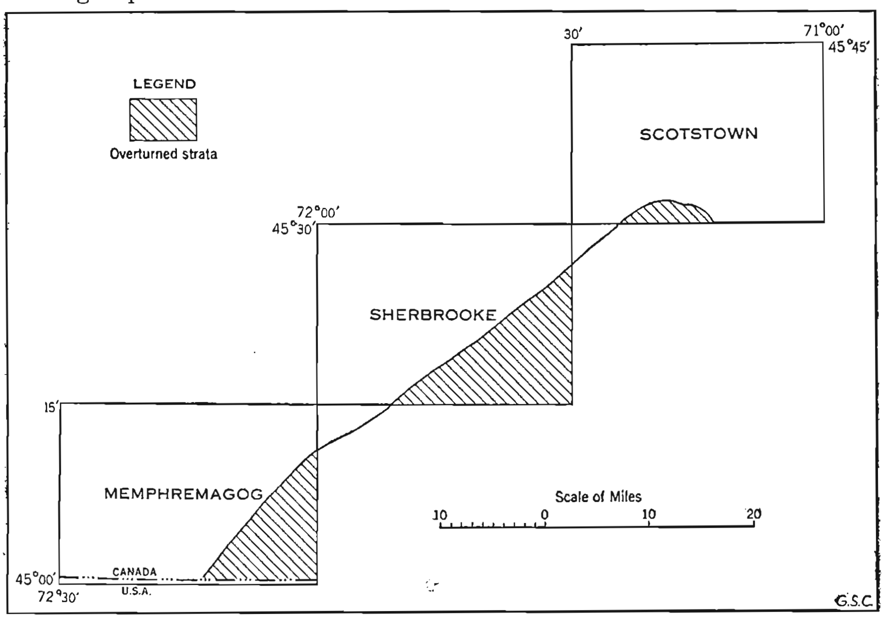

Figure 2. Index map, showing approximate boundaries of areas of overturned strata observed in Scotstown, Sherbrooke, and Memphremagog map-areas.

Age

No fossils have been found within the area under consideration, although careful search was made of any beds that seemed to lack much deformation. Recrystallization and crushing would seem to have destroyed any fossils that may once have existed. The only data of the sort, therefore, are still those given in an earlier report (22, p. 42). In 1932, two of the writer's assistants discovered graptolites in a bed of blackish sandstone in lots 11 and 12, rges. VIII to IX, Adstock tp. They were identified by Dr. R. Ruedemann of the New York State Museum as probably *Diplograptus euglyphus* Lapworth, thus fixing the age of the beds as Middle Ordovician (Normanskill). Further collections from the same locality were made by Dr. T. H. Clark of McGill University, whose identifications confirmed those of Dr. Ruedemann.

BEAUCEVILLE GROUP

Nomenclature

In 1900 H.M. Ami (5) referred briefly to the slates of Lake Memphremagog as the "Magog formation". This term, therefore, has priority over the term "Beauceville" and should perhaps supplant it. However, as the term "Magog formation" never came into general use, and the name "Beauceville" has now been applied to the group throughout a length, along the strike, of more than 100 miles, and is used in successive reports, it seems best to avoid confusion by retaining it.

J. A. Dresser (37) in 1910, and Robert Harvie (51) in 1912, applied the term "Farnham series" to the Beauceville of Memphremagog area. As the term Farnham was first applied by Ells to black slates on the west side of Sutton Mountains, this usage implies a correlation that has not been proved, and is, therefore, not followed here.

Some years ago Dresser (40) put on record several occurrences of what he termed the Magog conglomerate, and suggested that it marked an unconformity of regional extent. The writer has studied a considerable number of these occurrences, all of which consisted of the basal conglomerate of the Beauceville group.

In 1936 T. H. Clark (17) described the "George Pond breccia", which appeared to lie at the base of the Glenbrooke group as a local development. The writer has found that the "breccia" is a phase of the basal Beauceville conglomerate; it lies directly on a basic lava of the Caldwell group, so that in this place it carries numerous fragments of the lava.

The term "Beauceville" was coined by B. R. MacKay in 1921 to apply to a group of rocks on Chaudière River (Geol. Surv., Canada, Mem. 127). The writer has traced these beds continuously along the strike from that area to the International Boundary.

Conglomerate

Practically all the conglomerate of the Beauceville group lies at its base, only one outcrop being found that does not occupy this stratigraphic position. The basal conglomerate was found at all points throughout the region where the Caldwell-Beauceville contact is actually exposed, and at most of those where Beauceville strata outcrop within 50 to 100 feet or so of the contact. In a few places, conglomerates outcrop across widths of several hundred feet from exposed contacts, but it is believed that such widths are due either to folding or to very low dips of the plane of contact, so that Caldwell strata lie fairly near the present surface.

The basal conglomerate, where not much deformed, contains numerous pebbles of the Caldwell slates and a smaller number of pebbles of the Caldwell quartzites. This rather unusual makeup suggests rapid deposition with little previous transportation, for otherwise the slaty pebbles would have been ground to clay particles that wave or current action would have removed. The inference is strengthened by the fact that the pebbles tend to be subangular rather than well rounded.

In most places, however, shearing has converted the slate pebbles into a black slaty matrix for the harder quartzite pebbles. In such places, care must be taken to distinguish the true conglomerates from the crush breccias, which are fairly common in the district, but by painstaking work this may usually be done. Field recognition of conglomerates, even when the matrix appears very slaty, is much aided by the fact that the slate pebbles are commonly not completely sheared out; so that if a sample of the slate is cracked off with the hammer, and lifted carefully so that the slate laminæ do not fall apart but remain in their original relative position, little greyish or brownish fragments of the former argillite pebbles may usually be seen in it.

The conglomerate varies greatly in thickness. In places, as at the south end of Brompton Lake and east of Bowker Lake, the thickness is only a few inches; and in such places the pebbles are mostly small, up to the size of beans with a few up to an inch. In other places, widths of outcrop amount to tens, scores, and even hundreds of feet; but as the bedding is commonly obliterated by shearing these figures tell little of the original thickness, except that it was probably relatively great. In such places the pebbles commonly attain sizes of 1 inch to 2 inches, though in places larger ones are found. Thus, about $\frac{1}{2}$ mile northwest of St. Denis de Brompton, Orford map-area, some boulders in the conglomerate attain dimensions of 6 to 8 inches, and boulders of similar size were seen on the hill just west of Mont Joli at the south end of Webster Lake. Boulders up to 2 feet in length were observed east of Bowker Lake, on the east side of the road paralleling the lake about $1\frac{1}{8}$ miles from its south end, but such sizes are most unusual.

The pebbles of the conglomerate consist mainly of slate and quartzite, as mentioned. Where the conglomerate is in contact with lavas, however, pebbles of the lava also appear. Thus the conglomerate overlying the lava band on the east side of George Pond, Memphremagog map-area, contains numerous boulders of lava, particularly in the outcrops close to the contact. In a farmyard $1\frac{1}{4}$ miles northwest of St. Denis de Brompton, Orford map-area, some 200 feet northeast of the road, a patch of Beauceville conglomerate overlies thin-banded trachytes that dip vertically and are strongly drag-folded. The conglomerate contains pebbles of the trachyte.

An interesting contact of conglomerate and lava was found on the hill about $1\frac{1}{2}$ miles southwest of St. François Xavier de Brompton, Richmond map-area, where a large dyke of peridotite surrounds an inclusion of older rocks some 200 feet wide. On the west side, the inclusion rises 25 or 30 feet above the surrounding peridotite, yielding a vertical cross-section. The lower part is fairly massive trachyte lava, with a few inclusions of similar material. Some 10 feet higher, inclusions become rapidly more numerous, and the rock becomes a flow breccia, on which the conglomerate lies. Some difficulty was at first experienced in distinguishing the breccia from the conglomerate, but this disappeared with closer study. In the breccia all the boulders consist of lava, whereas in the conglomerate pebbles of various quartzites are numerous, as well as pebbles of the lava. Some of the lava boulders in the conglomerate are as much as 2 feet in diameter. The conglomerate has a grey, slaty matrix, which may be finely triturated lava. This matrix is quite schistose, whereas the underlying lava and breccia are not.

The contact was traced for some 200 feet along the west flank of the hill, and in that distance is nearly horizontal. Near the south end of the outcrop a mass of lava is entirely surrounded by conglomerate except at the base, which is hidden. The mass is 8 feet long, 6 feet high, and 3 feet wide; it appears to be either a huge boulder or else a pinnacle on the surface on which the conglomerate was laid.

It is, however, a very curious feature of these conglomerates that although both the basic andesitic lavas and the trachytes have a considerable development in the Caldwell group, and both are hard rocks that might be expected to resist wear, pebbles of them have not been recognized except close to contacts, in spite of close study. It suggests that on the whole there was little transportation of the products of weathering of the Caldwell group, but that these were worked over, possibly by gentle wave action, and remained near their place of origin. It will be recalled that the large proportion of slate pebbles in the conglomerate likewise suggests the same conclusion.

The matrix of the pebbles is commonly black slate identical with the slate that overlies the conglomerate. Here and there, hewever, the matrix is a light grey to darker grey greywacke, which is apparently merely the disintegrated and recemented material of the underlying grey Caldwell rocks.

Just north of the north end of East Branch Pond, Orford map-area, a very puzzling situation was found. The outcrops are near the end of the road that passes around the north end of the pond. At this place the flat valley bottom in which the pond lies is flanked, on the west, by a considerable hill. Outcrops are numerous on the side of the hill, and others are found in the valley bottom; but the top of the hill is drift covered and heavily wooded.

A part of the side of the hill is underlain by a lava resembling an altered andesite or basalt. Except for this, most of the hillside is occupied by an unusual rock of conglomeratic appearance. Beyond it, to the east, west, and north, is the ordinary black slate conglomerate of the Beauceville group.

The unusual 'conglomerate' is a grey rock that contains numerous lumps of brown weathering lava. These are of all sizes up to 3 or 4 feet in length, and some have most irregular shapes that suggest masses of semi-fluid lava hurled out of a crater. Many of them are highly vesicular, and some have the structure of flow breccia, with highly vesicular parts cemented together by less vesicular material. Some of these boulders are much epidotized.

Besides these fragments, the rock contains some rounded or angular fragments of light grey, fine-grained lava that looks like rhyolite; others of chert or chert-like rock; and a few of grey quartzite identical in appearance with the Caldwell quartzite.

The variety of pebbles suggested at first that this rock was a true conglomerate; and its close association with the basal conglomerate of the Beauceville group seemed to indicate that it was probably a local phase of that conglomerate, the differences being due to contemporary vulcanism. More detailed examination made that view untenable. In one place a chip of the black slate conglomerate, 10 inches thick and from 2 to 3 feet in its other dimensions, was found resting on the other rock, which may be termed agglomerate; and two pebbles in the black slate conglomerate consist of the basic lava. In another place the contact relations suggest that the conglomerate was laid down on an irregular surface of the agglomerate. In a third place the relations indicate that interbedding is impossible. In still a fourth place the black slate matrix of the conglomerate gradually becomes greenish as the contact is approached, suggesting that it contains some triturated lava. Finally, in several places small pebbles of lava were found in the black slate conglomerate close to its contact.

It is thus evident that the lava with its associated agglomerate is not an interbedded, local development of the Beauceville group, but that the Beauceville, on the contrary, overlies it unconformably. The lava, therefore, with the associated agglomerate, is to be considered as part of the older Caldwell group.

The term 'agglomerate' is used for the underlying conglomerate-like rock because it is so largely made up of fragments and bombs of the associated lava. The foreign fragments in it may be bits torn from the walls of the vent through which the lava arose.

The one instance of a conglomerate that does not appear to occupy a basal position in the Beauceville group was found in the northeast corner of St. Camille township, Dudswell map-area. Two bands are there found that may be parts of a single folded band, but this was not proved. The best exposures are on the southeast side of range line IX-X, St. Camille township, about 3,300 feet from the boundary of South Ham township. The conglomerate forms the base, or north side, of a quartzite bed some 300 feet thick; it was followed for about 750 feet. Its shape, for this distance, is lenticular; the greatest width is 99 feet, at a point 270 feet from the southwest end of the section examined, and this width decreases to 44 feet at each end. Roughly half of this conglomerate consists of pebbles, and the remaining matrix is a coarse grit. Most of the pebbles are less than 1½ inches in length, but a few range up to 5 or 6 inches. Most of the larger pebbles are white quartzite; a few are chert, cherty quartzite, or dark quartzite. Pebbles less than an inch long include both quartzite and slate. None of the pebbles is well rounded; on the contrary, they have various irregular shapes, and some are sharply angular. Thus they display every evidence of rapid accumulation with little wear.

Quartzite

Quartzites are uncommon in the Beauceville group, except as rather thin beds interbanded with black slates, as later described. In the northeast quarter of Dudswell map-area, however, for about 5 miles from the boundary of the Devonian rocks, quartzite bands are larger and fairly numerous. They range in composition from greywacke to fairly pure quartzite, and in thickness from a few feet to several hundred. The positions of the wider of them, mainly those more than 50 feet thick, are shown on the published 1-mile map[1]. Some of them, when traced, were proved to be lenses that thinned rather rapidly along the strike, and probably all are of this character; but this was not proved, as usually the outcrops were soon lost beneath the prevailingly heavy drift cover.

[1] Geol. Surv., Canada, Map 988A, Dudswell, Quebec.

Slates

The common rock of the Beauceville group is a dark grey or black slate, the colour of which is due to the presence of small quantities of carbon or graphite. The slates are evenly and thinly bedded; the beds range from 1 inch to 2 inches in thickness, and are characterized as a rule by an excellent secondary cleavage. Some years ago, when slate was more used than at present, they were much quarried. Interbanded with the dark slates in most localities are brownish grey beds, which the writer terms silt for purposes of differentiation. As later described, in the upper parts of the succession these silts become progressively more siliceous, and eventually pass into impure quartzites.

The slates as a rule are not well exposed. Like the limestones of the St. Francis group, erosion has reduced them to low-lying areas on which heavy deposits of drift have accumulated. Thus the slate areas are now rolling expanses that include some of the best farm lands of the region. However advantageous from an economic standpoint this condition may be, it makes it very difficult for the geologist to obtain much information as to their succession and structure.

For this reason little of value was learned about the structure of the slate areas until, in 1945, a well-exposed section was found in Sherbrooke map-area. It lies to the southwest of Bromptonville; about 3 miles from that village large outcrops afford special facilities for study. There it was found that the slates have been thrown into a succession of narrow folds with fairly steep dips on the flanks and fairly sharp crests. The distances between successive anticlinal axes is of the order of 700 feet. Since these observations were made, some smaller areas have been found with the same type of folds. The folding was accompanied, as might be expected, by a certain amount of faulting.

With this information at hand, it becomes evident that the great widths of the slate areas—up to 10 miles in Dudswell map-area—do not represent corresponding thicknesses, but have undoubtedly been formed by repetition of beds by folding and some faulting. Also, it may be added, it is useless under the circumstances to attempt to make estimates of thickness.

Lithological Changes

To study the lithological changes from the base of the Beauceville group upwards, a section was measured from the Devonian contact in the northwest corner of Scotstown map-area northwest to the base of the group in the adjacent part of Warwick map-area. The section is about 4¼ miles long, and the rocks are moderately well exposed in road cuts and natural outcrops along the road that leads from Weedon to South Ham village. Throughout this section the strike is uniformly north 40 degrees east, and the dip vertical or nearly so except in two places where drag-folding has produced shallower dips. In all the outcrops the beds face toward the southeast. Most of the determinations were made from cleavage-bedding relations, but a few from crossbedding. Two drift-filled gaps of nearly ½ mile each occur in the 4¼ mile section, with others of smaller size.

Narrow folds do occur in this section—one was found at the northwest end where the basal beds fold over an anticlinal crest of the underlying Caldwell beds, and another at the southeast end where a subordinate syncline of Devonian beds lies north of the main body—but on account of the shortness of the section it seems probable that they are fewer than elsewhere, and, if present, must occupy the drift-covered areas as the visible beds all face southeast. But whether present or not, it is obvious that the section, which begins at the basal conglomerate and continues upward to what was the surface in Lower Devonian time, must present a fairly continuous picture of such lithological changes as took place.

At the northwest end of the section, the basal conglomerate is well exposed on both sides of the Weedon-South Ham township boundary. It has the character already described, with some parts so sheared that only quartzite pebbles remain, whereas other less-sheared parts contain numerous slate pebbles. The pebbles are of all sizes up to 4 inches in length, but most of them are less than 2 inches. The conglomerate exposure is more than 2,000 feet wide, though its thickness is probably not more than a fraction of this figure.

A drift-filled valley 2,000 feet wide separates these outcrops from those next to the southeast. In the latter more conglomerate is found, with the grain of a coarse brownish grey grit. It is made up mainly of feldspar grains $\frac{1}{40}$ to $\frac{3}{40}$ inch in diameter, with various angular and irregular shapes, and a few of quartz. A few small pebbles of quartzite, some so fine grained as to be almost chert, are present. Most of them are about as big as peas, a few as large as beans, and the largest observed was tear-drop shaped, an inch long and $\frac{3}{8}$ inch at its widest part.[1]

Southeast of these beds, across a width of about a mile, black slate beds alternate with soft, brownish grey beds here termed silts. On a clean, glacially polished surface in lot 13, rge. X, Weedon tp., 3,170 feet northwest of range line IX-X, a 6-foot section of these beds was measured. The slate beds, forty-five in number, aggregated $50\frac{13}{16}$ inches in thickness; the narrowest was $\frac{1}{4}$ inch thick, the widest 6 inches, with most of them ranging from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches. Black slate thus constitutes 69·3 per cent of this section. The silt beds, also forty-five in number, had an aggregate thickness of $22\frac{1}{2}$ inches. The narrowest was $\frac{1}{16}$ inch, the widest $1\frac{3}{4}$ inches thick, with most of them about $\frac{3}{8}$ inch or less. Silt, therefore, constitutes 30·7 per cent of this section.

Near range line IX-X, and again just southeast of the road in range IX, in the extreme northwest corner of Scotstown map-area, it may be observed that the silts are gradually becoming harder, presumably more siliceous. Though still quite soft—about $2\frac{1}{2}$ to 3 on Mohs scale of hardness—they are sufficiently harder than the slates to appear massive, though the interbedded slates are strongly cleaved. Some of the silt beds appear relatively coarse in texture, due to the presence of numerous small crystals of ferruginous carbonate; their original composition may have been more calcareous.

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[1] *Author's note.* The description of this grit was written in 1943, at which time there was no reason to doubt that it was part of the Beauceville group. The description, however, fits so accurately much of the Sherbrooke grit, discovered in 1947, as to suggest that it may be an infaulted mass of that rock. The wide, drift-filled valley between the grit and the conglomerate to the north also suggests the possibility of a fault.

A quarter mile or less southeast of the last point some of the silt beds have become so siliceous as to be greywackes or impure quartzites, and some beds of fairly pure, light grey quartzite are also present. A 44-foot section measured just southeast of Mud Creek, in rge. IX, Weedon tp., shows twenty-four of the quartzite-greywacke beds with an aggregate thickness of 5 feet, or 11·3 per cent of the section. Most of these beds are 1 inch to 1½ inches thick, but one bed or group of beds attained a thickness of 10 inches.

The next outcrop to the southeast is about 2,400 feet distant, and is much more quartzitic. A measured 13-foot section comprises 44 per cent quartzite and 56 per cent slate. Beyond it a decrease was observed in the amount of quartzite present in the scattered outcrops; some of them, indeed, contain only slate and silt beds. Whether this is due to repetition of the older beds by faulting or some other cause, or to changes in the conditions of deposition, there is no means of determining.

In a road cut approximately 2,400 feet east of the west boundary of Scotstown map-area, there is an isolated outcrop of conglomerate. It is made up of slabs of dark grey slate up to 6 or 8 inches in length in a coarse, gritty, rather quartzose matrix. As it is entirely surrounded by drift, its relations to neighbouring beds could not be determined. Its composition suggests that it may be an outlier of Sherbrooke conglomerate.

Near their contact with the Lake Aylmer group, the Beauceville sediments again become more quartzitic, and display other changes as well. The quartzite becomes for the most part harder, light grey in colour, and presumably more siliceous, in place of the dark and rather softer siliceous greywacke of the lower horizons. Black slate disappears in large part, and instead there appears a greyish or greyish brown rock, which in places is hard enough not to have acquired a slaty cleavage. It will here be called argillite. The beds have become somewhat thicker, ranging mostly from 2 to 4 inches; and the beds of argillite, where exposed on spalled surfaces clean enough for study, are seen in many cases to be compound, made up of argillite alternating with stringers of quartzite. The quartzite stringers are not straight, or of uniform thickness; on the contrary, they thicken and thin most irregularly, and many pinch out along strike so as to assume lenticular or nodular forms completely surrounded by argillite. Measured cross-sections of such mixed beds indicate that they comprise some 36 per cent of quartzite in stringers mostly $\frac{1}{32}$ to $\frac{1}{8}$ inch in width, though a few attain $\frac{1}{2}$ inch.

As these outcrops are in general covered with lichen, it is difficult to arrive at a correct estimate of the general composition. Measured sections indicate, however, that the harder quartzite beds constitute about 45 per cent of the rock, argillitic beds about 55 per cent. If, however, the amount of quartzite in the argillite beds is taken into account, the proportion of quartzite is much larger. To investigate this, a cross-section 20 inches long was stripped of moss and measured. In it the quartzite beds constituted 42·3 per cent, the argillitic beds 57·7 per cent; but when the amount of quartzite in the latter was calculated, the total quartzite present in the section rose to 64 per cent.

Conditions of Deposition

The nature of the basal conglomerate of the Beauceville group suggests that the pre-existing land surface suffered a rather sudden submergence. This seems indicated by the fact that the pebbles, though freed of the fine soils that must have surrounded them, are not much rounded, and not apparently moved far from their original sources. It is difficult to account for the preponderance of slate pebbles in the conglomerates, as the underlying rocks are predominantly quartzites. Possibly the harder quartzites did not disintegrate rapidly under weathering, so that the slates, though inferior in quantity, supplied a larger proportion of weathered materials.

The primary submergence must have carried the surface to a considerable depth, for the next rocks to be deposited are the slates and silts, the fine grain and thin even bedding of which indicate deposition in fairly deep, quiet water. The writer cannot account for the alternation of black slate beds with those of brownish silt. The beds, although thin, seem rather too thick to be seasonal, unless unusual conditions of erosion prevailed on the surrounding land areas. No evidence was found to suggest that the beds are part of a deltaic deposit.

The gradual thickening of the beds in the higher horizons, and the change in lithologic character to quartzite and argillite, suggest gradually shoaling waters, possibly by gradual uplift, or possibly because the basin was becoming filled with sediments. The still thin, uniform beds, however, indicate quiet water, hence probably fairly deep; although the lenticular stringers of quartzite in the uppermost argillite beds would seem to indicate some current or wave action.

Relations to the Caldwell Group

The basal conglomerate of the Beauceville group contains pebbles of the quartzites, slates, and various lavas of the Caldwell group, hence obviously overlies that group with at least erosional unconformity. In Thetford region (22) little angular discordance was detected. In Orford map-area one place has already been briefly mentioned (page 34) where conglomerate overlies folded lavas, and in Richmond map-area, as inspection of the map shows, there are places where the base of the Beauceville cuts across the northeasterly strike of the Caldwell, suggesting angular as well as erosional unconformity. Other instances will now be described in detail, which prove without question that pre-Beauceville folding of the Caldwell group took place.

At the road corner about 3,300 feet east-southeast of the south end of Bowker Lake, Orford map-area, an irregular patch of Beauceville conglomerate and black slate overlies trachyte lavas and associated rocks, which here strike north 42 degrees east, dip 65 degrees northwest, face northwest, and plunge about 30 degrees southwest (Figure 3). At point A in the figure, the conglomerate, here only 4 inches thick, is directly in contact with the lavas; a few feet to the southwest the slate swings to cut directly across the strike of the lavas, as indicated. Therefore, the slate and conglomerate must form a chip or erosion remnant of no great thickness, which lies directly upon the eroded edges of the Caldwell rocks.

About 5,900 feet north-northeast of the same corner, on the east side of the road, a band of coarse grey quartz grit strikes north 70 degrees east and dips vertically. Black slate lay a foot or two away to the southeast, and when the intervening area was stripped, 3 or 4 inches of conglomerate was found in direct contact with the grit. On the southwest, numerous small outcrops of the black slate swing to the northwest directly across the strike of the grit band. Clearly, the grit must have been folded into something like its present position, and eroded, before the Beauceville was laid down.

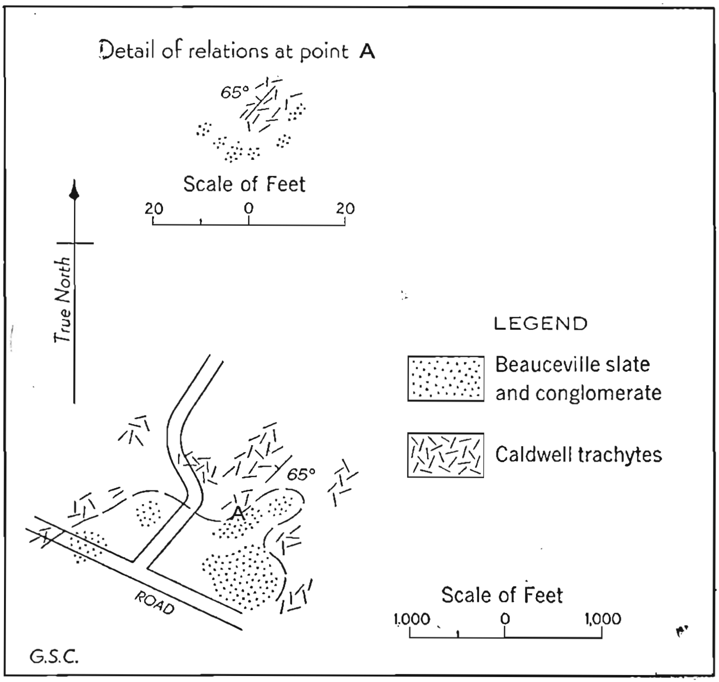

Figure 3. Plan of Caldwell-Beauceville outcrops at road corner 3,300 feet east-southeast of south end of Bowker Lake.

At the road corner half a mile east of the south end of Little Brompton Lake, a patch of grey quartzite appears, from the scattered outcrops, to be completely surrounded by the Beauceville black slate and conglomerate (*See* Map 994A). Within it, beds of quartzite pass abruptly along the strike into conglomerate for a few feet, then into quartzite again. The ends of the conglomerate strips, if chipped, show quartzite beneath the conglomerate. Obviously the conglomerate was deposited on a quartzite surface where some quartzite beds were eroded more deeply than others, and this surface is just now being exhumed.

Toward the northwest side of this area of outcrop some 30 feet or so of conglomerate-quartzite contact is well exposed, and has the relations shown in Figure 4.

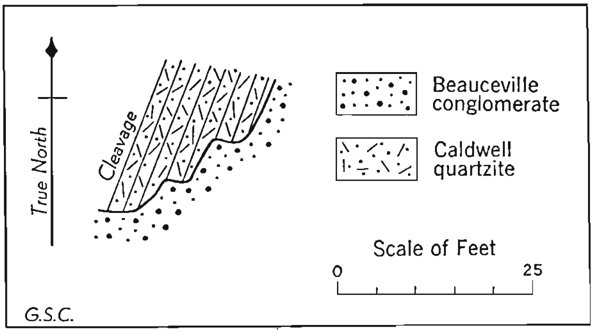

Figure 4. Plan of section of Beauceville-Caldwell contact ½ mile east of the south end of Little Brompton Lake.

In a farmyard 1¼ miles northwest of St. Denis de Brompton, on the northeast side of the road, and some 200 feet from it, trachyte lavas outcrop; they are beautifully banded, in thin bands that weather to look like chert, but on fresh surface are dark, apparently through the presence of considerable biotite. These have a general strike of north 30 degrees east, and a vertical dip, but have been intensely drag-folded. In the centre of this drag-folded area lies a flat patch of Beauceville conglomerate some 4 or 5 feet in diameter. The conglomerate is relatively undisturbed, and carries many pebbles of the underlying lava. It was clearly laid down after the folding and subsequent erosion of the lava.

In the Memphremagog area the contacts are less well exposed, and are concealed in places by the younger Bolton lavas, but one example of the sort was seen. The creek that flows east through the gap between Hogsback and Sugarloaf Mountains crosses a band of Caldwell lava, which is followed on the east by Caldwell quartzite and then by Beauceville conglomerate and black slate. In the bed of the creek the contact between the lava and the bedded quartzite is well exposed, and appears perfectly conformable. The quartzites strike north 35 degrees east and dip vertically. About 100 feet east of the lava-quartzite contact, a small patch of conglomerate may be seen lying directly upon the upturned edges of the quartzites. Below this, for some 1,500 feet downstream to the main Beauceville contact, the rock is all the Caldwell quartzite.

Contact Faulting

In the western part of Dudswell map-area the Caldwell-Beauceville contact is not the straight or gently curving line that characterizes steeply dipping formations. On the contrary, within the area of Caldwell rocks along the western border, numerous patches of Beauceville conglomerate and slate are present, many of them too small to map; and to the east, across a width of several miles, patches of the Caldwell rocks keep appearing through the younger Beauceville cover. These patches are of all sizes, from areas too small to map to others 2 or 3 miles in diameter; they are of various irregular shapes, but are generally elongated along the main northeasterly axes of folding. The only possible explanation of these peculiar relations appears to be that the contact has a very low dip to the east, but is rolling, so that the underlying Caldwell rocks are brought to the surface in many places. According to this conception, the Beauceville strata throughout the western 6 miles or so of Dudswell map-area can form no more than a rather thin veneer over the ancient post-Caldwell surface.

However, when the Beauceville conglomerate there is examined, it is found to be intensely mashed; the former slate pebbles have been reduced to a slaty matrix in which only the harder quartzite pebbles remain. The rock must have been subjected to intense compressive stress, and under such stress the soft yielding argillite beds must have flowed into narrow folds with great consequent shortening.

Further, at many contacts between Beauceville and Caldwell rocks, both in this area and the adjacent parts of Richmond map-area, a coarse breccia is found, made up of large and small, angular fragments of grey quartzite in a black slate matrix. Many of the quartzite fragments are 2 or 3 feet in length.

The close folding of the Beauceville strata, resulting in great shortening and mashing, while the underlying Caldwell surface retained its low dip and gently rolling character, implies that the contact plane was a plane of slip, over which the soft Beauceville rocks slid under the influence of the compressive forces that crumpled them. Such a movement would tear away small projecting parts of the old Caldwell surface and form the breccias observed; whereas the larger hills would remain, and appear as "windows" through the Beauceville cover when erosion brought the present surface close to the old contact.

Such a relation, though unusual, is not unknown. Billings (8) quotes two cases where similar relations have been inferred, one in the Jura Mountains, the other on the Wasatch Plateau of Utah. In each case, as in the present, one of the formations in contact is very weak, the other strong and resistant. In an earlier paper Billings (9) terms this particular type of movement a *strip thrust*.

The sequence of events implied by these relationships is, therefore, as follows: in pre-Beauceville time the Caldwell strata were first folded, and then, in the western part of Dudswell map-area, the folded beds were twisted into great drag-folds (page 24), which may have acted as braces or stiffeners against post-Beauceville movement. The folded strata were then reduced to a surface of rather low relief, with some hills a few hundred feet high. Submergence followed, and on this surface several thousand feet of Beauceville strata were deposited. The Taconic orogeny, toward the close of Ordovician time, folded and faulted all these strata; but in the western part of Dudswell area and the eastern part of Richmond map-area the soft Beauceville rocks tore loose from the strongly resistant basement to slide along the plane of contact.

Thickness

Toward the close of Ordovician time, folding and mountain-building took place, and this event was followed by a long period of erosion that went on, in places, until deposition of the Sherbrooke group began, and may have lasted in other places until deposition of the Lake Aylmer group. There can be no doubt that during this long period immense amounts of the Ordovician rocks were worn away; but as the strata undoubtedly had fairly steep dips, though probably not as steep as at present, perhaps this erosion would not greatly affect calculations of thickness. We know, however, that the Lake Aylmer group does lie with erosional unconformity on the Beauceville group, so that undoubtedly some of the upper beds were cut away before its disposition. Further, an unknown thickness of the Beauceville rocks now lies beneath the syncline of Lake Aylmer beds (Figure 5), and perhaps beneath the fault that bounds it on the southeast. The present exposed thickness of Beauceville beds may then be only a fraction of the original maximum thickness.

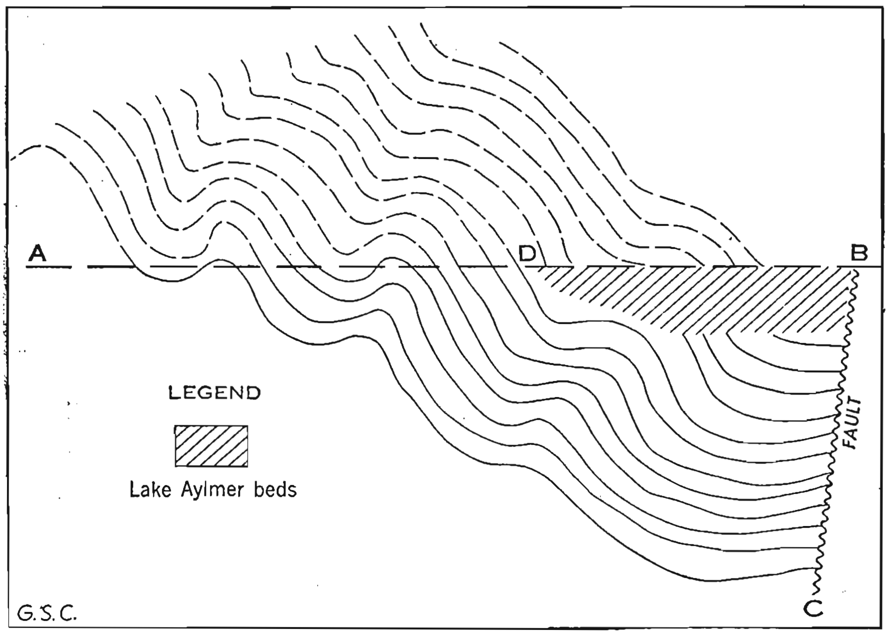

Figure 5. Hypothetical cross-section, showing that erosion after folding of the Beauceville beds need not affect calculations of their thickness. However, if the folded beds were eroded to a surface A-B before deposition of the Lake Aylmer group, and if after further folding and erosion and faulting (line B-C) the latter still fill the trough D-B, they will conceal from measurement considerable thicknesses of the upper Beauceville.

The section that has been described in detail would contain approximately 19,000 feet of beds, if no subordinate folds or faults are present. The work done shows, however, that at least two small folds are present, and observations elsewhere suggest that there are probably more. At least one important fault in the section has been suggested, and again observations elsewhere suggest that probably more exist. Considering these unknown factors, only a rough guess can be made that the thickness of the Beauceville is of the order of 10,000 feet or more.

Age

In Castle Brook, lot 5, rge. XV, Magog tp., graptolites are found in extraordinary profusion in thin-bedded graphitic slates across a width of 150 feet or more of strata. Much pyrite is associated with the slates at the base of this section; it suggests the presence of hydrogen sulphide, which may have been the agent poisoning the organisms.

The fossil beds lie about 300 feet below the road crossing the creek in range XV. The petrographic character of the graphitic slates in which the fossils are found have caused all writers to class them unhesitatingly with the Beauceville group, or whatever equivalent term they may have used; and the writer also sees no alternative to this course. Unfortunately, the geology of the stream bed is far from clear, and outcrops are lacking for considerable distances on each side. In the stream bed, the black graphitic slates are in sharp and apparently conformable contact with very hard, tough, grey quartzites, which would normally be unhesitatingly classed with the Caldwell group. In spite of careful search, nothing was found in the stream bed to indicate the upper side of the steeply dipping strata. Only the fact that they dip about 85 degrees to the southeast suggests that they may also face in that direction.

The quartzites, with no intercalated slates, extend up the bed of the brook some 250 feet. Just below the bridge they give way to a wide zone of breccia, composed of quartzite fragments in a black, slaty matrix. The breccia zone bevels the bedding at a small angle. In many ways it looks like the contact breccia found in many places at the base of the Beauceville group.

Above the bridge, outcrops become scattered, but one, about 300 feet above, was a clean, water-washed surface of a conglomerate containing small pebbles of quartzite and several varieties of slate. It appears to be definitely the basal Beauceville conglomerate.

Somewhat further upstream there are cliffs 10 to 15 feet high of black slate resembling the Beauceville slate. For a foot or two near the base these slates contain fragments of grey quartzite, which look as if they had been torn off by contact faulting.

Altogether, these arrangements suggest that a low-angle contact fault separates Beauceville rocks on the west side of the bridge from Caldwell quartzites on the east side; but there is no evidence of any faulting between the quartzites and the slaty fossiliferous beds.

Downstream from the fossiliferous beds, several hundred feet of drift intervene between them and the next outcrops. These are grey slates in uniform beds ½ inch thick or less, between which are intercalated harder grey, more siliceous beds. The lithologic character suggests the Caldwell group. No further outcrops occur between these and the boundary of the Glenbrooke group.

The geological relations of the fossil beds thus raise considerable doubt as to whether they form part of the Caldwell or Beauceville groups, but until further investigation shall yield more facts, the writer will continue to place them with the Beauceville.

The fauna of the Castle Brook shales has been described in detail by Ruedemann (67) and will not be discussed at length here. He states, "One of the classic graptolite localities in America is at Magog, Quebec .... Rust, Walcott, Richardson, and Hitchcock have exploited this locality, and Richardson states that the Magog slates 'are, doubtless, the most productive of graptolites of any rock yet discovered, either in Canada or the United States'.

"Unfortunately the graptolites stand out beautifully glossy and sharply outlined from the deep black hard slate and thereby hide the fact that they are incredibly distorted in two directions at right angles. This has led to some erroneous lists of fossils and especially to the creation of new species and varieties that have to be suppressed again as synonyms".

Ruedemann then gives several lists of fossil graptolites as published by earlier collectors, and continues:

"A perusal of the lists brings out the great number of new and strange species described. The cause for this is seen when one studies the preservation of the material............. It is evident that the graptolites though apparently beautifully preserved due to their sharp outlines and glossy white (Gumbelite) substance, are actually stretched almost beyond recognition. In a revision, Gurley's new species *Climacograptus kamptotheca* and *oligotheca* as well as the var. *laticaulis* of *C. caudatus* had to be rejected as distortions mostly of *C. caudatus*."

Ruedemann identified the following species from the Rust and Richardson collections:

Dictyonema cf. *neenah* Hall
Dendrograptus sp.
Thamnograptus capillaris Emmons c
Didymograptus sagitticaulis Gurley
Dicellograptus elegans Carruthers
Dicranograptus nicholsoni Hopkinson
D. cf. *gurleyi* Lapworth
Corynoides calicularis Nicholson
C. gracilis Hopkinson c
Orthograptus calcaratus var. *incisus* Lapworth c
id. var. *acutus* Lapworth (synrhabdosomes)
Glyptograptus euglyphus Lapworth c
Climacograptus bicornis (Hall) c
id. var. *peltifer* Lapworth
C. caudatus Lapworth c
C. modestus Ruedemann
C. parvus (Hall)
C. eximius Ruedemann c
C. wilsoni Lapworth
Cryptograptus tricornis (Carruthers)
Lasiograptus mucronatus (Hall)
Glossograptus sp. (young)
Also *Leptobolus* cf. *walcotti* Ruedemann, Orthoceras, Conularia, and Caryocaris

Ruedemann concludes, "This is a pronounced *Diplograptus-Climacograptus-Dicranograptus nicholsoni-corynoides gracilis* fauna. The most important graptolite of the group is, however, *Climacograptus caudatus.*

Climacograptus caudatus is listed by Elles and Wood as restricted and common in their zone 12 of *Dicranograptus clingani* which overlies the zone of *Climacograptus wilsoni* and is under the zone of *Pleurograptus linearis* (corresponding to our Utica). It is therefore a form of the British Hartfell shales, which are younger than the Glenkiln (Normanskill) shales.

"The Magog fauna is therefore undoubtedly younger than the Normanskill fauna. It is in line with this conclusion that the writer has found *C. caudatus* in the Snake Hill shale of early Trenton age."

Of late years two other collections of material from this locality have been made, and although they add nothing to Ruedemann's conclusion as to the age of the beds, they should be put on record. The first collection was made by J. W. Ambrose in 1941, and the forms were identified by Alice E. Wilson as follows:

Name	Age
cf. *Mastigograptus simplex* (Walcott)	Utica
Dicranograptus nicholsoni Hopkinson	Normanskill to Utica
D. nicholsoni var.	Normanskill to Utica
D. sp. (has mode of growth of *D. furcatus* (Hall), but too poorly preserved for certainty)	
Dicellograptus cf. *divaricatus* (Hall)	Normanskill
D. sp. (close to *D. smithi* but lacking the area of parallel growth)	
Diplograptus amplexicaulis (Hall)	Trenton to Utica
D. vespertinus Ruedemann	Trenton
Climacograptus bicornis (Hall) (identification doubtful)	Normanskill

Dr. Wilson comments, "The large percentage of graptolites of later than Normanskill age suggests a later, probably middle Trenton, age. A more complete study and revision of the graptolites might show a correlation with the Canajoharie shales of New York".

The second collection was made by the writer in 1948, and studied by D. J. McLaren. The collection was made in five lots, of which lots 1 and 2 were from opposite sides of the brook, close to the contact of the slates with the hard grey quartzites previously described. The other three lots were taken farther downstream, or southeast, that is roughly across strike, at intervals of 35, 16, and 65 feet respectively. As slates are rocks of relatively slow accumulation, it was hoped that these different lots would show distinct differences in age, but they do not appear to do so. Possibly the amounts collected were not large enough for such distinctions to be made.

Collection No. 1. G.S.C. No. 15857. In hard siliceous slates, taken close to their contact with light grey quartzites, Castle Brook, Magog township, rge. XV, lot 5:

Dicranograptus sp.
Glyptograptus cf. *tamariscus* Nicholson

Collection No. 2. G.S.C. No. 15858. South side of Castle Brook, Magog township, rge. XV, lot 5:

Dicellograptus sp.
? *Corynoides* sp.
? *Dicranograptus* sp.
Mesograptus sp.
Climacograptus scharenbergi Lapworth

Collection No. 3. G.S.C. No. 15859. 35 feet east across strike at right angles from lot No. 1:

Glyptograptus spp.
Mesograptus spp.
Orthograptus truncatus var. *intermedius* Elles & Wood
Glossograptus hincksii (Hopkinson)

Collection No. 4. G.S.C. No. 15860. 16 feet from lot No. 3, east or southeast at right angles to strike:

? *Corynoides* sp.
Glyptograptus teretiusculus Hisinger
Glyptograptus sp.
Mesograptus multidens Elles & Wood
Orthograptus calcaratus Lapworth
Climacograptus spp.

Collection No. 5. G.S.C. No. 15861. 65 feet from lot No. 4, cutting strike at about 70 degrees in a direction about 10 degrees south of east:

Glyptograptus sp.
Orthograptus sp.
? *Conularia* sp.

Dr. McLaren comments, "The general aspect of the fauna suggests a middle Ordovician age and where possible, specific identifications confirm this and allow a more accurate dating. In collection No. 4 the presence of *Orthograptus calcaratus* indicates the Hartfell group of Britain and *Mesograptus multidens* and *Glyptograptus teretiusculus* place the collection low in this group in the zones of *Climacograptus wilsoni* or *Dicranograptus clingani.* The presence of *Orthograptus truncatus* var. *intermedius* in collection No. 3 confirms this result, and *Glossograptus hincksii* suggests that the fauna represents the lowest Hartfell zone, that of *Climacograptus wilsoni.* There is no detectable difference in age within the five collections.

"The age of this assemblage may, therefore, be stated to lie above the Normanskill and to be the equivalent of a horizon within the Trenton group, probably lower Trenton.

"The fauna is highly deceptive at first sight. The apparent excellence of preservation is seen on closer examination to be false, for although the outlines of the graptolites show beautifully against the dark slate they are highly distorted tectonically. Those that lie parallel to the direction of shear are drawn out by as much as 25 or 30 per cent and those at right angles are correspondingly thickened. These circumstances make identification very difficult as all dimensions are totally unreliable. The species named, although individually unreliable are nevertheless sufficient to emphasize the main aspect of the fauna and to make an age determination reasonably certain. It is worth recording that one fragment of a *Glyptograptus* from collection No. 1 and two specimens of *Climacograptus scharenbergi* from collection No. 2 were beautifully preserved in full relief in pyrite and had resisted distortion completely. If further specimens preserved in this fashion could be obtained it would give a far better and surer knowledge of the fauna than the distorted outlines on the slate."

SILURIAN

SHERBROOKE GROUP

The Sherbrooke group has not hitherto been recognized as a separate lithological unit. Although previous workers in the district, including Kerr, Ambrose, Fortier, and the writer, all recognized the structural and petrographic peculiarities of the beds, lack of good contacts with the Beauceville group, and the general parallelism of the structure, have always caused the beds to be classified as part of the Beauceville. Evidence obtained, however, in September 1947, in lots 17-18, rge. VII, Orford tp. (about $2\frac{1}{4}$ miles slightly west of south of Orford Centre), shows clearly that the Sherbrooke beds overlie the Beauceville with large angular unconformity. Traced northeast, into Sherbrooke area, they are found to underlie the Devonian Lake Aylmer beds with no visible unconformity, though, as shown later, erosional unconformity is inferred. Recognition of the Sherbrooke as a separate group now makes it possible to identify many bodies of it as infaulted remnants, and to that extent adds to our knowledge of the structure of the district.

No information has been obtained as to the relations of the Sherbrooke to the Glenbrooke group. However, as the latter appears to be in part of Silurian and in part of Devonian age, it is probable that the Sherbrooke group is the older.

A few small remnants of Sherbrooke rocks are found along the south side of Sherbrooke map-area, south of Sawyerville.

Conglomerate

Conglomerate, though not generally present at the base of the group, occurs locally in a large number of places. At the type locality in lots 17-18, rge. VII, Orford tp., it is well developed, and other excellent exposures in the same township are in lots 12 and 15, rge. VI; lots 4 and 6, rge. IV; lot 8, rge. V; in the creek valley half a mile north of Rock Forest village; and again half a mile southwest of it. Some of the conglomerates considered to belong to the Lake Aylmer group in Dudswell and Sherbrooke map-areas appear, on re-examination in 1948, to be Sherbrooke. Among these are those forming the large hill in lot 6, rge. V, Stoke tp., about 3 miles west-southwest of Stoke Centre.

The basal conglomerate, where present, commonly consists of beds of coarse conglomerate, up to 4 or 5 feet in thickness, associated with beds of coarse grey grit or finer sandstone. In places an occasional bed of dark grey slate may also be present. In the conglomerate beds, pebbles constitute about half of the rock, in a grey, gritty matrix. Most of the pebbles—about 60 per cent—are grey quartzites, usually less than 2 inches in diameter and moderately well rounded. Most of the remainder are grey and black slates, which tend to have flat, slab-like shapes. They are apt to be somewhat larger than the quartzite pebbles; many between 4 and 6 inches in length have been seen, and a few up to 1 foot. Locally, chunks of coarse grit up to a foot in diameter have been observed. These contain numerous chips of grey slate, and can be matched with the occasional beds of similar composition in the Beauceville. A few small pebbles of quartz, and of black or grey chert, are usually present. The latter also tend to have slab-like shapes.

As the description shows, the conglomerate has no resemblance to the Beauceville conglomerate, and cannot be mistaken for it. Until the Sherbrooke was recognized as a separate group in 1947, however, the conglomerate was commonly mistaken for that of the Lake Aylmer group. It differs from it in the entire absence of pebbles of granite and rhyolite, whereas such pebbles constitute the major part of the Lake Aylmer conglomerate.

The statements in the preceding sentence are correct for the true basal conglomerates found in the areas southwest of Sherbrooke. Northeast of that city, bodies of conglomerate considered to belong to the Sherbrooke group do contain occasional widely separated pebbles of granite. It is difficult to determine, in these infaulted remnants, whether the conglomerates are truly basal; but the conglomerates were considered to be Sherbrooke because of the great preponderance of quartzite and slate pebbles. The occasional granite pebble they contain probably indicates that during Sherbrooke time the granite bodies that supplied pebbles to the Lake Aylmer conglomerate were just becoming unroofed.

In the area northeast of Sherbrooke, also, many bodies of rhyolite agglomerate seem to pass gradationally upward into conglomerates in which pebbles of quartzite and slate are associated with those of rhyolite; these beds then appear to be overlain by finer sedimentary beds of normal Sherbrooke appearance. Though in this intensely faulted area it is difficult to be certain of the geological relations, it appears as if the Sherbrooke period was here initiated by volcanic action. The matter will be discussed in more detail later.

Grits

Grit may be termed the characteristic rock of the Sherbrooke group, because most sizable outcrops contain some of it. The grits range in grain from small-pebble conglomerates to fine-grained quartzites or greywackes. The coarsest grits carry pebbles as big as peas or even beans, of quartzites, slates, and quartz. In some varieties, particularly those on Bunker Hill, the amount of quartz is so great that the rocks are true quartzites, and strongly resemble some of the Caldwell quartzites. However, all the grits, including the more quartzose varieties, differ from the Caldwell quartzose rocks in being rather weakly cemented. A relatively light tap or two with the hammer will break off a hand specimen of most of the grits, whereas heavy blows are usually required for the same result with the Caldwell quartzites.

The finer grained types contain, characteristically, numerous white or light grey, platy chips of irregular and angular shapes, and others of black slate resembling the Beauceville. The rock has the appearance of a tuff, and in the field was so considered, a conclusion to which its local lack of bedding and its association with rhyolite flows lent probability. Later study with the microscope did not altogether support the conclusion. Many of the whitish chips proved to be altered feldspar, instead of fragments of rhyolite; and grains found in some thin sections consist of both quartz and feldspar, as if the constituents were granitic debris. Others, however, are very fine-grained aggregates of crystals that, from their indices of refraction, appear to be mainly feldspars about oligoclase-albite in composition; if quartz is present the grain is too fine for certain identification. These fragments may, therefore, be of fine-grained acid lava. The matrix of the fragments appears to be a fine-grained mixture of quartz and feldspar, with much chlorite.

As stated, the grits range in grain size from small-pebble conglomerates to fine-grained quartzites, but all varieties, except the finest, retain a hint of the platy texture that is their outstanding characteristic. The beds are, usually, 1 foot to 2 feet in thickness, though both thicker and thinner beds appear.

Slates

Beds of slate are found at all horizons of the Sherbrooke group, even interbedded with the conglomerates and grits near the base. Beds of slate separating thick beds of quartzite or grit are rarely more than an inch or two in thickness, but larger masses of it are found locally at the lower horizons, and in these, the beds where distinguishable are usually 6 to 8 inches thick. This slate where not much sheared is a rather massive, blue-grey rock.

The upper measures of the group consist of a great thickness of 'striped slates' very similar to those of the Beauceville group and commonly classed with them in the past. In several places in Memphremagog area, however, they may be seen to overlie the Sherbrooke conglomerates and grits conformably.

These slates form beds of very uniform width and straightness. Like the Beauceville slates, the width ranges mostly from 1 inch to 2 inches. They display excellent slaty cleavage, so that on good exposures it is easy, from the cleavage-bedding relations, to determine the structure. They differ from the Beauceville slates in that alternate beds consist of darker and lighter grey slate, instead of black slate and brownish silt. Very commonly the slates carry numerous metacrysts of an iron-bearing carbonate, and in some beds these are very large.

Magnificent exposures of the slate are visible on the west shores of Lovering Lake in Memphremagog map-area. These show, too, the interbedding of the slates with the characteristic grits of the group. A continuous section of slates approximately 2,200 feet thick is there exposed, unless outcrops have been repeated by undetected faults. This band continues northeast for some 13 miles, nearly to the north end of Magog Lake, where it is faulted out. At its south end it appears to be cut off again by a fault, or faults, approximately along the bed of the creek that drains the lake.

It is possible that the band of slate that lies between this band and the Glenbrooke rocks on Lake Memphremagog may also be Sherbrooke slate. Petrographically this slate resembles the Sherbrooke in that it is made up of lighter and darker grey bands; but as no bands of the characteristic Sherbrooke grit were found it was mapped finally with the Beauceville. Such problems must, of course, continually arise where one must rely on mere petrographic similarities for correlation.

Carbonate Beds

A few beds of the Sherbrooke group carry lime carbonate, and weather to brownish tints instead of the usual grey. One such band, about 4 feet wide, encountered near Rock Forest, effervesced vigorously with dilute acid and had the general appearance of impure limestone. A thin section, however, showed that the carbonate content was not more than about 10 per cent. The remainder was a mass of white mica and other alteration products such as chlorite, with a few small grains of quartz and feldspar.

On a small island near the middle of the west side of Lovering Lake, a band of the fairly coarse platy tuff also effervesced vigorously with acid. Carbonate in this rock must have been confined to a relatively small part of the matrix.

Rhyolite

No rhyolite was observed in the Sherbrooke beds in Memphremagog or Orford map-areas, but both southwest and northeast of Sherbrooke, in Sherbrooke map-area, several thin flows are interbanded with the sedimentary beds, so that no doubt can exist as to them being an integral part of the group. None of the flows is more than 100 feet thick, and none, owing to the paucity of outcrops, could be followed far. No attempt has, therefore, been made to show them on the geological map. The longest observed flow was traced $\frac{3}{4}$ mile in lots 5 and 6, rge. II, Orford tp. In this distance it strikes a little north of west and dips north at a low angle. Other flows, not traceable for more than 25 to 200 feet, lie in lot 7, rge. I, lot line 7-8, rge. III, and lot 10, rge. III, Orford tp. In the last locality, several thin flows strike about north 45 degrees west, suggesting drag by the Magog River fault. About 3,100 feet due southwest of Beauvoir a thin flow of rhyolite is interbedded with Sherbrooke 'striped slates'.

Lavas and Associated Sediments of Stoke Ridge

The wide bands of rhyolite and more basic lavas in Sherbrooke and Dudswell map-areas, and the sedimentary rocks associated with them, have long been a puzzle to geologists. Ells and other early workers considered them Precambrian, a usage followed by most later writers. The present writer, on the 1-mile maps of Sherbrooke and Dudswell map-areas published in 1948 classed them with the Ordovician, because of the bands of black slate that separate them and with which they are apparently interbedded. Even then it was recognized, however, that the lavas have some curious features for which this classification offers no adequate explanation, and these, with further field facts discovered during the season of 1948, demand a revision of the earlier view.

The main body of lavas is found in Stoke Ridge, which rises in Dudswell map-area to a height, on Mount Chapman, of more than 2,100 feet above sea-level. There the lavas constitute a mass 5 miles wide, composed almost wholly of rhyolite with minor amounts of basic lava and cut by dykes of granite. In Sherbrooke map-area this band narrows, near Lennoxville, to about $\frac{1}{2}$ mile, and similar bands appear to the east and west of it. One of these, on which the city of Sherbrooke is situated, is 2 miles wide, and roughly three-quarters of it is composed of basic lavas, meta-andesites and slightly more acid types. The distribution, as far as known, is shown on the accompanying map and in more detail on the 1-mile map of Sherbrooke area, 911A.

In passing, it should be stated, however, that the present mapping is very generalized, and the real distribution could be shown only on maps of a much larger scale. Actually, the band mapped as basic lava includes many small bodies of rhyolite; some bands of rhyolite include thin bands of black slate; and practically all the sedimentary bands include rhyolite bands ranging from a few feet up to 100 feet in thickness. A few of them are shown on the 1-mile map.

The rhyolites, where unsheared, are composed of phenocrysts and broken phenocrysts of quartz and oligoclase commonly about An_{20} in composition, in a very fine groundmass presumably of the same minerals with a few flakes of white mica. The phenocrysts have sizes up to 2 mm., and the feldspars are little altered. The grain of the groundmass is usually 0·02 to 0·05 mm., and as the feldspar is both fresh and of about the same refractive index as the quartz, estimation of relative proportions is impossible without adopting some method of staining. Where sheared, the rhyolites are converted into mica schists, but except where deformation has been extreme, a fracture face across the cleavage will generally display the quartz phenocrysts in the fine-grained white groundmass.

A specimen of the porphyritic rhyolite from the Eustis mine was analysed by J. S. Stevenson (72) as follows:

	Per cent
SiO_2	78·71
Al_2O_3	11·22
Fe_2O_3	0·74
FeO	1·21
MgO	0·77
CaO	0·95
Na_2O	4·35
K_2O	0·82
TiO_2	0·25
	99·02
Sp. gr.	2·703

G. V. Douglas (24), who mapped some 6 square miles around the Eustis mine in 1937, concluded that the porphyritic rhyolite, or quartz porphyry as he termed it, was intrusive into the surrounding sedimentary rocks. Examination of the larger area has indicated the untenability of this view. Not only has no coarse grain developed in the large masses to the northeast, as should be the case were the masses intrusive, but the rhyolites display excellent flow textures in places where they are not sheared; they also pass, as later described, into agglomerates with some interbanded flows. In addition, the basic lavas associated with them display pillow textures in various places.

The largest body of basic lavas associated with the rhyolites extends from some 2 miles northeast of Sherbrooke to a point about 5 miles southwest of it. Thin flows of rhyolite, not mapped, are interstratified with the more basic types. The latter include flows ranging in composition from trachyte to andesite. The andesites are commonly characterized by well-developed pillow structures, but usually these have been sufficiently deformed to destroy their value for determining structure. Only in one place, $2\frac{1}{4}$ miles north-northwest of Albert Mines, was it possible to obtain a dependable observation indicating that the flows face east at that point.

Near the St. Francis-Massawippi fault, and particularly southwest of Lennoxville, the lavas have suffered pronounced deformation with development of cleavage, and in places have been extensively carbonated. This is especially true of the rhyolites; the andesites, perhaps because of their greater distance from the fault, have in general remained more massive and have not been carbonated to any great extent. Carbonation, which where complete destroys all trace of the original nature of the rock, seems to have been particularly active where the bands were sharply bent by the deformation to which they were subjected. The carbonated material has generally a greenish tint, which doubtless accounts for the local name 'greenrock' applied to it around the mines. Douglas (24), who studied the alteration in some detail, states: "In the field, carbonates are seen in the slack zones of crumpled sediments, and as lenses and veins replacing the (sericite) schist and diorite. The thin sections show minute veinlets penetrating the rocks and establishing zones of carbonate in them. These zones show a typical replacement margin, with isolated crystals of carbonate in advance of the main body of that material".

In the area southwest of Sherbrooke, the flows and associated sediments all dip southeast, and the scattered observations obtained on the structure indicate that they also face in that direction. Close to the St. Francis-Massawippi fault they are intensely sheared, and the cleavage planes are intensely drag-folded; away from the fault the shearing and drag-folding gradually decrease and die away. It seems reasonable, therefore, to ascribe this deformation to the thrust along the fault; and, if so, the shape of the drag-folds indicates upthrust of the southeast side of the fault. The shape of these folds on the horizontal plane (*See* Map 994A) also suggests that the southeast side moved toward the northeast.

With this general description of the lavas and their distribution, let us pass to the features that require explanation, both of the lavas themselves and of the sedimentary bands between them.

The Sedimentary Rocks. At the southwest end of the lava bands, near North Hatley, the rocks are mainly sericitic schists. In places bedding can be seen, and is commonly much contorted. Petrographically these beds are like those of the Caldwell group, and traced southwest during the summer of 1948 they were found to pass gradually into less metamorphosed beds undoubtedly of Caldwell age.

Northeast of North Hatley the sediments interbanded with the lavas are all dark grey to black slates. In most places deformation is too great for bedding to be detected, but in a few places bedding showed the alternation of black slate with brownish silt characteristic of the Beauceville group. In the earlier examination of 1945 they were so classified, and a rather careful re-examination of the outcrops in 1948 failed to bring out any reason for not continuing to do so.

If these conclusions are correct, then the Beauceville rocks mentioned must either overlie the Caldwell beds or be faulted against them. It is possible the contact may be of the ordinary type, as the general plunge of the folds is to the northeast; and in an area where outcrops are so small and scattered as here, such a contact might easily go undetected. The entire lack of any outcrop of the characteristic basal conglomerate of the Beauceville group inclines the writer to believe, however, that the contact is probably a fault; and, accordingly, a possible fault has been indicated on the map.

Near the village of Ascot Corner, specifically 1¼ miles to the southwest and ½ mile to the north, are two occurrences of rock that puzzled the writer when the area was first examined in 1945, as they are unlike the surrounding, supposedly Beauceville strata. Re-examined in 1948, they were at once recognized as typical Sherbrooke beds, the first an assemblage of coarse and fine grits, the second of conglomerate. Another outcrop of conglomerate, somewhat doubtfully assigned to the Sherbrooke group, was found on the hillside 1 mile southwest of Eustis. The presence of these outliers appears to establish, fairly conclusively, the pre-Sherbrooke age of the other sedimentary rocks.

Within the areas of sedimentary rocks are some small dyke-like bodies of rhyolite. Many of these parallel the cleavage fairly closely, but some cut across the structure. Thus, in a new road cut about 3,000 feet north-northwest of the bridge across St. Francis River at Lennoxville, a dyke of rhyolite cuts vertically through intensely contorted and drag-folded black slates. The rhyolite is itself somewhat sliced and sheared, but its deformation is trifling compared with that of the slates, into which it appears to have been intruded. The writer, therefore, advances the suggestion that some, at least, of these small rhyolite bodies may have been feeders to the larger masses that are undoubtedly flows.

Structure of the Lavas. A curious feature of these larger bands of lava is that each at its southwest end and throughout most of its length is composed of non-fragmental lava, *but passes at the northeast end into coarse agglomerate.* In the big band that ends near Dudswell, such agglomerates are developed over a length, northeasterly, of some 3 miles; in the other two bands lying west of this in Sherbrooke map-area the agglomerate parts are about a mile long.

These arrangements suggest that the lavas were first extruded as a succession of massive flows, and that the volcanic period ended with violent explosions, forming the coarse agglomerates. If such a succession were then tilted toward the northeast, erosion would cut away rapidly the upper horizons to the southwest. Eventually a new erosion surface would display the arrangements now seen, with agglomerates at the northeast end and massive lavas southwest of it to the point where the erosion surface intersected the base of the volcanic pile causing it to disappear, as it does near North Hatley.

That such a northeasterly tilt is present is evident at Sherbrooke. The southern part of the city is now being rapidly built up, and when studied in 1946 many new road cuts and excavations for cellars, sewers, etc., were available for examination. In these many contacts between acid and basic flows were visible, and the northeasterly strike prevailing farther south could be seen swinging around the nose of a fold, turning first north and finally to the northwest. At the nose the dip, elsewhere steeply southeast, swings to northeast and flattens to angles of 10 to 15 degrees. These angles indicate, therefore, that the plunge is to the northeast, and the amount of that plunge at this point.

On the main street of the city, which parallels St. Francis River, cliffs 20 to 30 feet high rise behind the buildings on the west side. These are man-made features; the hillside has been blasted out to make room for the buildings. On these exposures the flows can be seen to maintain the same gentle northeasterly plunge observed 1¼ miles to the south. A still better section showing the same relations is visible in the bed of Magog River, near its confluence with the St. Francis. At the northeast end of Stoke Ridge, 18 to 20 miles to the northeast, the recorded dips and plunges indicate that the rocks still maintain a plunge to the northeast.

However, we do not now have one continuous sheet of lava plunging northeast, but at least three separate bodies, each of which dips southeast and two of which are underlain on the northwest by slates apparently of Beauceville age. To obtain such arrangements, the original sheet with the basement rocks must have been faulted, and the fault blocks tilted toward the southeast. That such faulting took place is clear from the evidence observed about 1 mile northeast of the radio tower on the eastern outskirts of Sherbrooke. There intensely contorted black slates have a cleavage striking north 40 degrees east and a vertical dip, but the strike of the contact is north 5 degrees west. The rhyolite itself is considerably sheared close to the contact, and the shearing, though somewhat contorted, has the same general strike as the contact.

It will also be noted that the agglomeratic part of the two bands in Sherbrooke map-area lies about 13 miles to the southwest of the agglomeratic part of the big band in Dudswell map-area. If these were formerly parts of a single sheet, as the hypothesis here advanced suggests, then these western parts must have been horsts squeezed up to a great height by the stresses prevailing at that time.

It is concluded, therefore, that these bands of lava were poured out on an older surface, apparently of folded Beauceville slate. They were fed, in part at least, by dykes cutting the underlying slate. After deposition they were tilted to the northeast; then they and the basement rocks were cut into long narrow fault blocks, which were tilted so as to dip southeast.

Relations to Sherbrooke Group. It is evident that these great masses of lava are completely cut off by faults from the beds of the Sherbrooke group; hence until further information is obtained their relations must remain in doubt. Their relation to the underlying slates appears to be unconformable, as is also that of the Sherbrooke group, and small bodies of similar rhyolite have been found, as described, interbedded with the Sherbrooke sedimentary strata.

Northeast of Sherbrooke there are various places where coarse-bedded agglomerates are overlain directly by finer rhyolitic tuffs and then, apparently, by the ordinary grits and slates of the Sherbrooke group. A specially good locality of the sort lies about 1¼ miles southeast of Beauvoir. Unfortunately, outcrops are not continuous, but separated by areas of drift up to 100 feet or so in width; and in this complex, intensely faulted area there can be no certainty that such areas do not conceal faults the effect of which cannot be **known.**

Until further data are obtained, therefore, the writer can only tentatively suggest that the lavas are probably of Sherbrooke age. The agglomerates and tuffs that seem to form the base near Beauvoir suggest that they were extruded in the early part of that period.

Lavas of Scotstown Map-area

In this map-area some infaulted blocks of lava display no other relations whatever to any surrounding rocks. Their petrography suggests that they should be correlated with the Sherbrooke (?) lavas of Sherbrooke and Dudswell map-areas; and, like the lavas of Sherbrooke area, they are host to copper deposits of similar character. Until evidence to the contrary is obtained, therefore, the two must be classified together.

The lavas form a band that commences near the corner of Weedon, Lingwick, Bury, and Dudswell townships and extends northeast to the Mount Aylmer granite mass, which intrudes it. Beyond the granite mass, lavas of similar composition continue for some 11 miles into Disraeli map-area[1].

The lavas in Scotstown area are in fault blocks, and, therefore, have most irregular shapes. The main band, in rges. I and II, Weedon tp., consists chiefly of andesites and basalts with pillow structures, flow breccias, and other characteristic lava forms. Several good determinations of structure were made on these, indicating that the flows strike northeast, dip almost vertically, and face southeast. Northeast of Salmon River the basic flows become thinner and are interbanded with trachytes and rhyolites. South of Trout Lake a large mass consisting almost wholly of rhyolite agglomerate is completely bounded by faults and the Lake Aylmer granite.

The northwestern boundary of these lavas is the great fault termed by F. R. Burton (12) the Weedon thrust; it brings them into direct contact with the Lake Aylmer group. The southeastern boundary of the lavas lies in a deep, soil-filled valley, which, for reasons described in the later section on faulting, is also inferred to conceal a fault. A similar pronounced valley lies between the lavas and the St. Francis rocks in Disraeli map-area to the north. In a former report (22) the writer said of these, "As the flows face southeast at their southeastern edge, the St. Francis sediments still farther southeast must overlie them, unless a fault of which there is no evidence lies between .... On these grounds the writer has classed, tentatively, the lavas with the sediments of the St. Francis series". The work in Scotstown map-area has shown with some certainty that the St. Francis-lava contact there is a faulted one; and that probably a considerable age difference between them exists. It is reasonable, therefore, to conclude that the contact in Disraeli map-area is also faulted, so that the correlation suggested in the older report is incorrect.

Relations to Beauceville and Caldwell Groups

In the type locality in Orford tp., lots 17-18, rge. VII, the areal relations of the Sherbrooke to the Beauceville and Caldwell groups are as shown in Figure 6. The Sherbrooke beds dip at low angles in most parts,

[1] Geol. Surv., Canada, Map 417A, Disraeli, 1938.

and their folds plunge northeast at 20 to 25 degrees. Just below the base of the Sherbrooke beds, numerous large outcrops of black striped slates, which appear to be typical Beauceville strata, strike north 45 degrees east, dip very steeply northwest, and face northwest. Although the actual contact is concealed, there can be no doubt that the Sherbrooke beds overlie the Beauceville with large angular unconformity.

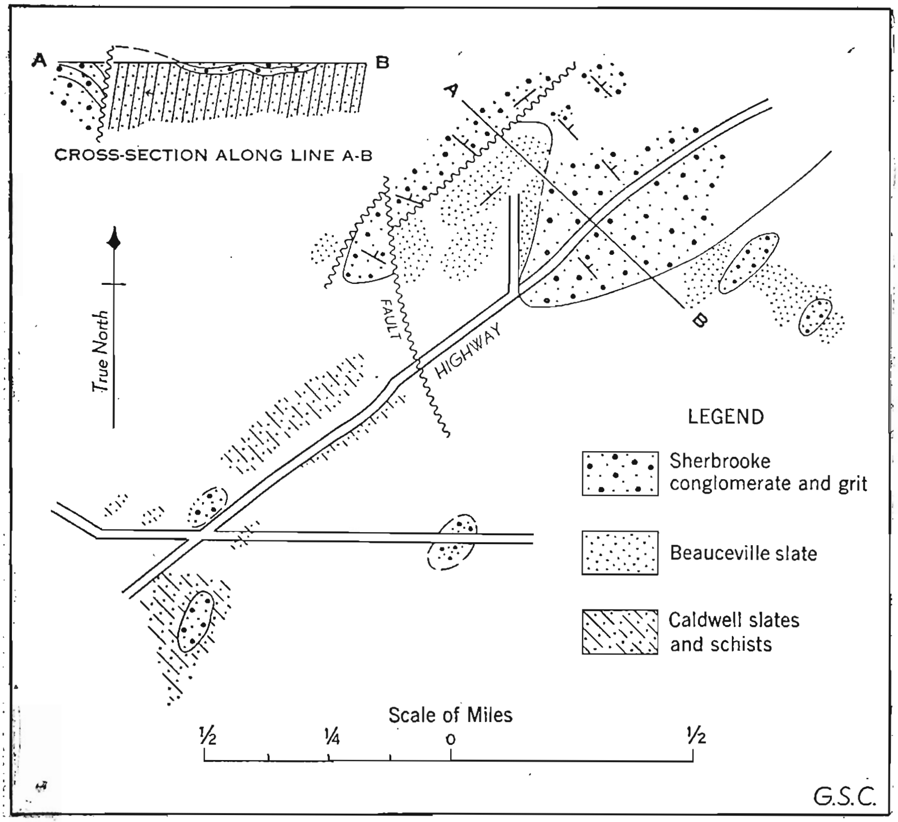

Figure 6. Plan and cross-section, lots 17-18, rge. VII, Orford tp., and vicinity, showing relations of Sherbrooke rocks to Beauceville and Caldwell strata.

About a mile southwest of the junction of the short branch road there (Figure 6) with the highway, a small knob of flat-lying Sherbrooke beds overlies intensely contorted, grey slates, considered to be Caldwell. Half a mile east of the same junction, similar relations with Beauceville slates were seen in two places. Actual contacts may be seen at one of the latter localities, the grits overlying the eroded upturned edges of the older slates.

In lot 8, range line IX-X approximately, Hatley tp., about 200 feet east of a deserted house, a patch of massive Sherbrooke grit some 4 or 5 feet long lies on a surface of black Beauceville slates that strike north 35 degrees east, dip vertically, and are dragged into small folds that plunge northeast at 30 degrees. In one place the actual contact was seen, where a crudely triangular protuberance of the black slate, some 6 inches in diameter, is completely surrounded by the grit.

In lot 24, rge. V, Stanstead tp., just at the road corner, Caldwell grey slate and quartzite strike north 45 degrees east and dip vertically. The slate is so strongly sheared that cleavage is practically parallel with the bedding. Some 10 feet to the northeast along the strike is a patch of unsheared grit about 30 feet long and 10 feet wide. Though no direct contact is visible, it can hardly be doubted that the grit overlies the folded and sheared Caldwell strata.

On the southeast side of Bunker Hill, about $\frac{3}{4}$ mile from the south end of Lake Massawippi, and almost at the point where the road swings from a nearly west course to southwest, an outcrop of sheared Beauceville conglomerate is bounded on the north and west by Sherbrooke grit. The conglomerate would seem to be a projection of the basement on which the grit was laid. In one place, a hole about 2 feet deep in the conglomerate is filled with the grit, and a cross-section completely exposed. Similar relations, less completely exposed, were seen nearby in several places.

About a mile northwest of the south end of lake Massawippi is the junction of the Ayers Cliff-Magog highway with the road along the northwest side of Bunker Hill. Near this junction important relationships were observed in several places, and will now be described. Rhyolites cross the road just southeast of this junction, and a little farther southeast are interbedded with the hard Caldwell quartzites, whereas in the creek bed north of the junction, and on the banks adjacent, are excellent outcrops of typical Beauceville conglomerate. The areal relations indicate that at this place a small erosion remnant of the Beauceville overlies surrounding Caldwell strata.

In the field between the road junction and the creek, Sherbrooke grit containing a few pebbles of quartzite tops outcrops of the schistose Beauceville conglomerate. The contact, which is rather difficult to detect because of lichen on the surfaces, appears to be a most irregular one.

Just southeast of the road junction are outcrops of coarse rhyolite tuffs containing numerous angular fragments of weathered rhyolite up to the size of beans. With them are interbanded some flows, and the strike of the assemblage is north 50 degrees east, the dip vertical to steeply northwest. In one place a chip of grit about 8 feet long, 1 foot wide, and 3 to 6 inches thick, was observed resting directly on the eroded edges of the tuff beds. About half the grit consists of chips of black slate up to $\frac{1}{8}$ inch in diameter, which could have been supplied from the black slate matrix of the nearby Beauceville conglomerate.

Approximately northwest of this junction, and on the north side of the creek, a small cliff face displayed the relations shown in Figure 7A, between Sherbrooke quartzite and Beauceville slate. The slate has a well-developed cleavage striking north 70 degrees east and dipping vertically to steeply north. The quartzite is massive.

Some 300 or 400 feet west of the last locality, the relations shown in plan in Figure 7B were observed. The rocks here in contact are the Sherbrooke grits and the Beauceville black slates.

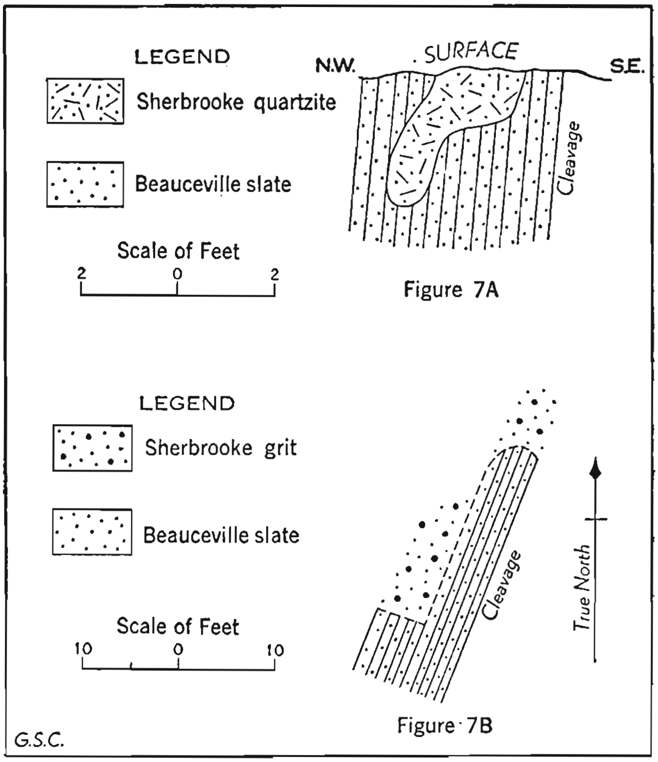

Figure 7. A. Cross-section on a small cliff face near creek, northwest end of Bunker Hill, showing Sherbrooke quartzite filling a hole in the post-Beauceville erosion surface.

B. Plan, about a quarter mile north of junction of road along northwest side of Bunker Hill with Magog-Ayers Cliff highway, showing further relations between Sherbrooke and Beauceville strata.

The occurrences cited have been described in detail, because, owing to the highly faulted nature of the Sherbrooke remnants, good contacts are few. They are, however, sufficient to indicate that the Sherbrooke strata lie with great structural and erosional unconformity upon the older Caldwell and Beauceville beds. Obviously, the latter were closely folded, and the folds reduced to a surface of at least moderate relief, before the Sherbrooke beds were laid down.

Where not faulted, the sprawling, irregular shapes of the Sherbrooke remnants, in the midst of an otherwise closely folded region, is excellent evidence of their unconformable character and rather flat-lying structure. The main mass of the sort is that between Turnertown and McConnell;

near it several small bodies are scattered here and there. Evidently the present surface, in that locality, lies very close to the pre-Sherbrooke surface.

Internal Structural Relations

Northeast of the type area in Orford township, the Sherbrooke group tends to lie in broad open folds that plunge northeast at angles ranging from 10 to 25 degrees. Large parts of the body of Sherbrooke rocks between the type area and St. Francis River constitute the crest of one fold, or of a succession of very gentle folds, and thus have small northeasterly dips. Away from such crest areas, however, the strike becomes northeast and dips steepen to 50 or 60 degrees.

Northeast of St. Francis River the crest areas become much narrower, and are usually measurable in terms of a few hundred feet. Most of the beds dip at angles between 45 and 60 degrees, and some, locally, are vertical or nearly so. Some of the steeper dips may be due to the tilting of fault blocks.

In Memphremagog area, dips are rarely less than 45 degrees, and more commonly lie between 60 degrees and vertical. Such dips did not seem reconcilable with the sprawling distribution of some bodies, which should imply low dips. This difficulty presented a puzzle for some time, because for some reason bedding in those grits is rarely to be seen; but the anomaly was resolved when outcrops in lot 17, range line III-IV approximately, Stanstead tp., displayed enough bedding for the structure to be clear. It there became evident that although dips range from 45 to 65 degrees, the folds are very narrow, of the order of some 10 to 20 feet from crest to crest. The plunge determined in them was 16 degrees to the northeast. Folding of this type would seem to justify the inference that slippage took place along the pre-Sherbrooke surface, but the inference has little other evidence to support it.

Nearly all the bodies of the Sherbrooke group are bounded on one or several sides by faults. No normal contacts have been found, even after recognition of the group, in either Dudswell or Sherbrooke map-areas; and those in Orford and Memphremagog map-areas are confined to the few that have been described. It is not surprising, therefore, that the group has gone so long unrecognized. The geologist travelling the area merely crosses a soil-filled valley—one of a thousand—to come from one group into the other; no difference in structure marks a change, as both are folded along parallel lines. The Sherbrooke rocks, to the present, have, therefore, always been considered merely as members of what is here termed the Beauceville group.

In the section west and southwest of Sherbrooke, for some 3 miles from the city, the rocks between Magog River and the Sherbrooke-Magog highway have been converted to schists; and a lesser degree of schistosity has been induced in the strata farther southwest along the highway, about to the western border of Sherbrooke map-area. In view of the gently folded nature of the rocks of this section, the writer attributes most, if not all, of this schistosity to the Magog River overthrust.

The drag of this fault, presumably, has had the effect of pushing upper beds bodily northwestward over lower beds, wherever the two were separated by incompetent slate or argillite. Thus, along the highway it is common to see cleavage-bedding arrangements such as those shown in Figure 8A, and the arrangements shown in Figure 8B were observed 2 miles from the river in lot 6, rge. III, Orford tp. The writer can explain these only by concluding that cleavage was first developed normally by lateral pressures, and then deformed by a movement of upper beds northwestward.

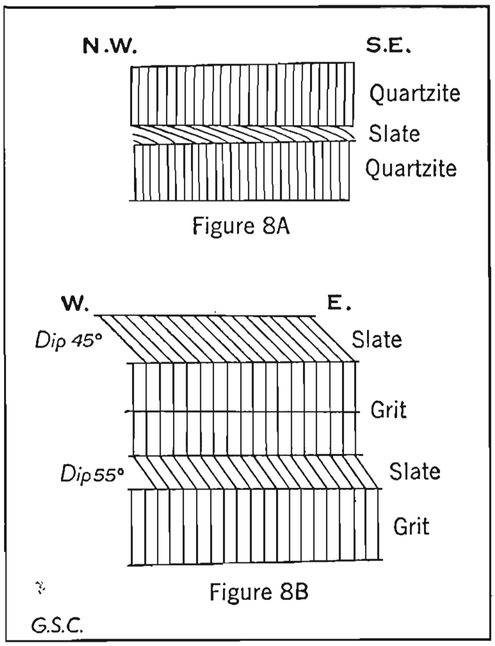

Figure 8. A. Cross-section typical of relations shown at many places along the highway between Sherbrooke and Lake Magog; thick beds of Sherbrooke quartzite or grit dipping gently northeast display cleavage at right angles to the bedding; slate beds between them have cleavage deformed as shown.

B. Cross-section, lot 6, rge. III, Orford tp., looking north, showing cleavages developed in Sherbrooke grits and slates; in the harder beds the cleavage stands at right angles to the bedding, which here has a low dip to the north; in the interbedded slates it dips east at 45 and 55 degrees respectively.

Age and Origin

It has been shown that the Sherbrooke group was deposited after the period of intense Taconic folding; and apparently long enough afterward for erosion to have cut down the Taconic mountains, in places at least, to a fairly flat surface. The area over which the various faulted remnants are now found is some 60 miles long and 3 or 4 miles wide; if the remnants south of Sawyerville were deposited in the same settling basin, the width must have been more than 18 miles. Although these dimensions are probably only fractions of the original size, they do suggest some sort of long narrow basin, possibly an intermontane valley.

The basal conglomerates of the group appear to be localized in distribution, suggesting that the materials may have been swept down by rapid streams to be deposited close to their mouths. This again suggests fairly mountainous topography adjacent to the basin of sedimentation. The pebbles in the conglomerate are poorly rounded and a fairly large proportion are slabs of slate. Evidently they were not subjected to long-continued wave or current action, facts that again suggest that they were swept down rapidly by fast streams, and were probably deposited in some protected basin where wave action was slight.

The grits of the group contain many angular chips of partly weathered feldspar and of slate. Again, wave action must have been relatively small for such materials and such shapes to have been preserved.

The uppermost known beds of the group are a thick succession of thinly and uniformly bedded slates. These characters, which indicate fairly undisturbed deposition in quiet water, suggest that further sinking of the region took place after deposition of the beds of grit. A considerable depth of water must have been attained, even in a protected basin, to permit beds like those of the slates to be laid down.

The facts cited appear most easily explicable, therefore, by concluding that deposition took place in some intermontane valley brought below sea-level by a regional depression of the land. The lack of fossils in the rocks may be due to the fact that in the earlier stages of deposition the waters of the inlet were shallow, and kept fresh by the streams entering it. The slates of the group are now so badly deformed that any fossils they may have contained could have been destroyed.

If the inferences as to the topographic development of the region in Sherbrooke time are correct, they suggest only a moderate lapse of time after Taconic folding was completed. Unfortunately, this period of folding is not very precisely dated. The lack of Ordovician sediments younger than the Beauceville suggests that uplift began about the end of Trenton, or perhaps in Utica time. Folding may have been complete by the end of the Ordovician, or early in the Silurian period; and in either case the physiographic condition above suggested could have been attained fairly early in the Silurian.

Turning now to the conglomerates of the group, it has been shown that the rocks of which they are composed are mostly fairly fresh and unweathered. In contrast, the conglomerate at the base of the Glenbrooke group, as will be shown, indicates long and thorough weathering of the pre-existing surface; and the age of that part of the group, as indicated by rather unsatisfactorily preserved fossils, seems to be Middle to late Middle Silurian. It may be inferred, therefore, that deposition of the Glenbrooke began much later than that of the Sherbrooke group; and thus, by an entirely different line of reasoning, the conclusion is reached that the Sherbrooke beds must have been laid down fairly early in Silurian time.

SILURO-DEVONIAN

GLENBROOKE GROUP

The Glenbrooke group forms two long synclines, one of which underlies Lake Memphremagog; the other appears a short distance west of the lake. In addition, a small infaulted mass appears on the east flank of Chagnon Mountain, in Orford area.

The Glenbrooke group is made up of a conglomerate at the base, named by T. H. Clark (17) the Peasley Pond conglomerate because of its excellent development there. Above it is a thickness of several hundred feet of grey or brownish grey, limy shale or argillaceous limestone, the Glenbrooke shale. This grades in turn into a fairly pure, dark grey limestone that weathers light grey. On account of the lime content, these rocks are mostly poorly exposed, but an excellent section is visible in the bed of Glenbrooke Creek, which flows east from George Pond to Sargent Bay, Lake Memphremagog.

Conglomerate

The basal conglomerate of the group, described by Clark (17) under the name Peasley Pond conglomerate because well developed near that place, is a striking and unusual rock that cannot be mistaken for any other conglomerate of the district. As a rule, 75 per cent or more of its pebbles are quartz; the remainder are nearly all of chert or cherty quartzite though locally pebbles of slate or argillite have been found. A variation from the norm is found in lot 17, rge. IX, Potton tp., where 100 feet or more of conglomerate is exposed. There the lowest visible beds contain only some 25 per cent of quartz pebbles, and the others are quartzites, many of them fine grained; but a few feet above, stratigraphically, the beds resume the usual composition.

Few of the pebbles are more than 3 inches long, and most of them are about an inch, though in some outcrops they are reduced to about the size of beans. In shape they are characteristically angular and subangular, though large ones exhibit a moderate degree of rounding. The matrix is a grey to dark grey grit.

The conglomerate is well stratified, with beds ranging in thickness, commonly, from a few inches to 2 feet, though coarse conglomerates in beds up to 20 feet thick were found southwest of Vale Perkins. With the conglomerate are associated beds of quartzite, sandstone, and grit, mostly of grey and brownish grey colours. At Peasley Pond the exposed thickness of the formation is about 190 feet. In lots 12 to 18, rge. IX, Potton tp., the thickness is somewhat greater, about 250 feet in places, of which at least 100 feet is conglomerate. Commonly, however, the thickness is much less. At Cherry River the conglomerate beds are only 3 feet thick, and are succeeded by about 6 feet of grit and 20 feet of finer grained, dark grey quartzite. Relatively small thicknesses characterize the band that lies east of George Pond.

The composition of the conglomerate, made up largely of quartz pebbles, with the remainder mainly cherts and fine-grained quartzites, indicates that the rocks of which it is the residue underwent unusually long and complete weathering. Such a condition could obtain only after a land area had been reduced to a low, practically peneplaned surface. It would also seem to imply that the land surface remained comparatively stable throughout this long period, for had it risen much, rejuvenation accompanied by rapid erosion would have occurred; had it sunk much, it would have been invaded by the sea.

If these inferences are correct, the conglomerate must have been formed (1) after the Taconic mountains had been reduced to base level; and (2) after the base-levelled surface had weathered long enough to reduce to clay-like products every constituent except quartz and some residuals of the hardest quartzites.

Argillite

Above the Peasley Pond conglomerate lies a considerable thickness of limy argillite, which in most places exhibits a good cleavage justifying its classification as a slate. Nearly everywhere it carries enough calcium carbonate to effervesce vigorously with dilute acid.

The rock is rather dark grey or bluish grey on fresh surfaces, and generally of somewhat massive appearance in hand specimen. Cleavage planes, however, tend to make it break down into large slabs. The beds are 4 to 6 inches thick, but bedding is commonly difficult to detect except on unusually clean or well-weathered surfaces. In a few places the bedding planes were seen to be marked by strings of holes weathered a half inch or so below the general surface. No reason for this peculiar behaviour could be detected.

In the section described by Clark (17) from the creek entering Sargent Bay from the west, he measured a thickness of 900 feet of shale beds. Fossils were found in that section, but have not been detected elsewhere.

Limestone

The Glenbrooke argillite appears to grade upwards, with a few alternations, into a fairly pure, dark grey limestone, which weathers light grey. It is well exposed along the lower part of Glenbrooke Creek, and on the east shore of Lake Memphremagog. Scattered outcrops of it may be found elsewhere, but on the whole exposures are poor. In the Glenbrooke section, a thickness of 290 feet is exposed (Clark, 17). The limestone carries few and rather poorly preserved fossils, due to the fact that it is everywhere badly deformed, and in many places recrystallized. The writer estimates that the purer limestones constitute less than half, possibly not more than one-third, of the Sargent Bay limestone. The larger part is slaty or siliceous limestone, some of which has been utilized for flagstones.

Five analyses of the limestones are given by M. F. Goudge (50, p. 241). All of them are of the purer type of limestone encountered.

—	205	206	207	208	209
SiO_2	5·10	12·00	4·72	16·76	1·72
Fe_2O_3	0·29	0·44	0·88	1·82	0·62
Al_2O_3	0·61	0·66	2·92	3·70	0·32
$CaCO_3$	92·39	84·82	88·43	73·47	91·68
$MgCO_3$	1·38	1·71	2·34	3·25	4·79

205. Magog ....Abandoned quarry, lot 1, rge. XVI, Magog tp.
206. Georgeville .....Abandoned quarry, lot 27, rge. II, Stanstead tp.
207. " .....Just north of brook emptying into Macpherson Bay, 1 mile south of village.
208. " .....Shore of Macpherson Bay.
209. Magoon Point ..Abandoned quarry; stone used for making lime.

Relations to Beauceville Group

It has been shown that the intense Taconic deformation intervened between the deposition of the Glenbrooke and Beauceville strata; hence, it is obvious that they must be separated by a great angular unconformity. In the field, however, this unconformity is not easy to detect, partly because of the lack of good horizon markers in the Beauceville group, partly because the Glenbrooke has been folded into vertical attitudes, like the Beauceville, and partly because of the extensive faulting along most contacts.

It has been indicated, however, that along the margins of the western or Sargent Bay syncline faulting either did not take place, or was confined to slippage along the contact during folding. The map shows that south of Sargent Bay the eastern boundary of the syncline cuts across a Beauceville-Caldwell contact at an angle, approximately, of 25 degrees. On the west side of the syncline, west of Sargent Bay, an anticlinal wrinkle in the underlying rocks has brought to the surface a long narrow area of Caldwell lavas and quartzites. The axis of this anticline is truncated by the base of the Glenbrooke, at an angle of about 10 degrees.

Evidently, therefore, post-Taconic erosion in places removed all the Beauceville beds from anticlines, to expose the underlying Caldwell strata, before deposition of the Glenbrooke began.

Internal Structural Relations

The Glenbrooke group forms two roughly parallel synclines, one underlying Lake Memphremagog north of Fitch Bay, the other a short distance west of the lake and crossing the upper end of Sargent Bay. They may be termed the Lake Memphremagog and Sargent Bay synclines respectively. In both the strata have been closely folded to lie in vertical and near-vertical attitudes.

The western or Sargent Bay syncline appears to be normal, in the main. On both sides, in many places, the basal Peasley Pond conglomerate outcrops, hence it is concluded that these contacts are probably not faulted, although some slipping may have occurred along them during folding.

At its south end, this syncline disappears in the extensive area of drift west of Owl Head. Both northwest and southwest of Vale Perkins the western boundary is offset by small faults, and faults probably also account for the abrupt increase in width at Knowlton Landing. At its north end, its contact against the Bolton lava is probably a fault, and faulting certainly accounts for the abrupt disappearance of the syncline not far north of Peasley Pond. Argillite, with conglomerate at its base, constitutes most of the beds now found in the syncline, although Clarke (17) states that "small and scattered outcrops (of limestone) may be seen from Millington southward to Vale Perkins".

The larger "syncline" appears to be in the main an infaulted remnant. At its northern end it disappears beneath a large area of drift. Contacts seen at Cherry River are normal, and display the Peasley Pond conglomerate overlying Beauceville slate without faulting or disturbance. South of Cherry River the western contact is nowhere exposed, but in places, as near the north end of Memphremagog map-area, it lies in a pronounced valley that may well be a fault. The eastern boundary of this "syncline" is a strong fault. The basal conglomerate is not found at any point, but a wide, intensely sheared zone is visible in several places, namely, in the bed and bank of the creek flowing into Quinn Bay; in a road cut just north of the branch road into Belmere Point; and at the point where the map shows the contact crossing the road east of Macpherson Bay. At the last point a branch road runs in to some cottages on the shore, and a cut in the hillside, apparently made to secure road metal, displays intensely sheared rock. The southern mile of the contact, measured from Lake Memphremagog, is a narrow, steep-sided valley, in which outcrops in lot 15, rge. I, Stanstead tp., on the west side of the valley, showed much crushing and shearing.

The rock in this "syncline" appears to be mainly limestone, fossiliferous in places, though the fossils are badly distorted. The structure seems fairly complex. Exposure is poor, except along the shores of Lake Memphremagog, where much rock appears. Detailed study by a competent palæontologist would undoubtedly bring to light much information yet unobtained.

Age

A considerable collection of fossils was made in 1911 by Robert Harvie (51) from the Glenbrooke Creek section across the argillite. These were examined by P. E. Raymond, who determined the following forms:

Dalmanites lunatus Lambert; abundant.
Dalmanites sp. ind.; probably new; common.
Calymene sp. ind.; rare.
Bronteus pompilius[1] Billings; rare.
Ceratocephala cf. *C. goniata* Warder; rare.
Chonetes sp. ind.; rare.
Coelidium sp. ind.; rare.
Operculum of gastropod, like that referred to *Oriostoma* by Kindle.
Orthoceratites indeterminable; common.

[1] *Bronteus pompilius* (a name that seems to have fallen into disuse) was described from Square Lake, Maine, in Proc. Portland Soc. Nat. Hist., 1862, p. 123, Pl. 1, fig. 25. Raymond states that it is probably Lower Devonian in age.

Of the above list Raymond wrote: "Trilobites form the most important part of this collection. The specimens of cephala and pygidia are numerous, and, though distorted, fairly well preserved. The most common one is very similar to *Dalmanites pleuroptyx* Green, but differs from that species in having fewer rings on the axial lobe of the pygidium and fewer ribs on the pleural lobes. It is, therefore, referred to Lambert's species, described from the Silurian at Littleton, New Hampshire (Bull. Geol. Soc. Am., XV, p. 480, 1904). The other species of *Dalmanites*, represented only by pygidia, is characterized by its rounded outline, the absence of a caudal spine, and the few (about 10-13) rings and ribs (8-9) on the pygidium. The presence in this fauna of a *Calymene* and a *Ceratocephala* of the type of *C. goniata* indicate the middle Silurian age of the strata at this locality.

"The fossils from a second locality, a little higher in the section, are mostly indeterminable. The pygidium of a species of *Encrinurus* was recognized, and some of the *Orthoceratites* are identical with those in the lower beds.

"The strata at a third locality on the other limb of the syncline are full of badly squeezed brachiopods, none of which could be recognized with certainty. The most common shell is a rhynchonelloid, possibly a Wilsonia. Two or three specimens appeared to be *Atrypa nodostriata* Hall, and another looked like *Leptaena rhomboidalis*. With these was a large and well preserved specimen of *Favosites gothlandicus* Lamarck."

In 1913 Robert Harvie (52) made a collection of fossils from a triangular, apparently infaulted, mass of limestones near Mountain House, on the west side of Lake Memphremagog. E. M. Kindle reported on the collection as follows:

"The collection includes the following species: Crinoid stems, *Favosites* cf. *basaltica, Favosites* sp., *Zaphrentis* sp., *Spirifer* cf. *arrectus, Actinopteria* ?, *Panenca* .....?, *Proetus* ..... sp.

"The deformation and partial metamorphism of all the material render any determinations beyond generic highly problematic, except in the case of one of the two species of *Favosites* which is either identical with or closely related to *F. basaltica*. The very poor state of preservation of the fauna prevents close comparison with other faunas and the most that can be said regarding its correlation is that it is highly probable but not entirely certain that the fauna is of Middle or Lower Devonian age."

In 1941, two collections of fossils were made by J. W. Ambrose[1] from the Mountain House locality. These were examined by Dr. Alice E. Wilson of the Geological Survey of Canada. The first collection was of loose material gathered from the bed of a brook in lot 11, rge. IX, Potton tp., just east of an old dam site. Dr. Wilson reported the following forms:

Zaphrentis sp. A
Z. sp. B
Cyathophyllum sp.
Favosites cf. *helderbergiae* Hall
F. cf. *basalticus* Goldfuss
F. sp.
Cladopora sp.

[1] Unpublished MSS.

Diphyphyllum sp.
Stropheodonta sp.
Atrypa spinosa Hall
Spirifer cf. *arenosus* Conrad
S. sp. distorted cf. *S. montrealensis* Williams
cf. *Panenka* sp.
Conocardium cuneus (Conrad)
Several unidentifiable pelecypods
Holopea sp.
Dalmanites sp.
Homalonotus sp.

The second collection was made near Mountain House itself, and was composed of the following:

Streptelasma sp.
Zaphrentis sp. A
Heliophyllum sp.
Favosites cf. *basalticus* Goldfuss
F. sp. A
Atrypa spinosa Hall
cf. *Panenka*
Conocardium cuneus (Conrad)

Dr. Wilson comments, "These two lots are evidently from approximately the same horizon and are Devonian in age". To the writer Dr. Wilson has stated that they probably represent an Onondaga horizon, i.e., Middle Devonian.

On the east side of Lake Memphremagog, Silurian fossils have been found in two localities, which may be parts of a single narrow band. The southern of these is in lot 18, rge. I, Stanstead tp., or about 800 feet east of the head of Quinn Bay. The fossils were found on the southeast corner of a knoll that lies just north of the big bend in a side road leading out to Belmere Point. The rock here is a badly sheared nodular material, with nodules of hard calcareous material in a slaty, somewhat calcareous matrix. The latter weathers readily to an earthy dust, leaving the nodules free. They appear to be partly silicified fossils in an accumulation of calcite. Some of them, gathered by F. A. Kerr[1] in 1923, were examined by E. M. Kindle, who identified from the material a *Conchidium* of undetermined species, and another form doubtfully *Conchidium*. Dr. Kindle commented, "A *Conchidium* badly crushed and distorted but showing the spondilium and coarse plications of this genus indicate for this lot a Middle Silurian horizon".

Other fossils were gathered by J. W. Ambrose[1] from this locality in 1943, and were examined by Alice E. Wilson. She identified:

Stromatopora sp.
Conchidium sp.
Pelecypod

Dr. Wilson commented: "The specimens are crushed, but the internal structure of one specimen from this locality shows the presence of a species of *Conchidium* which signifies a Silurian horizon".

[1] Unpublished MSS.

The second locality, found by F. A. Kerr[1] in 1923, is stated by him to lie about 2 miles south of Oliver and ½ mile east of the Magog-Georgeville road. His material was examined by E. M. Kindle, who found that the only identifiable form was *Favosites favosus*, a Silurian species. Kerr describes the rock at this point as a massive limestone, on the weathered surface of which silicified fossils stand out prominently. Some of them appeared to be complete crinoids, but owing to their poor state of preservation none of the few specimens successfully extracted was recognized as such.

All other collections from the west side of the lake appear to represent a Devonian horizon. In 1923, F. A. Kerr[1] made collections from twenty-one different points, all of which carried much the same fauna. Forms determined from these collections by E. M. Kindle included:

Crinoid stems, abundant in some horizons
Favosites cf. *basaltica* (abundant)
Syringopora ?
Cladopora roemeri ?
Favosites sp. Tubes small as in *F. placenta*
Favosites cf. *emmonsi*
Stromatopora sp.
Orthoceras ? sp.
Zaphrentis ?
Favosites other species

"Most of the collections contain specimens of one or more species of favosite corals. One of these is near, if not identical with, *F. basaltica*. These lots are believed to represent a Middle Devonian horizon".

In 1941 and 1943, J. W. Ambrose[1] also made a number of collections from the Devonian of the east side of the lake. Only two of these, when examined by A. E. Wilson, proved to contain diagnostic material. The first was from lot 1, rge, XVI, Magog tp., at a point lying 4,800 feet on a bearing of north 77 degrees east from the nearest road corner on the Magog-Georgeville road. The forms identified were:

cf. *Heliophyllum* sp.
Favosites cf. *limitaris* Rominger
Favosites sp. very fine

"The corals are very poorly preserved, but their association is suggestive of a Devonian horizon".

Ambrose' second collection was from lot 23, rge. I, Stanstead tp., in a creek 1,000 feet southwest of the highway. The only form identified was *Favosites* cf. *F. basalticus* Goldfuss, which, Dr. Wilson remarks, probably indicates a Devonian horizon.

From the preceding descriptions it will be noted that whereas the Glenbrooke shales appear to contain, from the rather unsatisfactory material available, a fauna of Middle or late Middle Silurian age, the limestones of Lake Memphremagog, which are presumably to be correlated with the limestone of Sargent Bay, contain a fauna of Devonian, approximately Onondaga, affinities. Therefore, unless errors have been made in identifying the poorly preserved specimens, or unless the range of the identified species

[1] Unpublished MSS.

is greater than yet known, it seems necessary to conclude that a disconformity representing an important time interval exists between the argillites and the limestones. The conclusion seems unavoidable, in spite of the fact that between the two a smooth gradation seemed to exist, both in the Glenbrooke Creek section and in the creek section on the east side of Quinn Bay.

It may here be noted that the Peasley Pond conglomerate is strikingly similar in composition, so far as one may judge from descriptions, to the Clough conglomerate of the Littleton-Moosilauke area of New Hampshire (10); and M. P. Billings, who mapped that district, expresses the opinion that the Clough conglomerate is closely related to, if not identical with, the Shawangunk conglomerate of New York. The Shawangunk formation carries Middle Silurian fossils in its upper part, and the Clough conglomerate directly underlies the Fitch formation in which Billings (11) found fossils of Middle Silurian (Niagaran) age. The Fitch formation, according to Billings, includes: (1) white and buff marble; (2) grey limestone and marble; (3) buff, dolomitic slate; (4) buff to brown, arenaceous, dolomitic limestone; (5) grey, calcareous slate; (6) white to grey, arenaceous limestone and calcareous standstone; (7) calcareous sandy slate; (8) grey, fine-grained, calcareous arkosic conglomerate; (9) grey impure quartzite; (10) white to grey arkose; (11) white quartz conglomerate with quartz pebbles 1 inch to 3 inches long; and (12) grey slate. It thus comprises a considerably greater variety of rock types than the Glenbrooke argillite, which is mainly composed of grey slates, grey, calcareous slates, and argillaceous limestones, arenaceous limestones, and some beds of fairly pure limestone. There is, however, a pronounced similarity between the two, and the differences might readily be explained by assuming that the Glenbrooke was deposited in somewhat deeper, more quiet water than the Fitch.

The general resemblance of the two areas is increasd by the fact that the Fitch formation is overlain by the Littleton formation, of which the middle part has been proved by fossil evidence to be of Lower Devonian (Oriskany) age.

DEVONIAN

LAKE AYLMER GROUP

The Lake Aylmer group is found in Scotstown, Dudswell, and Sherbrooke map-areas. It is the southwestward continuation of a band that continues northeast through Disraeli and Thetford map-areas (22). In the southern part of Dudswell map-area the band is broken, by folding and faulting, into two narrow parallel bands.

The rocks of the group comprise a conglomerate at the base, overlain by slates, limy slates, and very pure limestones. In one place some bands of very acid rhyolite were found interbedded with the limy strata. No definite succession of strata seems to prevail throughout the area, though in a district so much faulted as this, such a statement should be accepted with reservations. Conglomerate is confined mostly to the base of the succession, but northeast of Silver Lake, Dudswell map-area, there is a band of conglomerate that seems to lie at a much higher horizon. In places the conglomerate is overlain directly by slate, and it in turn by limy slates and limestones. In other places, impure limestones appear close to the top of the conglomerate.

The purer limestones of the group are highly fossiliferous, but no fossils have been found in the other types.

The structure of the band in Scotstown and Dudswell map-areas appears to be that of a compound syncline of which the southeast side has been partly faulted away. The remaining areas appear to be mainly fault blocks, although normal contacts are found in places.

The discovery of the Sherbrooke group in the autumn of 1947 has made necessary a complete re-study of the Sherbrooke-Lake Aylmer areas. An effort was made in the summer of 1948 to revise the earlier mapping, as previously some parts of the Sherbrooke, particularly the conglomerates, had been classed with the Lake Aylmer group, whereas the more slaty parts had commonly been placed with the Beauceville. With the recognition of the Sherbrooke, many changes in mapping were made, and it was also recognized that some slate areas, previously considered Beauceville (?), are in all probability part of the Lake Aylmer group. Time did not permit, unfortunately, of a thorough re-examination of the whole problem, and it is highly probable that further study will show that parts of the region now mapped as Lake Aylmer group are really Sherbrooke.

Conglomerate

Conglomerate occurs, so far as known, wherever the base of the Lake Aylmer group is exposed; but its variations in thickness suggest that it may be absent in places, and these, being underlain by softer strata, would be places of low relief and probably covered by drift. The conglomerate itself is very resistant to erosion, and generally stands up as high ridges.

In Scotstown map-area the conglomerate is well exposed on the south side of the syncline in rge. II, Weedon tp., at intervals for 5 miles from Salmon River southwest. On the north side of the syncline, it is exposed in two bands that cross the Weedon-Ham South road in rge. VII, Weedon tp. The northwestern of these bands is a small downfold; the two are parts of the same bed or set of beds. In Dudswell map-area some conglomerate is found west of Clear Lake and both east and west of Silver Lake, but the fault contact against the Sherbrooke group on the north is in the main free of conglomerate to a point about due northwest of Silver Lake. Then conglomerate appears in all exposures along the western contact as far as the south boundary of Dudswell map-area, and also in the second band to the west of the main band. The extensions of these bands into Sherbrooke map-area are practically all conglomerate.

On the east flank of Stoke Ridge a small outcrop of the conglomerate is found about 1½ miles northwest of East Angus. It is an infaulted mass, as the rocks of the St. Francis group lie to the east, and on the northwest a wide zone of intense shear separates it from the rhyolites of Stoke Ridge. The band of conglomerate is about 60 feet wide, and is overlain by intensely sheared and contorted limestone containing numerous crinoid stems in small unsheared inclusions.

A distinctive feature of the Lake Aylmer conglomerate is the preponderance of rhyolite pebbles; in fact, care must usually be taken to distinguish it from rhyolite agglomerate, which is common in Sherbrooke map-area and adjacent parts of Dudswell map-area. In most outcrops some 90 per cent of the pebbles are acidic lavas, mainly rhyolites, the various types of which create an illusion of extraordinary variety. Thus, there are non-porphyritic rhyolites, and rhyolites with quartz phenocrysts, with feldspar phenocrysts, and with both; amygdaloidal rhyolites of varying degrees of porosity, some nearly pumice; rhyolite flow breccias; and white and dark cherts, presumably formed by volcanic waters.

However, the conglomerate is distinguished from the rhyolite agglomerates of the region by the presence of pebbles of other types. These include a considerable number of a coarse grey granite, a few of quartzite or greywacke, and, in places, slabs of slate. Most of the pebbles are well rounded, indicating fairly long-continued wear prior to their final deposition.

In conglomerates of this type, the pebbles are generally crowded together, of all sizes up to a foot or more in diameter, and constitute half or more of the rock. The matrix is commonly a coarse grit in which grains of quartz, chert, and rhyolite up to the size of peas can be seen. In other places the matrix is sandy, and in some even slaty. In the band crossed by the Weedon-Ham South road, the matrix at the base of the band is grit, but near the top becomes a well-cleaved grey slate or silt that weathers black.

Two miles northeast of the last-mentioned locality, and approximately on strike, conglomerate of an entirely different character appears. Pebbles of granite and rhyolite are almost entirely absent and most of the pebbles are of greyish slates and quartzites. The pebbles are smaller, only 2 or 3 inches in length, and compose only about 10 per cent of the rock. The matrix is a coarse grit. When Scotstown area was examined, in 1943, this rock was considered an unusual variant of the Lake Aylmer conglomerate. Its composition now suggests that it is an erosion remnant of the underlying Sherbrooke conglomerate.

The Lake Aylmer conglomerate displays wide variations in thickness. Thus in Scotstown map-area the northwestern band is 110 feet wide where it crosses the Weedon-Ham South road. On the hill northwest of Fisher Hill the southeastern band displays a width of 630 feet, with neither top nor bottom exposed. Just southwest of Salmon River, in rge. II, Weedon tp., there is a width of 1,700 feet of conglomerate and interbedded strata. In Disraeli map-area north of Scotstown area, T. H. Clark (22) reports thicknesses of conglomerate that range from 290 feet to about 2,500 feet.

In general, conglomerate is confined to the base of the Lake Aylmer group, but here and there a second horizon of it has been found. Thus, Clark (22) found, in Price township, two thick bands of conglomerate separated by some 2,000 feet of slate. A second locality of the sort was found near Silver Lake, Dudswell map-area. The lake lies on the axis of an anticline that strikes east-northeast and plunges in that direction at a low angle, about 10 degrees. One thick conglomerate is found on the southwest side of Silver Lake; down the plunge limestone appears, underlying the bed of the lake and the low area northeast of it, a total width of about $\frac{3}{4}$ mile. On the slopes of the hill northeast of Silver Lake the limestone may be seen to grade upward into impure limestones, which in turn pass into limy slates. Finally the slates are overlain by a second band of conglomerate.

Origin. The peculiar composition of the Lake Aylmer conglomerate, its extraordinary variations in thickness, and its occasional recurrence in the succession, all combine to suggest that unusual factors must have contributed to its formation.

The universal presence of pebbles of slate and quartzite matching the corresponding rocks of the Beauceville group, and the unconformable relations of the basal beds to the Beauceville (described later) together indicate that ordinary processes of erosion are responsible for part, at least, of the conglomeratic materials.

On the other hand, the large proportion of rhyolite pebbles, and the local occurrence of great thicknesses of the rhyolite pebble-beds seem to demand explanation. They can hardly have been derived by ordinary processes of erosion from older lavas, partly because there are none near some of the largest accumulations of conglomerate, and partly because the older lavas include much andesite and other basic types, but practically no basic lava is found in the pebbles. Further, the pebbles include amygdaloidal and near-pumiceous varieties, which are nowhere found in place in the older lavas.

The presence, in one place, of rhyolite flows interstratified with Lake Aylmer beds, as later described, suggests an explanation that appears to cover all the phenomena. It is that the epoch began with volcanic activity, but that, as all the lavas were highly acidic, the activity was mainly explosive, and the products were ash rocks rather than flows. The fragments, falling into the shallow sea, were worked over and acquired their present rounded forms, and at the same time became mixed with some of the products of erosion of the older sedimentary beds. Repetition of the igneous activity at some later date would produce the similar conglomerates found in places in the upper measures of the group. Such an hypothesis accounts fully for the composition of the conglomerates, their wide variations in thickness, and the amygdaloidal character of some of the pebbles.

The composition of the conglomerates, of course, raises the question whether the rhyolites of Stoke Ridge may not be more closely akin to the Lake Aylmer group than to the Sherbrooke group, as now tentatively classified.

Slate

The Lake Aylmer slates are dark grey or bluish grey rocks, most commonly in beds 6 to 8 inches thick. To the north and northeast of Beauvoir, however, in Sherbrooke area, a band of slates that overlies the Lake Aylmer conglomerate with conformity displays beds only 1 inch to 2 inches thick. Bedding on the slates is everywhere difficult to detect, except on very clean polished surfaces. Cleavage is everywhere well developed, and where bedding is also visible, the cleavage-bedding relations facilitate structural determinations. Where bedding is not visible, and relations to some distinctive rock of the Lake Aylmer group cannot be found, the slate is almost indistinguishable from the Beauceville slate. In some places its presence may be suspected by its featureless character; Beauceville slates must be very strongly sheared before their excellent bedding is completely obliterated.

The slates, as previously mentioned, do not occupy any particular horizon in the group. In the locality mentioned above, a great thickness of slates, outcropping over a width of nearly a mile, directly overlies the basal conglomerate. Northeast of Silver Lake, Dudswell map-area, there appear to be two bands of it, the upper very thick, apparently interbedded with limestones.

Limestone and Marble

The limestones of the Lake Aylmer group have a fairly wide range of composition, from very pure blue limestones and white marbles to impure, argillaceous types. The purer varieties are confined mainly to the Dudswell-Lime Ridge-Marbleton area, though found in smaller quantities elsewhere. The fairly pure blue limestones are almost the only beds in which fossils have been found. Even a small admixture of muddy sediment seems to have meant death to the life of the time, for fossils disappear abruptly.

The limestones are mostly high-calcium types, with little dolomite. The following analyses quoted by M. F. Goudge (50) give some idea of the range of composition, though presumably those analysed were mainly purer varieties that might be used commercially.

—	242	243	244	245	247	248	249
SiO_2	1·92	23·50	0·45	1·14	29·92	6·08	8·30
Fe_2O_3	0·24	1·24	0·22	0·17	0·98	0·45	0·85
Al_2O_3	0·75	3·06	0·35	0·34	1·54	1·48	1·17
$CaCO_3$	94·77	62·64	97·92	97·27	63·23	87·87	87·93
$MgCO_3$	2·05	4·20	0·51	1·21	3·60	3·30	1·60

242. Dominion Station. Abandoned quarry, lot 13, rge. VI, Dudswell tp.
243. Lime Ridge. From road cut ⅓ mile south of village.
244. " Bottom level, quarry of Dominion Lime Co.
245. " Outcrops 600 yards north of quarry, Dominion Lime Co.
247. Marbleton. Outcrops lot 3, rge. VI, Weedon tp., on highway.
248. St. Gerard. Abandoned quarry, lot 2, rge. VII, Weedon tp.
249. " Abandoned quarry, lot 26, rge. VII, Weedon tp.

The limestone of a ridge running northeast of the school at St. Adolphe de Dudswell has been converted into a glistening white marble of striking appearance across a width of about 140 feet. The width is not uniform, but varies from place to place along the strike. The band strikes north 40 to 45 degrees east, and has a near-vertical dip. Fossils visible in the blue limestone outside the marmorized band disappear completely in it.

The cause of marmorization appears to have been structural disturbance—intense twisting of the strata with resulting fragmentation and recrystallization. Possibly the marmorized zone is the locus of a fault. In one place near the southeast edge of the zone, a bed of the ordinary blue limestone, slightly brecciated, is twisted by a drag-fold, which shifts it 3 feet to the northwest. There, the drag-folded part of the bed is intensely brecciated; much of the rock is crushed to a powder to form a matrix for the remaining fragments; and both matrix and fragments are converted into very white, finely crystalline marble.

In other places at the edges of the marmorized band, the blue limestone is broken into a multitude of irregular fragments mostly less than an inch in length, without good orientation but with long axes striking in general north 65 to 70 degrees east. They are cemented by a very small amount of brownish grey matrix. A few patches of marmorized material seen in this mixture seem to have been fossils, chiefly corals. Toward the marmorized band, first the matrix, and finally the fragments, become completely converted into marble.

Heat produced by the movements described seems to have been the sole cause of the marmorization. A sample of the marble analysed by Goudge (50) was 96·3 per cent calcium carbonate, and contained only a trifle more silica and magnesia than the purest limestones of the district. No conclusion, therefore, is justified that any material has been introduced.

Fossil Localities. In Scotstown map-area the only place possibly worth a collector's attention is about 1,700 feet from the north border and 2·62 miles from the west border. In Dudswell map-area a good place for collecting is at St. Adolphe de Dudswell, a few hundred feet southwest of the church. Another excellent locality is the creek bed just below the sawmill at Duplin, in rge. IX, Stoke tp. A highly fossiliferous bed was seen in rge. IX, Dudswell tp., about ¼ mile southwest of the Lime Ridge-St. Camille road, but the outcrop is a smooth, flat face, so that collecting from it would require chisels.

Rhyolite

In Scotstown map-area, at 2,400 and 4,000 feet due west of Fontainebleau village respectively, two bands of rhyolite outcrop within the Devonian strata, striking north 20 degrees east with near-vertical dips. An anticlinal axis lies between them, so that the two bands were parts of the same flows. The total thickness of the rhyolite is about 100 feet: it is overlain by limestones, and underlain directly by black and white cherts and black slate, below which limestones or limy slates again appear.

Much of the rhyolite is highly porphyritic, with numerous large phenocrysts of quartz and feldspar in a hard, light grey, fine-grained matrix. Some parts of it are massive, other parts highly fragmental flow breccias with fragments and matrix of the same composition. Still other parts have relatively small phenocrysts: and, passing upward, the porphyritic types give place to a fine-grained acidic lava without visible quartz, possibly a trachyte or dacite.

Relations to Beauceville Group

Contacts of the Lake Aylmer group with the Beauceville group are usually either concealed or faulted, but may be seen in three places. In Scotstown map-area, at the northwestern contact of the small infolded syncline of conglomerate in rge. VII, Weedon tp., a hill rises sharply in a little cliff some 200 feet southwest of the Weedon-Ham South road. On the face of the cliff the contact was stripped of moss, and within a length of

20 feet the conglomerate was seen to angle across the bedding of the underlying slates and quartzites in three places, for an aggregate width of 14 inches. At the top of the cliff, some 50 feet farther southwest, the conglomerate crosses the bedding of the underlying rocks for about 5 feet; and a part nearby stripped of moss again showed bevelling on a small scale—about 2 inches—in three places within a length of 10 feet.

In Sherbrooke map-area, lot 5, rge. III, Orford tp., about 1¼ miles northwest of the Sherbrooke golf club, a beautiful contact is visible about 400 feet north of the road along lot line 5-6. The underlying "striped slates" strike north 50 degrees east, dip almost vertically, and face northwest. They also display a sharp fold (Figure 9). Conglomerate bevels these beds at an angle of about 25 degrees, and also cuts across the fold. The conglomerate and overlying beds here lie in gentle folds with low dips, in sharp contrast with the underlying, steeply dipping slates.

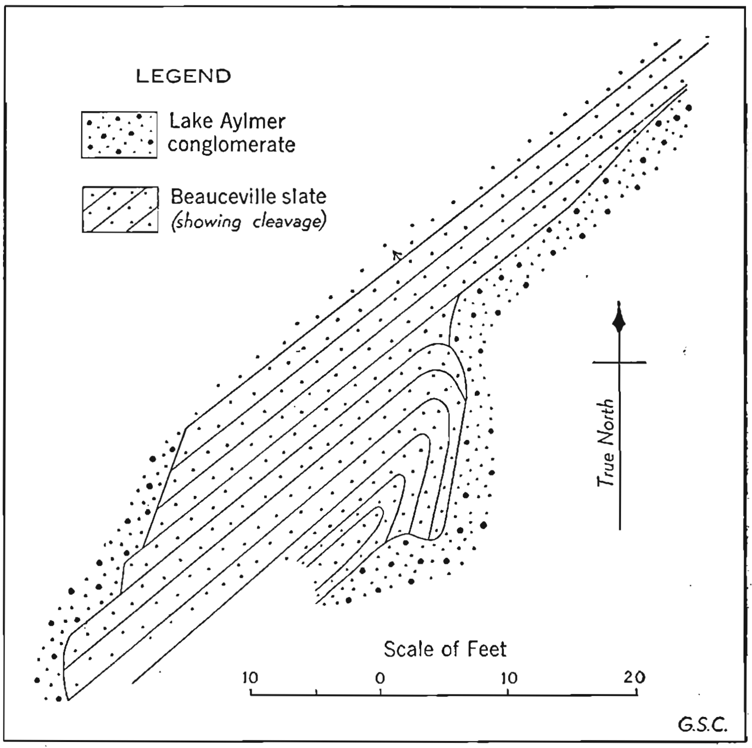

Figure 9. Plan of Lake Aylmer-Beauceville contact in lot 5, rge. III, Orford tp.

Half a mile northeast of this locality, in lot 4, rge. III, Orford tp., and about 100 feet west of the road along range line II-III, beds of Lake Aylmer conglomerate and grit strike northwest with a low dip to the northeast, down the plunge of the fold. About 50 feet south of the last outcrop, a low ridge of beautifully bedded Beauceville slates rises, displaying the same strike and dip as in the previously described locality. Either this outcrop was a hill on the pre-Lake Aylmer surface, or perhaps a small fault has brought the two series into contact here. The side slope of this ridge strikes about north 45 degrees east and dips 30 degrees to the northwest, thus bevelling the bedding of the slates at about 60 degrees. On the glacially polished surface can be seen four or five flat chips of grit plastered right across the upturned edges of the slate beds. The largest of these chips is 5 feet long with a greatest width of 2 feet. Thus, this bit of surface must be very close to the pre-Devonian surface here. Whether the grit belongs to the Sherbrooke or Lake Aylmer groups is uncertain; in the field it was thought to be Sherbrooke, from its composition; but as the two groups are structurally conformable, the point is unimportant in considering the relations to the Beauceville.

Relations to Glenbrooke Group

The relations of the Glenbrooke and Lake Aylmer groups can be inferred only from their fossils, as they are nowhere in contact. It has been shown, on the somewhat unsatisfactory fossil evidence, that the lower part of the Glenbrooke is probably of late Middle Silurian age, whereas the upper limestone parts are Devonian, probably Middle Devonian (Onondaga). T. H. Clark (18, 22) has shown, fairly conclusively, that the limestones of the Lake Aylmer group are of Helderberg (Lower Devonian) age. If the Glenbrooke determinations are correct, therefore, the Lake Aylmer group must have been laid down during the interval between the deposition of the lower and upper parts of the Glenbrooke group.

It is difficult to envisage the land and sea relations that must have existed if this conclusion is correct. The southern end of the Lake Aylmer group lies only about 12 miles from the northern end of the Glenbrooke group. Each group was marine, indicating that some seaway through the district must have existed when each was deposited. How such seaways could have existed without, apparently, mutually invading the areas now occupied by the two groups, is a question for which the writer can suggest no answer.

Relations between Sherbrooke, Glenbrooke, and Lake Aylmer Groups

No relations between the Sherbrooke and Glenbrooke groups are observable. They are in contact only for a distance of about 2 miles, east of Quinn Bay, Lake Memphremagog; and throughout this length they are separated by a strong fault.

As has been shown, however, the nature of the conglomerate at the base of the Glenbrooke group indicates a previous long and very thorough weathering of the rocks on which it lies, whereas the conglomerate at the base of the Sherbrooke group does not. As both overlie the folded Caldwell and Beauceville rocks, it is, therefore, inferred that the Sherbrooke group is considerably older than the Glenbrooke.

The relations between the Sherbrooke and Lake Aylmer groups are well exposed at the east end of lot 6, rge. IV, Orford tp., and also about $\frac{3}{4}$ mile southwest of Beauvoir. At each place the typical basal conglomerate of the Lake Aylmer group, loaded with boulders of granite and rhyolite, may be seen lying with apparent conformity on Sherbrooke beds.

Although, however, no angular unconformity has been seen, it is most probable that an erosional unconformity exists. In the first locality mentioned, the Lake Aylmer conglomerate is found only a short distance, stratigraphically, above the basal conglomerate of the Sherbrooke group, as if all the higher beds of the Sherbrooke group had been eroded away. Again, about a mile to the northeast, in lot 5, rge. III, Orford tp., conglomerate of the Lake Aylmer group can be seen resting directly on the eroded edges of the Beauceville striped slates. Outcrops of the Sherbrooke group are present all around, so that it must be concluded that at this point all the Sherbrooke was removed before the Lake Aylmer was deposited.

Age

The age of the limestones of the Lake Aylmer group has been well established by T. H. Clark (18, 22) as Helderberg (Lower Devonian). No fossils have been found in any of the beds below the limestones, hence further data on the range of the group are lacking.

DEVONIAN OR LATER

BOLTON GROUP

In the area lying between Lake Memphremagog and Sutton Mountains, many bodies of altered basaltic lavas have been found. When the contacts between the Caldwell and Beauceville groups had been determined, it became evident that some of these lavas form long narrow bands within the Caldwell group, paralleling its bedding. Both this relation, and other evidence obtained at contacts, made it clear that these lavas form part of the Caldwell group. Other bodies of basaltic lava, on the other hand, display no relation to the bedding of either the Caldwell or Beauceville group, but sprawl indifferently across it in various irregular shapes. Obviously these lavas can have no relation to the sedimentary groups, but must have been extruded after they were folded into their present near-vertical attitudes. On account, however, of the petrographic likenesses of the two lavas, it would be difficult to make the distinction between them until the structure of the area was cleared up by separating the Caldwell and Beauceville groups. Previous workers in the area failed to make the separation—which in fact is unusually difficult in Memphremagog map-area, because of poor exposures—and hence reached diametrically opposite conclusions as to the age of the lavas, depending on whether they placed most weight on the relations of the older or the younger types, as now recognized.

The name 'Bolton' was first used by T. H. Clark (16, 20) in the name 'Bolton igneous group'. In this he included all the lava, a gabbro that he assumed to be its intrusive equivalent, and peridotite with which it is areally associated. He expressed doubt as to the inclusion of the peridotite; and in fact, as will be shown, the peridotites are much older than the other two. It may be that the gabbro is the intrusive equivalent of the lava, but actually its intrusion took place after the lava had been folded and faulted; so that, except for similarity of composition, there is no field evidence for such a conclusion. Consequently, the name 'Bolton' is here confined to the lava alone, and to some small bodies of slate that overlie it conformably.

Clark found dykes of the gabbro cutting the folded Beauceville strata, and, as he considered the gabbro and lava correlative, this led him to conclude, correctly as it chanced, that the lavas overlie the Beauceville unconformably. His non-recognition of the existence of two lavas here led him into error; for when he found east of George Pond the 'George Pond breccia', which contains fragments of lava (17) lying beneath the Peasley Pond conglomerate, he necessarily concluded that the Bolton lava must be older than the conglomerate, and, therefore, pre-Silurian in age. Actually, the 'George Pond breccia' has proved to be Beauceville conglomerate containing fragments of an underlying Caldwell lava. Hence, this occurrence furnishes no evidence of the age of the true Bolton lava.

In 1941, J. W. Ambrose (3) re-examined the western half of Memphremagog map-area, and flatly contradicted Clark's conclusions, stating that all the lavas are conformably interbedded with the "Cambrian and Ordovician sediments". Obviously, he was most impressed by the perfect conformability of the Caldwell lavas with their surrounding sedimentary beds; as he also lacked the criteria needed for separation of the lavas into two groups, he was forced to lump them all together. Hence, although, as his platting sheets show, he was possessed of most of the facts described by the writer in the following pages, he felt forced to disregard those that seemed to contradict his final conclusion.

These confusions disappeared quickly when the Caldwell-Beauceville contact was mapped, and some of the lavas were recognized as part of the Caldwell group. Then the Bolton lavas, purged of their bastard associates, could be studied for what they are. Evidence will be presented to prove that they are the latest surficial rocks of the district, post-dating both the Glenbrooke group and most, at least, of the deformational movements that folded them. The group comprises a thick succession of basaltic lavas, together with some slates that conformably overlie them. The lavas, either alone or with gabbro, underlie all the larger hills of Memphremagog map-area between Memphremagog Lake and Sutton Mountains, and their northward extension in Orford map-area.

Lavas

The Bolton lavas are mostly altered basaltic types, though some rhyolite was also found on the eastern slopes of Chagnon Mountain. Typically they are grey-green, massive, fine-grained rocks that in many places display magnificent pillow structures and amygdaloidal textures. Although mostly holocrystalline, quite a number of the specimens gathered appear to have solidified so quickly as to have formed glass or near-glass. H. W. Fairbairn (46), who examined these rocks with T. H. Clark, has distinguished a uralite type and an ankerite type, but, as already mentioned, these workers did not differentiate between the Caldwell lavas and those here termed Bolton; all of the ankeritic occurrences observed by the writer belong with the Caldwell lavas.

Under the microscope the rock is seen to be a mass of secondary minerals, so much so that it is doubtful whether any of the primary minerals have been preserved. In some of the fresher looking specimens, feldspar, about An_{15}, constitutes 40 to 60 per cent of the rock, and may be primary, and a few of these carry large hornblende crystals that also seem to be primary. In some instances larger feldspars give the rock a porphyritic texture. Grains of quartz are occasionally observable. With these possible exceptions, the minerals are secondary. Much actinolite is present, and needles of it cut across laths of feldspar. Chlorite replaces not only the hornblende minerals but also feldspar and quartz. In one thin section, veinlets of it have cut and partly replaced a large crystal of quartz, the remaining fragments of which all extinguish simultaneously. Clinozoisite, with a little zoisite and epidote, is abundant, and in many specimens has replaced feldspar almost completely. Some titanite is present, usually partly or completely altered to leucoxene. Calcite and sericite are found in some sections.

A specimen of this rock was analysed for H. W. Fairbairn (loc. cit.) by F. A. Conyer of the Department of Mineralogy, Harvard University. He obtained:

	Per cent		Per cent
SiO_2	49·44	Na_2O	3·06
Al_2O_3	15·92	K_2O	0·50
Fe_2O_3	2·33	TiO_2	1·43
FeO	8·11	MnO	0·10
MgO	6·10	CO_2	1·31
CaO	8·20	H_2O	3·40
			99·90

This analysis is very close to Daly's average composition of 198 basalts. It suggests that the alterations undergone by the rock have been mainly rearrangements of the original constituents, with little or no addition of material.

Slates

In a few places in the district a slate appears to overlie the Bolton lavas conformably. Previous writers have not distinguished it from the other slates, but its stratigraphic position, and compositional differences, demand its recognition as a separate stratigraphic unit.

The slate was first observed about 2 miles southwest of Vale Perkins, on the north side of the road leading from that place to Mansonville. At this place there are excellent outcrops of the Bolton lava, and four flows were distinguished, three of which grade from a massive base to a well-pillowed top. These flows strike north 13 degrees west, dip vertically, and face easterly. The uppermost flow, which is only 4 or 5 feet thick, has a brecciated top. Directly on it lies a very light grey, sheared material carrying rounded or elliptical nodules full of very small vesicles, some of which are filled with iron carbonate. It was taken to be the sheared top of the flow beneath. Directly on this, with the contact visible, lies a black slate that weathers light grey. It is very thin bedded, is notably less sheared than the Beauceville slates, and has the same strike and dip as the lavas.

The slate has a width, at right angles to the strike, of about 130 feet. Near the east side of the outcrop the beds become intensely contorted, with many sharp drag-folds that have near-vertical axes. The contorted slate ends, on the east, against a dyke of massive gabbro.

The slate band was traced a half mile or so to the north, and similar conditions found to prevail. Near the north end of the traverse the uppermost flow, which is there only about a foot thick, is not sheared and can be seen in direct conformable contact with the slate. The latter appears fairly massive on the weathered surface, but when broken is found to have a pronounced slaty cleavage. The surface also displays hints of colours other than grey—purples and pinks particularly—suggesting a tuffaceous origin. In the slate, also, are thin beds, and nodules that may be the representatives of broken beds, of very fine-grained, hard, reddish or reddish grey rock, apparently chert.

To the east of these outcrops, next to the continuation of the gabbro dyke, the slate is so much contorted that its harder beds have been broken into fragments, forming a breccia or pseudo-conglomerate.

It was concluded that the deformation of the slate has been caused by a fault, movement on which must have been nearly horizontal, as the plunges of the drag-folds indicate. At some later date the gabbro was injected along the fault plane.

A band of slate of rather similar appearance was traced for a short distance along the east side of Sugarloaf Pond. As in the previous instance, it lies between the Bolton lavas and a dyke of gabbro that parallels the contact. Outcrops are not sufficiently good, however, to determine any relations, so that the inclusion of this slate with the Bolton slate must be considered doubtful.

A small body of the Bolton slate was found in Orford map-area, about $\frac{1}{2}$ mile south of the east end of O'Malleys Pond. An excellent contact of the slate and lava is visible about $\frac{1}{4}$ mile northeast of the road junction. The contact strikes north 3 degrees east, and dips 48 degrees east; pillows in the lava face east. The slate, as before, is rather hard and weathers light grey; and there is no evidence at the contact of a break of any kind. In the slate, an inch above the contact, lies a plate of lava $8\frac{1}{2}$ inches long and 2 inches wide at the widest part. It looks as if a fragment or bomb had been dropped into the mud deposit shortly after deposition had begun. The long axis of the plate parallels the contact below.

The presence of these slates, and their relations to the lavas, implies the existence of complex structural conditions that cannot be properly understood without much more detailed study than the writer has given. Consider, for example, the western band of lava that runs south from Pevee Mountain. West of Sugarloaf Pond, as the facts to be cited show, massive, unpillowed lava, obviously basal, rests unconformably on much contorted Beauceville slate on both sides of the band. It would seem, therefore, that the lava must lie roughly flat, except for initial dips, in this section. The section of the same band 2 to 4 miles south has the pillows on the east side extending to the contact; they dip vertically and face east; and the conformably overlying slate also dips vertically. Obviously, therefore, this section of the lava band must be a tilted block, and the tilting could have been accomplished only by faulting. Some of this faulting was obviously the fault inferred just east of the slate band, but it has not been traced more than a couple of miles, and other faults, presumably needed for the tilting, have not been found at all.

Relations to Caldwell Group

Around Orford Lake the Caldwell rocks include schistose quartzites, slates, and a band of trachytic lavas. They have a general northward strike, but the most easterly sedimentary band displays a large drag-fold, which accounts for the bulge in its width south of the lake. The relations are shown both on the general map and, on a larger scale, in Figure 10. North of the lake, the Bolton lavas form a south-striking band that ends near the lake in irregular fashion. South of the lake they constitute three isolated masses. The arrangements indicate clearly that the lavas are remnants of a larger sheet that lay with great angular unconformity on a surface eroded on the folded and sheared Caldwell rocks. The lavas themselves are not sheared.

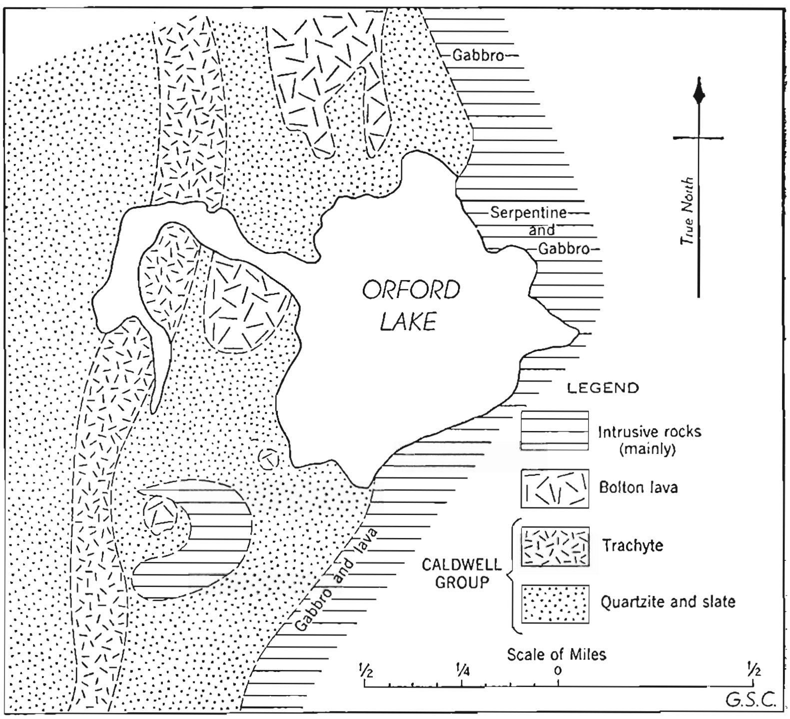

Figure 10. Occurrences of Bolton lavas around Orford Lake.

The relations are particularly well exposed at the south end of the body of lava at the north end of the peninsula that juts north into the lake (Figure 10). Although the actual contact there is covered by drift across a width of some 30 feet, it is obvious that the massive lava truncates, almost at right angles, the cleavage of the schist, which strikes north 5 degrees east and dips vertically. Further, a little within the edge of the lava is an inclusion of the schist about 15 by 15 by 2 feet in dimensions, which has obviously been picked up or torn off by the movement of the lava.

Relations to Beauceville Group

In lot 26, rge. IX, Potton tp., on the east side of the road between Hogsback and Pevee Mountains, a tongue of massive lava some 20 feet in width cuts almost at right angles across the strongly developed cleavage of black slates, which strikes north 20 degrees east and dips almost vertically. Although no contacts are visible, it can hardly be doubted that the lava lies with great angular unconformity on a surface eroded on the folded slates.

Similar relations were seen about half a mile south of Vale Perkins, where the lava boundary striking about north 45 degrees east bevels the cleavage of the slates striking north 15 degrees east and dipping vertically.

Very beautiful relationships were seen due west of the south end of Sugarloaf Pond (*See* Figure 11). The Bolton lavas rise here in an almost vertical cliff, overhanging in places, and at the foot of this cliff their contact with the Beauceville slates can be seen for a length of several hundred feet, clean cut and sharp. The black slates are intensely sheared, the cleavage striking north 10 degrees east and dipping 78 degrees west. The base of the lava bevels directly across this cleavage, striking north 45 degrees east and dipping 45 degrees northwest. The base of the lava is massive, but at the top of the cliff pillows appear, elongated to strike north 50 degrees west and to dip at 50 to 60 degrees northeast.

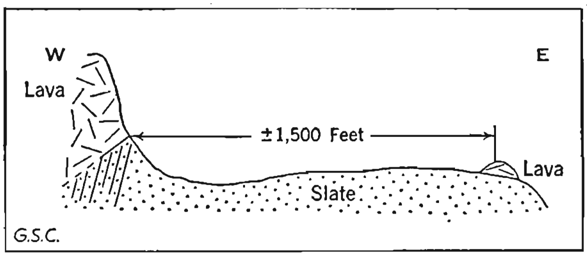

Figure 11. Cross-section illustrating relations of Bolton lavas and Beauceville slates west of Sugarloaf Pond.

East of this contact, greatly contorted slates outcrop, but become much less contorted toward the road. About 1,500 feet from the contact a thin patch of strongly flow-textured, highly amygdaloidal lava overlies the slates. The patch (*See* Figure 11), perhaps 100 feet in diameter, is represented by three or four scattered outcrops.

On the west side of the lava band, almost directly west of the outcrops just described, similar relations were found. The contact is here exposed for a length of some 75 feet. The underlying slate is again strongly cleaved, with no bedding visible. Cleavage strikes north 20 degrees west and dips 72 degrees east. The contact has a variable dip, ranging from 55 degrees east in one place to 68 degrees east in another. The strike varies, within a few feet, between north 10 degrees east and north 40 degrees west, bevelling cleanly the cleavage of the slates. The lava, again, is massive at the base, but toward the top of the hill pillows appear, striking north 7 degrees east, dipping 85 degrees west, but facing east. Part way up the hill the lava surrounds an inclusion of black baked slate about 25 feet in diameter.

Northwest of Millington, the lava of the south face of Place Mountain bevels directly across a succession of slate beds that strike north 20 degrees east and dip vertically.

These facts—and others might be cited—indicate clearly that the lavas flowed out on a surface eroded on the folded Beauceville strata. Under these circumstances, it might be expected that here and there holes might be worn through the lava cover, exposing the Beauceville beneath. This has proved to be the case, and perhaps the most striking illustration is afforded by the valley cut along the fault that separates Hogsback and Sugarloaf Mountains (*See* Figure 12). A good-sized creek follows this valley, and in times of low water its bed displays almost continuous rock exposures. The fault mentioned follows the north wall of the valley, and in one or two places is exposed on the north bank of the creek. From one side of the ridge to the other, all the exposures in the creek bed are the Beauceville slate, though everywhere uphill on the south, within a few hundred feet, the lavas of Sugarloaf Mountain outcrop. There can be no doubt, therefore, that the floor on which the lavas were poured out was a surface little above the present creek level.

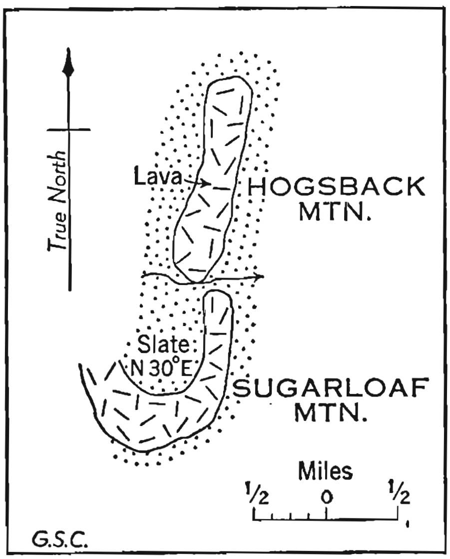

Figure 12. Sketch, showing relations of Bolton lavas to Beauceville slates around Hogsback and Sugarloaf Mountains.

On the north side, the fault that shifted that side ¼ mile to the west also dropped it down, and the base of the lava lies below creek level. Near the fault, which is nearly vertical where visible, the slaty cleavage has been dragged from its normal strike, north 35 degrees east, to strike north 15 degrees west; and, against the fault itself, to a due east-west strike.

Other examples, though perhaps less striking, are equally convincing. South of Owl Head Mountain, in rges. X and XI, Potton tp., are two crudely semicircular areas from which the overlying lavas have been eroded to expose the sedimentary floor beneath (*See* Figure 13), where cleavage in the Beauceville slate strikes a few degrees east of north and dips vertically.

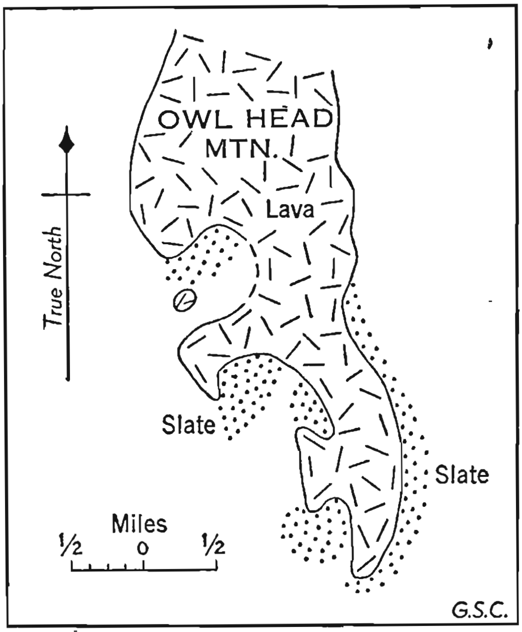

Figure 13. Relations of Bolton lavas to Beauceville slates south of Owl Head Mountain.

Bolton lava is in direct contact with slate on the west shore of Lake Memphremagog northeast of Owl Head Mountain, and the contact is beautifully exposed for 25 or 30 feet. The contact strikes north 20 degrees west, into the shore, whereas the general cleavage of the slates is north 15 degrees east, the dip vertical. At the contact the lava has been drag-folded, as shown in Figure 14, and around the noses of the drag-folds the cleavage of the slates, across a width of 6 to 8 inches, is twisted into parallelism with the contact. Obviously, therefore, the lava was deposited on a slate in which cleavage had already been developed; and when the lava in turn was drag-folded, this cleavage was distorted.

Relations to Gabbro and Pyroxenite

On the east side of Chagnon Mountain, in rge. XII, Bolton tp., about 1,400 feet south of the east end of Orford Lake and 200 feet west of the road, a pyroxenite body, with a poorly defined vertical cleavage, is overlain by massive Bolton lava; and both are intruded by hornblende gabbro, the edges of which are chilled (*See* Figure 15).

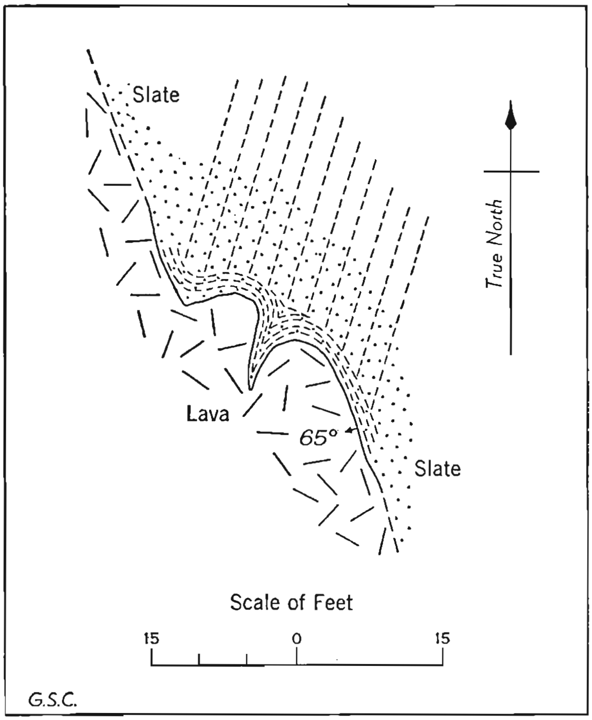

Figure 14. Relations of Bolton lavas to Beauceville slates on lake shore northeast of Owl Head Mountain; broken lines represent cleavage.

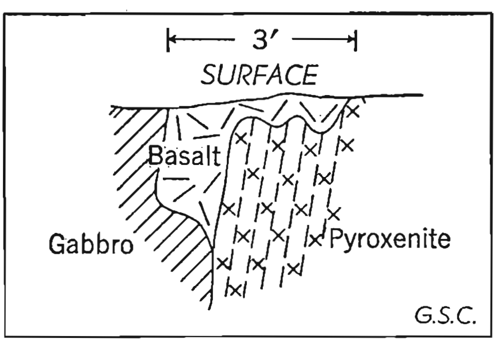

Figure 15. Vertical cross-section, looking south on east slope of Chagnon Mountain; showing relations of gabbro, basalt, and pyroxenite; broken lines indicate poorly developed cleavage.

Relations to Glenbrooke Group

About ¼ mile northeast of Peasley Pond (*See* Figure 16), a fault striking northwesterly cuts off the Glenbrooke rocks from Beauceville slates to the northeast. Northwest of Peasley Pond, however, Bolton lavas continue unbroken across this fault, and it is, therefore, obvious that the Glenbrooke rocks here must have been folded into their present position, faulted against the Beauceville, and eroded to a surface not too far from the present one, before the lavas were poured out.

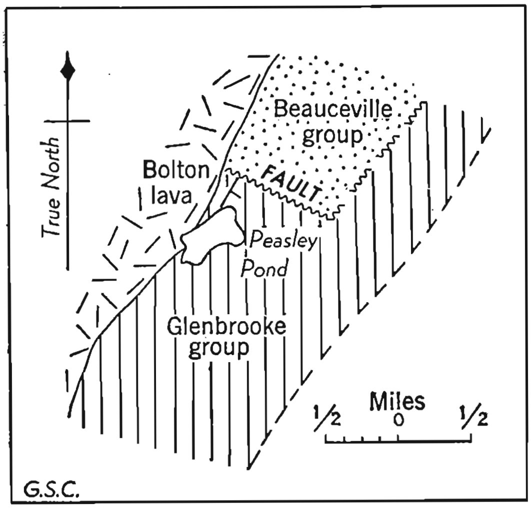

Figure 16. Relations of Bolton lavas to Glenbrooke and Beauceville groups, north of Peasley Pond.

In lots 2 and 3, range XIV, Magog tp., or about 3½ miles northwest along the highway from the western limits of the town of Magog, a critical, well-exposed area of considerable size, south of the highway, displays clearly the relations of the Bolton lavas both to the Glenbrooke group and to the Beauceville and Caldwell groups. A careful pace-and-compass survey was made of the area, on a scale of 528 feet to the inch (*See* Figure 17).

In the northern part of the area sketched, it may be observed that the boundary of the Bolton lava trends southeast to cut across the bedding of Caldwell trachytic lavas, with which are interbanded some grey slate and quartzite. These strike north 20 degrees west, dip vertically, and possess a moderately well developed cleavage striking a little east of north. Two small patches of Beauceville conglomerate rest upon the eroded edges of the Caldwell rocks. After following a southeast course for some 660 feet, the boundary of the Bolton lava turns sharply south for 140 feet, then projects eastward in a nose about 150 feet long. Probably this lava filled a gully eroded along a small fault, as a sharp bend in the strike of the older strata occurs here.

At the end of the nose, the boundary of the Bolton lava turns to run southwest. In so doing it bevels across the strike not only of the Caldwell rocks, but also that of a band of Peasley Pond conglomerate. The latter outcrops on the sides of an abandoned railway cutting some 35 feet south of the last outcrops of lava. The beds of conglomerate strike north 10 degrees west and dip steeply west. This strike, projected only 35 feet, would carry the conglomerate beneath the lava.

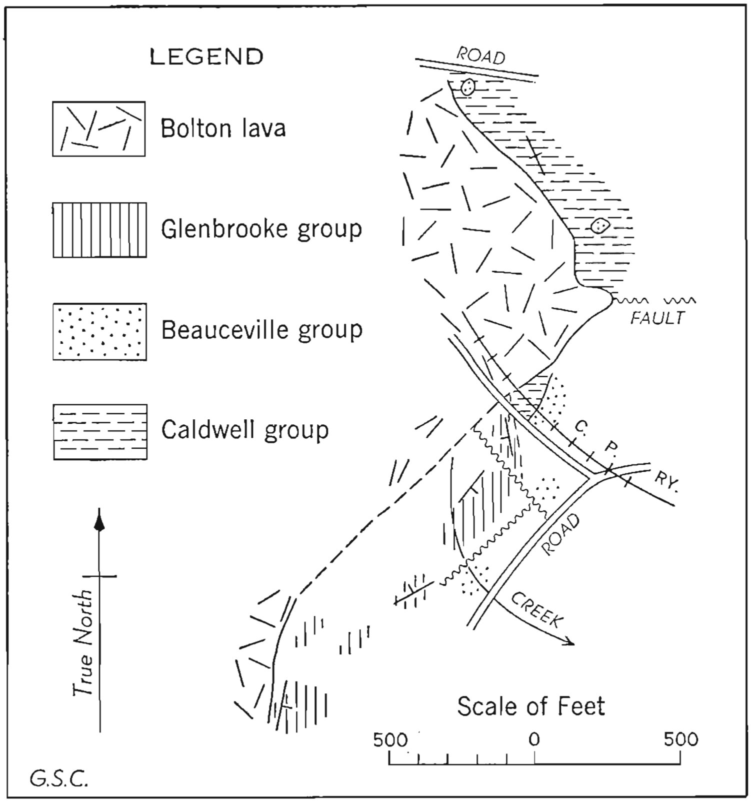

Figure 17. Contacts of Bolton lavas with Glenbrooke and older groups, on lots 2-3, rge. XIV, Magog tp.

As these beds strike west of north and dip west, and other beds of conglomerate and slate about 100 feet to the south strike north 35 degrees east and dip southeast, a fault between them is inferred. It looks as if the northern beds of conglomerate represent the east limb of a small syncline of Glenbrooke beds, the southern beds the west limb. If the conclusions are correct, then the intervening fault is also bevelled by the lava.

Conclusions

The data given indicate clearly that the Bolton lavas are, with exception of the overlying slates, the youngest surficial rocks of the region. It has been shown that they overlie with great angular and erosional unconformity the folded rocks of the Caldwell and Beauceville groups, and the peridotites intrusive into the Beauceville. The evidence with regard to the Glenbrooke group is perhaps somewhat less direct, but there appears little reason to doubt that it also was folded, faulted, and eroded before deposition of the lavas.

The nature of the surface on which the Bolton lavas were laid down would be an interesting subject of investigation. In places, as around Orford Lake where the lavas appear in scattered patches, or around Hogsback or the southern end of Owl Head Mountains, the surface would appear to have been not far from the one at present developed on the sedimentary rocks. On the other hand, the steep inward dips observed on both sides of Pevee Mountain, and on the east side of Owl Head, suggest deep valleys that the lava filled. In this connection it may be mentioned that at the north end of Pevee Mountain the lava ends in a long, gradually narrowing point, as if it had filled there a gradually widening gully.

On the whole, therefore, the known relations suggest a surface of moderately low relief, with some valleys of unknown depth.

The lavas have been somewhat folded. Narrow folds were observed in the area pictured in Figure 17, and pillows in many places show a considerable variation in strike and dip, a feature that may be due in part to folding, and in part to deposition on very irregular surfaces. The relations described from the west shore of Lake Memphremagog (Figure 14) indicate drag-folding of the lavas. The dips of the observed contacts on both sides of Pevee Mountain, and on the east side of Owl Head, 55 to 68 degrees, are so much steeper than ordinary valley slopes as to suggest folding.

Thus it seems clear that this region was affected by deformative movements after the main Acadian folding and faulting was complete. The only deformative movements affecting the eastern part of the continent after the Acadian, so far as the writer is aware, outside of gentle epeirogenic movements, were those that folded the Appalachian ranges in Permian time, but the Quebec region has commonly been considered beyond the influence of this orogeny.

The only facts at hand bearing on this question are those given in the preceding paragraphs, showing that the lavas flowed out on a surface of moderate relief with a well-developed hill and valley topography.

Folding and faulting, as well known, are extremely slow processes. Movements of a few feet, or even inches, are followed by long periods of stillstand during which erosion is active, and areas elevated by movement may be largely, even completely, cut away. The final part of any orogeny, therefore, when movements were becoming relatively few and widely spaced, might have erosion dominant over uplift, degrading the surface faster than it was being raised. During the closing stages of a movement such as the Acadian, therefore, a land surface could develop such as the Bolton lavas appear to have covered, and they could then be deformed by the final stages of that movement.

To the writer it seems preferable to conclude that this happened rather than that they were deformed by movements in late Palæozoic, Permian time. The interval between the Acadian and Appalachian movements included part of the Devonian and all of the Carboniferous period—ample time for complete peneplanation. To obtain a surface such as that beneath the Bolton group, therefore, such a peneplain must have been uplifted and rather deeply eroded before the Bolton lavas were poured out and subsequently deformed. Of such a history there is as yet no evidence whatever.

LAVAS POSSIBLY PART OF THE BOLTON GROUP

Near Fitch Bay

On the east side of Lake Memphremagog, paralleling Fitch Bay and a short distance west of it, are several elongate masses of basic lava. These are dark grey and greenish grey rocks, in places largely replaced by iron-bearing carbonate. Excellent pillow structures in places indicate the rock to be lava. Two thin sections displayed little but secondary minerals, such as white mica, kaolin, chlorite, epidote, calcite, etc. Some grains of quartz and some ragged remnants of badly altered feldspar may be all that is left of the original minerals.

The rock is very massive and unsheared, although a few schistose phases have been found locally. The massive character is especially striking along the shores of Fitch Bay, where the other rocks have been rendered highly schistose by the St. Francis fault. For this reason it was suspected that the lava might be younger than the shearing, and, therefore, younger than the sheared Caldwell and Beauceville strata; and evidence was sought either to confirm or contradict the hypothesis.

The break between the long and the small bodies of lava about 1½ miles southwest of Fitch Bay village is a broad valley about 75 feet deep. Though the valley seems filled with drift, search showed the presence in it of rather numerous, small, low outcrops of slate, extending across the interval between the two lava masses. If these two masses were ever continuous, therefore, the lava must overlie the folded slate, and the valley has been cut completely through it to expose the slates below.

East of the south end of the small body of lava mentioned above, and about 650 feet away, a very small body of lava about 100 feet in diameter overlies the sheared slates, like an outlier.

At the north end of the small body of lava, slates and quartzites again outcrop, separating this body completely from the larger mass ¾ mile northwest of Fitch Bay village.

The latter, however, displays still more incontrovertible evidence. The road running north from the village passes along low ground near the foot of the steep lava hill on the west. The relations are shown in Figure 18. The solid boundary shown in the figure represents the position, roughly, of the base of the hill; the dotted boundaries are the contacts between the lavas and the Beauceville rocks. The latter consist of highly cleaved and in places badly contorted black slates, a few of the strikes and dips of which are indicated in the figure; but the general strike of the cleavage is north to slightly east of north. The lava is not much cleaved. Two tongues of lava cut directly across the structure of the slates, to cross the road into the field east of it, where they are lost beneath fairly heavy drift.

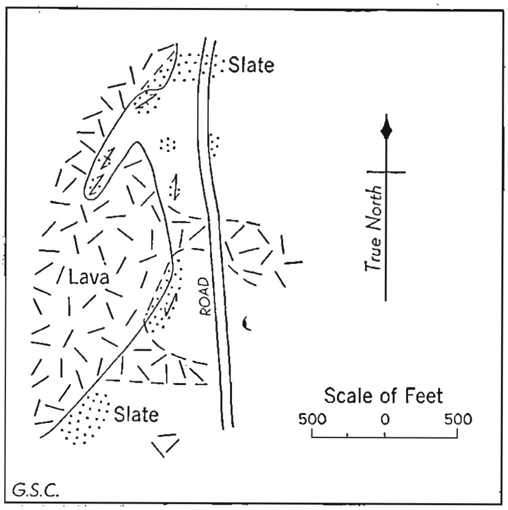

Figure 18. Plan, showing relations of Beauceville slates and conglomerates to the lavas of Fitch Bay, one-half to three-quarters mile north of Fitch Bay village.

Similar relations were seen along the southeast boundary of the long lava band, northeast of the road that crosses Fitch Bay narrows. In a traverse between this road and the creek about half a mile to the northeast, three places were noted where tongues of lava 30 to 40 feet long, and up to 50 feet wide, project across the cleavage of the slates. Although no sharp contact was found in any place, such relations are possible only if the lavas overlie the folded slates.

It is thus incontrovertible that the lavas overlie the older rocks with great structural and erosional unconformity. The sedimentary rocks must have been folded into near-vertical positions, then deeply eroded, before the lavas were poured out. The lack of deformation of the lavas along the St. Francis fault indicates also that they post-date that fault.

Although the lavas are more badly altered than the Bolton lavas west of Lake Memphremagog, and are not in contact with anything later than the Beauceville group, their similar lack of deformation, and similar relations to the basement on which they lie, justify tentative correlation with the Bolton.

Near Waterloo

In the western end of Orford map-area a band of basic lavas about 4½ miles wide at the Montreal-Sherbrooke highway extends from a point about a mile east of Frost village past the town of Waterloo. Narrowing gradually, it extends northeast about 10 miles to end about West Ely; beyond this point it is confined to scattered patches. South of the highway it extends a little past Foster, where its extension is hidden by drift.

This band of lavas is on strike with the band mapped by Clark (16) in Sutton map-area, and termed by him the Tibbet Hill schist. It is also on strike with a band of similar lava mapped by the writer in the eastern half of Richmond map-area.

Most of these lavas are fine-grained, hard, greenish grey rocks that locally display pillow structures, amygdaloidal textures, flow breccias, and other characteristics of lavas. Toward the centre of the wider part of the band, however, there is a considerable development of more acidic types, mainly trachytes.

The basic varieties bear an extraordinary resemblance to the basic lavas, previously described, which are interbedded with the schistose sediments of the Sutton schists. The criteria by which they can be distinguished are as follows.

The Waterloo lavas are rather massive rocks, and where sheared the cleavage planes are plane surfaces. The Sutton lavas are in general more highly sheared, and the cleavage planes in many places are highly distorted and drag-folded, exactly like the cleavage planes of other parts of the Sutton schist.

The Waterloo lavas contain no vein quartz whatever, except: (a) locally in a few places where they have been intensely sheared, apparently by faults, and (b) over widths of a few feet next to contacts with the Sutton quartzitic schists. There, meteoric waters seem to have carried silica for short distances into the lavas, from the schists. The Sutton lavas, on the other hand, have narrow seams of quartz between the leaves of schist, like the sedimentary schists; and also, like them, contain varying amounts of quartz in wider veins.

It is obvious, quite apart from the geological evidence about to be presented, that the Waterloo lavas must have suffered much less deformation and quartz-injection than the Sutton lavas. Neither Clark, in mapping the Sutton map-area, nor the writer, in Richmond map-area, realized these distinctions; and these areas should be re-studied to determine what proportions of the lava bands in those areas belong to the older and younger types. On the accompanying map, the lava band in Richmond map-area is coloured like the lava near Waterloo, but it is probable from the descriptions in the writer's notes that part of it is Sutton lava.

Lithology. The basaltic parts of the Waterloo lavas are fine-grained, greenish grey rocks, with a hardness in fresher specimens of about 6. Some varieties are highly amygdaloidal, the amygdules filled usually with epidote, though larger ones also carry quartz and a few flakes of white mica. About 55 to 60 per cent of the rock is fine-grained feldspar having about the same index of refraction as balsam, hence is probably about An_{15} in composition. Augite seems to have been the principal other constituent, but is now largely replaced by epidote, chlorite, and uralite. Magnetite in very small grains and strings of grains constitutes about 5 per cent.

Acidic types seem to occupy the centre of the lava band throughout a distance of some 5 or 6 miles; a point west of Rochelle village seems to be about the centre of the strip. Work was not sufficiently detailed, however, to determine whether the acidic lavas constitute a continuous band throughout the distance mentioned, or whether their occurrence is sporadic.

One specimen, taken near the extreme west end of rge. IV, Stukely tp., is a fine-grained, dark grey rock that weathers light grey. Under the miscroscope it was seen to consist mainly of feldspar in grains about 0·03 mm. in diameter. Its index of refraction indicates it to be about An_{25} in composition. The remainder consists of very fine-grained irregular bits of colcurless or very pale green mineral, possibly actinolite, with a little ilmenite. The rock would seem, therefore, to be about trachyte in composition.

A more acid variety was found about 1½ miles east of the west end of rge. VII, Stukely tp. It is very fine grained, and light grey in colour, and has a directed texture due probably to flowage in the final stages of consolidation. In thin section it is seen to be porphyritic; about a third of it consists of phenocrysts of quartz and fresh oligoclase, An_{25}, up to 0·6 mm. in length. About four-fifths of the phenocrysts are quartz, somewhat granulated around the edges. The phenocrysts lie in a fine-grained matrix consisting largely of white mica, which is probably an alteration product of a quartz-feldspar mixture.

Relations to the Schists of Sutton Mountain. The relations of the Waterloo lava to the schists were first observed along the road running south-southwest from Rochelle, about 650 feet south of its junction with the road running west through rge. VII, Stukely tp. The main contact of the lavas and schists crosses the road there, but east of the contact, perhaps 100 feet or so from the road, poorly exposed patches of lava outcrop among exposures of the schist. The best exposed of these was carefully sketched (*See* Figure 19). The patch of lava is completely surrounded by schist, the cleavage of which has an average strike of north 30 degrees east, with a near-vertical dip, but is much drag-folded on a small scale. The lava is only slightly cleaved, and its areal relations show clearly that it must overlie the schist. At the northeast corner of the patch the contact of the lava swings round in a series of hooks, as shown. These are not caused by step faulting—no faults at all were seen—hence must mean that the lava was poured out on a slightly irregular erosion surface developed on the drag-folded schists.

This evidence makes clear the relationships of the other more poorly exposed patches of lava nearby. Obviously they must be erosion remnants of the larger mass, which must once have extended farther east than at present.

At a point 1¾ miles due west of Valcourt church, the eastern edge of a small mass of the Waterloo lava is well exposed against slightly schistose quartzite for a total length of about 160 feet, except for one gap of 22 feet. The contact bevels the cleavage of the quartzite at a small angle, and displays other small irregularities. Clearly, the lava was deposited on a slightly irregular erosion surface of schistose quartzite.

The best evidence of the unconformity of the lavas on the schists, however, is that furnished by the general mapping. The patchy and irregular nature of the lava in the western ends of rges. X and XI, Stukely tp., and the similar patchy arrangements west of Valcourt, seems to indicate that the patches are either erosion remnants or infaulted bodies.

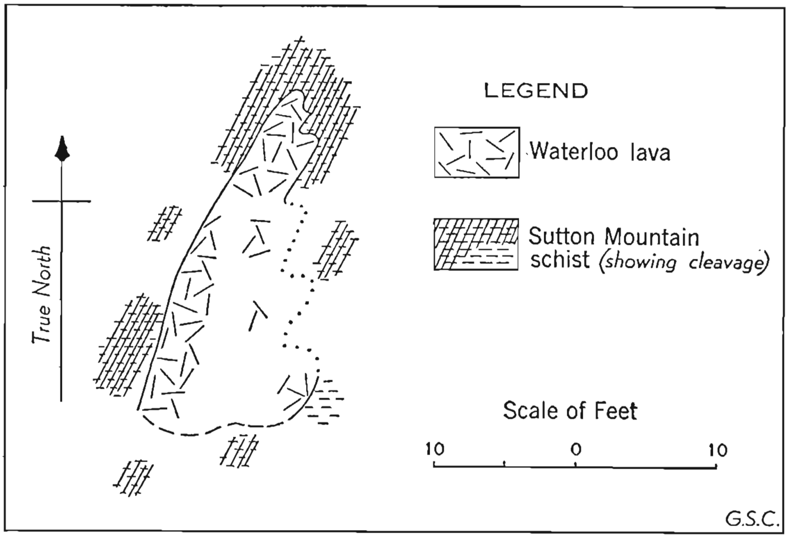

Figure 19. Plan, showing relations of patch of lava of the Waterloo type to the surrounding Sutton Mountain schist, about $1\frac{5}{8}$ miles south-southwest of Rochelle. The schist has numerous drag-folds not shown in sketch.

Age. It is clear, from the facts cited, that the Waterloo lavas overlie both the Sutton schists along their east boundary. The Waterloo lavas are on the whole rather more deformed than those of the Bolton group, but both their composition and their relations to the underlying rocks are much the same. The possibility, therefore, that they should be correlated with the Bolton lavas should not be overlooked.

Grey, Slaty Lavas. Along the west side of the band of Waterloo lavas, in Orford map-area, is a band of soft, grey, slaty rocks easily mistaken for sedimentary argillites. Their hardness is about that of a hard slate, and in most places they have a moderately developed cleavage. When first seen in the field they were taken for true slates, probably members of the Sutton schist group; but this view soon proved untenable. No bedding is discernible in them, even on the cleanest surfaces; on the contrary, such surfaces commonly show a rock of fairly uniform nature filled with rounded or elliptical nodules up to an inch in length. Some of these nodules are filled with numerous small vesicles; others contain a single larger one up to $\frac{1}{8}$ inch in diameter. These features suggest a volcanic rock of some kind, either a flow breccia or an ash rock; and as no angular fragments could be found, the latter possibility is ruled out.

In lot 28, rge. X, Shefford tp., at the point where the road crosses the Shefford-Stukely boundary, the grey rock is filled with somewhat larger rounded or elliptical lumps, each of which has a round or elongated amygdule at its centre. Such nodules are common in lavas that were approaching consolidation when the amygdules developed; the latent heat absorbed by the gas when it came out of solution to assume the gaseous state caused immediate freezing of the lava immediately surrounding each amygdule. The writer has observed the phenomenon in many places, though so far as he is aware it has not been described in the literature.

This amygdaloidal material grades downhill and westward into a massive, featureless, grey rock that looks like massive lava. Three feet to the east is massive green lava of the Waterloo type. The relations thus seem to indicate that the grey slaty lava underlies the Waterloo lava. Otherwise the relations between them are as yet unknown. Possibly the grey lava may be a locally developed, older phase of the Waterloo lavas.

A thin section of the massive grey lava showed, as might be expected, nothing but a featureless mass of secondary products, mainly white mica, with some almost colourless chlorite, and considerable—15 to 20 per cent—fine-grained magnetite.

South of these exposures, in rge. IX, Shefford tp., the grey lavas display a well-developed flow breccia with numerous fragments 1 inch to 2 inches in diameter.

In lot 2, rge. XI, Ely tp., the grey lavas are interbedded with about 50 feet of slaty sedimentary beds, the beds about $\frac{1}{8}$ inch in thickness. They strike north 65 degrees east, dip almost vertically, and are strongly drag-folded, so as to indicate movement of the southeast side to the southwest. The plunge of the drag-folds is about 70 degrees southwest, so that the movement must have been almost horizontal, the southeast side moving up at a low angle. As the next outcrops seen to the north are of an entirely different character, these drags may have been due to the proximity of a strong fault.

In Richmond Map-area

A band of lavas of Waterloo type is exposed in the east half of Richmond map-area. It is 13 miles long, 3 miles wide at its north end, and about 1 mile at the southwest end. The narrowing was considered probably due to faulting, when the area was examined in 1946, but the more recent work indicates that it could also be due to elevation of the underlying basement rocks, in the unmapped half of Richmond area.

The lavas of Richmond map-area are dark green, usually massive rocks composed mainly of about 50 per cent fresh oligoclase-albite, with the remainder chlorite, ilmenite, leucoxene, and a little white mica. Considerable areas display no volcanic characteristics, but coarse flow breccias and amygdaloidal phases are common in others.

According to the writer's notes, the southeast side of the lava band is commonly very schistose, and difficult to distinguish on that account from the sedimentary schists with which it is in contact. It is possible, therefore, that this part of the band may consist of the older, Sutton lava. The schistose lava was eventually distinguished from the sedimentary schists by the uniformity of its composition and its prevailing epidote-green tint. The sedimentary schists, on the other hand, vary rapidly in composition across the strike, and have grey colours.

Some ash rocks are associated with the lavas in the northeastern part of Richmond map-area. Good exposures can be seen 1 mile to 1½ miles due south of Scotch Hill. They are slaty, poorly bedded rocks striking north 25 degrees east and dipping steeply northwest. One bed carries scattered fragments of lava 2 to 6 inches in diameter, many of which have large amygdules. One of them was 1½ inches long and an inch across; it had a lining of red jasper $\frac{1}{20}$ inch thick, and the interior was filled with crystalline quartz and bright green epidote.

A chip from one of these fragments proved fresher than any specimen obtained from the main body of lavas. It contained some 25 to 30 per cent of fresh albite in crystals about ½ mm. in length, squeezed and bent, and about the same amount of hornblende in ragged crystals up to 1 mm. The latter carry numerous inclusions of feldspar, magnetite, and other minerals, thus giving the impression that they are secondary. Ilmenite constitutes 8 to 10 per cent of the thin section, an optically negative pyroxene about the same amount, and alteration products, including some carbonate, make up the remainder.

Southwest of St. Francis River the flows are thinner and interbanded with thin-bedded slaty rocks of light grey, dark grey, and greenish grey tints. The interbanding may be well seen in a roadside outcrop about 2,100 feet northeast of Gore station.

Relations to the Sedimentary Rocks. The southeastern contact of the lava band is almost everywhere a drift-filled depression a few hundred feet wide. Only in one place, lot 18, range line IX-X approximately, are outcrops reasonably numerous, though small, across the contact. There the Caldwell quartzitic schist, which strikes northeast and dips northwest, is followed on the northwest by a black slaty rock, then by a thinly banded rock that looks like a bedded mixture of basic ash and more ordinary sediment. This is followed, in turn, by the chloritized lava. There is no evidence to indicate that the lava does not overlie the schists conformably. If the observations are correct, they again suggest that the southeast part of the lava band belongs to the older, Sutton lava.

On its northwest side the lava is in contact with massive grey quartzites. Most of the contacts are faulted, but in two places unfaulted contacts were found. The first is about 2,000 feet northwest of the north end of Spooner Pond; there the quartzites are interbanded with some thin beds of grey slate, and cleavage-bedding relations indicate that the beds, which strike north 45 degrees east and dip vertically, face toward the southeast. The lavas overlie the sedimentary beds directly, with no sign of any break between them; and one quartzite bed close to the contact is heavily loaded with hematite. The sediments and lavas pass around two drag-folds, and the structure is that of a syncline plunging southwest.

The second locality is about 2 miles west-northwest of Richmond, in lot 5, rge. VIII, Melbourne tp., where a narrow, northeast-striking fault block of quartzite and lava was found. The quartzite lies on the northwest side of the lava, strikes north 35 degrees east, and dips 65 degrees northwest. Cleavage-bedding relations obtained in several places indicate that the beds face southeast, and are, therefore, overturned. Thus the lavas must overlie the quartzites.

The succession at this contact consists of fairly massive grey quartzites on the lower, northwest side, followed by 100 feet or more of blackish slate of a type closely associated with the lavas in this district. Two beds of coarse white quartzite are interbedded with the lower 30 feet of this slate, and above it lies the lava.

Both of these contacts display good bedding in the sediments, and the lavas appear to overlie them with perfect conformity. However, further work, in the less metamorphosed rocks to the west, should produce fossil evidence that will clarify this problem.

Sedimentary Rocks Associated with the Lavas. Along the west side of the mapped part of Richmond map-area lavas of the Waterloo type are in contact with a rather wide band of slaty rocks ranging from rather light grey to dark grey. They are well stratified in beds a few inches thick, and structure is readily determinable from cleavage-bedding relations. Their contact with the lavas was sought in the valley of Ulverton River just northeast of where highway 32 crosses it; there it was found that the lava is overlain by the slates without any visible break. From the contact the slate continues, across the strike, at least three-quarters of a mile, maintaining, except for two large drag-folds, a fairly uniform northwest dip at about 45 degrees and facing northwest. The plunge is about horizontal, on the average; local plunges range from nil to 30 degrees, and are northeast in some places, southwest in others.

Thin sections of the slates show 35 to 40 per cent of fresh oligoclase-albite, with a few grains of quartz, in a matrix mainly of white mica. The quartz and feldspar grains are 0·1 to 0·15 mm. in diameter. Biotite and magnetite are accessory.

Other beds that appear to be associated with the slates are found throughout the northwestern quarter of the mapped part of Richmond map-area, but outcrops are too scattered for definite relations to be determined. Some resemble a very tough, dirty-looking quartzite, but the microscope shows that 75 to 80 per cent of the rock is fresh oligoclase-albite in grains 0·1 to 0·15 mm. in diameter, with a few grains of quartz about the same size. Some 4 or 5 per cent of ilmenite and leucoxene are present, and the remainder is mainly pale green chlorite and a little carbonate. Thus the rock is very like the slates in composition, except for the smaller proportion of matrix.

The 'quartzite' described was found 1½ miles due west of The Narrows, St. Francis River, but similar rocks were found in several places in the neighbourhood.

Many of the slates supposedly associated with the Waterloo lavas here have faintly purplish or reddish tints. It will be recalled that the slates associated with the Bolton lavas are similarly coloured. Some of them have the secondary cleavage well enough developed to have been of commercial importance. A large quarry on the northeast shore of St. Francis River about 1·87 miles from the north boundary of Richmond map-area utilized slates that appear to belong to this group.

INTRUSIVE ROCKS

The intrusive rocks of the region include peridotite and pyroxenite, gabbro, and granite. The peridotites and pyroxenites underlie an area of several square miles in the northern part of Orford map-area, and are found in smaller, discontinuous, usually dyke-like bodies southwest to the International Boundary in a zone rarely more than 2 miles wide that follows the eastern boundary of the Sutton Mountain schists. Gabbro, or a complex intermixture of gabbro and Bolton lava, underlies much of Baldface, Orford, and Chagnon Mountains, and forms numerous, usually small, dykes elsewhere throughout the region. Though it is possible that gabbro of more than one age may be present, the bulk of it is thought to be post-Bolton. Bodies of granite are found in Scotstown, Sherbrooke, Orford, and Memphremagog map-areas. The most important, commercially, with an area in Canada of about 5 square miles, lies on the east side of Lake Memphremagog, and crosses the International Boundary. Several other small, scattered masses have been mapped.

PERIDOTITES

In the east half of Richmond map-area the principal mass of peridotite is a long dyke-like body that underlies the pronounced depression occupied by Steele Brook, Salmon Brook, and The Gulf. Throughout most of this distance it is only 600 to 1,200 feet wide, but west of Greenshields the width increases to ¾ mile. In this wider section, a deposit of chromite was worked during the last war, and parts of it display small veins of asbestos. As usual in the Eastern Townships, the peridotite is highly serpentinized.

This dyke on its southeast side bevels at a small angle a succession of geological contacts between Caldwell lavas, Caldwell quartzites, and Beauceville rocks. On its northwest side, Caldwell rhyolite appears abruptly throughout most of its length, and Caldwell quartzite southwest of Kingsbury. These facts, and the steep narrow valley that it follows, combine to indicate that the dyke has been injected along a major fault, along which movement was renewed after injection.

Some smaller masses of ultrabasic rock mapped in Richmond and Sherbrooke map-areas, are nearer pyroxenite in composition than peridotite. In these either the edges, or the whole mass, have been altered to white masses of rather fibrous, somewhat talcified tremolite. The coarse pyroxenites of Thetford district are rarely to be seen here.

The main dyke of peridotite continues south from Richmond area into Orford map-area for about 2 miles, as far as Mud Lake. Beyond this, for 5½ miles, it has not been found, but may lie beneath Mud and Bowker Lakes. At the southwest end of Bowker Lake, peridotite again appears, but is there only about 250 feet wide and is intensely sheared. On strike, 2 miles to the southwest serpentine again appears, with about the same width, and is sheared on the southeast side. For the next 5½ miles it has not been found, but from Eastman a narrow dyke follows the east side of Missisquoi Valley, interruptedly, as far as the International Boundary.

A much larger mass of serpentinized peridotite is found in Orford map-area on both sides of Brompton Lake, underlying an area, roughly, of 11 square miles. This body yielded considerable amounts of chromite during the last war.

In Memphremagog map-area, in addition to the main dyke already mentioned, various dyke-like bodies, most of them of no great length or width, are found. All lie within a mile or so of the Missisquoi Valley fault, though whether this relation has any genetic significance is not known.

The composition of the peridotites has been thoroughly discussed in an earlier report (22) and will not be considered here.

In the same report the age of the peridotites was determined to be post-Beauceville. Evidence to the same effect was found in Orford map-area. In the valley of the creek that flows from Deer Lake into Webster Lake peridotite was found intruding the basal conglomerate of the Beauceville.

GRANITES

Scotstown Map-area. Five bodies of granite are found in this area, in addition to many dykes that seem tributary to the larger masses. The northern two are separated by a gap of only 2 miles, and are probably the exposed parts of a single larger body that, in the gap, lies only a short distance beneath the present surface. This inference is suggested by the fact that the St. Francis slates in the gap are intensely metamorphosed to minerals like sillimanite, staurolite, and andalusite.

These granites are grey, coarse-grained, equigranular rocks for the most part, though large phenocrysts of feldspar are present in places. They carry 25 to 30 per cent of quartz; the feldspars include both orthoclase or microcline and oligoclase; and the ferromagnesian mineral is generally a small amount of both muscovite and biotite. Some varieties also contain hornblende or augite; and quite basic hybrids have been formed locally by digestion of the adjacent older rocks.

Three dykes of granite cut the beds of the Lake Aylmer group in rges. VI and VII, Weedon tp. They are rather fine-grained rocks, not very similar to the satellite dykes of the larger masses described; consequently, any correlation with them is open to doubt.

Dudswell Map-area. No granite has been found in this area, except the rather numerous dykes that cut the rhyolites of Stoke Ridge. Their presence probably indicates that the main body, which outcrops in Sherbrooke map-area, underlies the rhyolites at no great depth.

Sherbrooke Map-area. The northern part of this area contains one granite mass about 7 miles long, with an average width of about 1½ miles. A second body, 1½ miles in length and about 600 feet in maximum width, lies southwest of the first with a gap of 1½ miles between them.

These granites differ from those in Scotstown map-area in containing little or no potash feldspar. They comprise about 25 per cent of quartz, some 50 per cent of rather badly sericitized albite, 15 or 20 per cent of very fresh oligoclase, about An_{35}, and small amounts of a somewhat chloritized biotite. The grain is coarse and equigranular.

In places, particularly near the southwest end of the main mass, this granite is much sliced and sheared, and even converted into a mica schist in a few places. The proximity of the sheared parts to the great fault that follows St. Francis River suggests that the shearing is related to the fault.

Orford Map-area. The only body of granite in this area is found near the northwest shore of Chain Pond. According to Y. O. Fortier[1] it is composed of about 40 per cent quartz, some 28 per cent orthoclase, 20 per cent albite, and 10 per cent of dark constituents, mainly muscovite and biotite. The orthoclase is fairly fresh, but the albite much altered to sericite. Biotite is somewhat chloritized. Zircon and apatite are accessory.

The granite is rather fine grained and equigranular, and unusual in that the mass has been completely brecciated into angular fragments, most of them not more than 3 or 4 inches in diameter. The movement causing brecciation clearly took place at some time after the granite was completely consolidated, as each fragment is separated cleanly from the matrix by a smooth surface, like a pebble in conglomerate. The matrix, which is relatively small in amount, is finer in grain than the fragments, and, according to Fortier, has clearly been formed by crushing of the coarser material.

Memphremagog Map-area. The largest mass of granite in this area lies across the International Boundary, on the east side of Lake Memphremagog. It is commonly referred to as the Stanstead granite. In Canada

[1]Unpublished manuscript.

the mass is about 3 miles long from east to west, and $1\frac{3}{4}$ miles wide. In addition to this, many dykes of similar granite cut the rocks of the Glenbrooke group on Lake Memphremagog, and others cut rocks of the St. Francis group northeast of the main body. Many large quarries have been established on the Stanstead granite (13) and are in active operation.

The Stanstead granite is a grey, equigranular rock with a grain of 3 to 4 mm. The composition varies a little from place to place, but averages some 15 to 20 per cent quartz, about 75 per cent feldspar, ranging between albite and oligoclase-albite, a few crystals of microcline, and some 5 per cent biotite. The minerals are fairly fresh.

This granite is singularly free from inclusions, in fact none whatever were observed in either outcrops or the numerous quarry walls. No relict structures are present. At contacts with the older rocks, the granite cuts across pre-existing structures. The body, therefore, displays every evidence of having been injected as a fluid mass, rather than having been formed by granitization of older rocks.

Within the general boundaries of the granite mass are several patches of St. Francis sedimentary rocks, in places highly contorted. These seem to be remnants of the original roof of the mass; if this conclusion is correct, the granite cannot be deeply eroded.

Age

The Stanstead granite mass cuts only rocks of the St. Francis group, but on Magoon Point a large dyke identical in appearance and composition, both as regards the component minerals and their proportions, intrudes strata of the Sherbrooke group, metamorphosing them and throwing off stringers into them. This granite is, therefore, of post-Sherbrooke age; and as the first succeeding period of disturbance was the Acadian, in Middle Devonian time, it may reasonably be concluded that the granite was intruded at this time.

The various bodies in Scotstown map-area also cut only rocks of the St. Francis group. In composition they are also characterized by the presence of both orthoclase and oligoclase-albite, and are otherwise much like the Stanstead granite, though containing somewhat more potash feldspar. Two of them lie across the course of the Weedon thrust, and so far as known have not been cut by it. It seems probable, therefore, that these masses are also related to the Acadian orogeny.

The large mass of granite in Sherbrooke map-area has been intensely sheared near the fault along St. Francis River, apparently by the same forces that likewise sheared the older formations. It would seem, therefore, to be older than the Acadian orogeny, at least. It may, therefore, have been injected either during the Taconic disturbance, or during the earliest stages of the Acadian.

The same seems to be true of the small body of granite near Chain Pond in Orford map-area. It has been completely brecciated after becoming solid, hence would seem to be older than the Acadian period of disturbance.

Granite pebbles are fairly common in the basal conglomerate of the Lake Aylmer group of rocks, and it is possible that these originated from these bodies of supposedly pre-Acadian granite. If so, these could not have been unroofed until near the beginning of Devonian time, as no granite pebbles are present in the Sherbrooke or Glenbrooke basal conglomerates, though a few are found in some conglomerates of the Sherbrooke group, the stratigraphic position of which is not definitely known.

QUARTZ DIORITE

On Trousers Lake and southward about half way to Bolton Centre there are some small masses of a rock termed quartz diorite by J. W. Ambrose, but which in composition seems nearer a granite. The rock is light grey, rather fine grained (0·5 to 1·0 mm.) and unusual in that it is loaded with sharp-angled inclusions of quartz, chert, and various schists, which display no indications of attack from or digestion by the matrix. The rock contains much quartz; Ambrose states about 20 per cent, but the one thin section examined by the writer carried double that amount. The quartz is present in aggregates of small crystals and irregular masses, some of which have crudely vein-like shapes up to 3 mm. in length. Its unusual appearance suggests that it may be a secondary introduction.

The bulk of the remainder of the rock consists of orthoclase, with abundant little flakes of sericite, and albite, somewhat clouded by kaolin. The total amount of ferromagnesian mineral is small; most of it is actinolite in large scattered crystals.

GABBRO

In Orford map-area, gabbro underlies much of Orford, Chagnon, and Baldface Mountains, in large masses intrusive into the Bolton lavas. In addition, it forms many dykes, most of which are too small to map on the 1-mile scale.

The gabbro is a dark green, equigranular rock, mostly of medium grain (1 to 2 mm.), but with both finer and coarser phases. Though hand specimens appear fairly fresh, the microscope shows it to be very completely altered. One thin section contained a little feldspar of about the composition of labradorite, and it is thought that probably the original feldspar may have been of this nature. Now, however, although the outlines of the original feldspar crystals are still visible under crossed nicols, the feldspar itself is completely altered to aggregates of chlorite, sericite, clinozoisite, etc., and such remnants of feldspar as remain unaltered are albite-oligoclase in composition, about An_{15}. These remnants are probably themselves secondary. One or two sections showed some remnants of augite, but if this was the original ferromagnesian mineral it is now completely altered, except for such rare remnants, to blue-green hornblende, colourless hornblende, chlorite, epidote, etc. Leucoxene forms up to 4 or 5 per cent of some sections, and is probably secondary after ilmenite.

In age, this gabbro is almost the youngest rock of the district. It intrudes the Bolton lavas, which, as already indicated, post-date the folding movements that deformed the Lower Devonian rocks. Unlike the gabbro of Thetford district, which nowhere intrudes the Beauceville strata, this gabbro forms numerous dykes within the Beauceville. In Thetford area, gabbro is intruded by peridotite; around Orford Lake these gabbros intrude peridotite. The gabbro of Thetford area differentiates in many places to yield products close to pyroxenite in composition; this gabbro has not been observed to do so. No gabbro has yet been detected in this area that may possibly be correlative with the gabbro of Thetford district.

Gabbro similar to that of Orford map-area extends south into Memphremagog map-area, to underlie the west end of Place Mountain. Farther south, numerous dykes of gabbro have been found, but except in one instance display no evidence of any but post-Beauceville age. The instance mentioned is that of the gabbro filling the fault $1\frac{3}{4}$ miles southwest of Vale Perkins (page 82). This dyke is evidently post-Bolton.

Near the north end of Sherbrooke map-area, a body of gabbro has been injected into the rocks of the St. Francis group. It is sill-like in a general way, but changes width rapidly along strike. It ends abruptly to the southwest, probably due to a fault. No special study was given to the mass; it appeared to be an ordinary, fine- to medium-grained, badly chloritized gabbro. If the writer's conclusion is correct, that it is faulted off at its southwest end, it must antedate the period of faulting, and is probably older than the gabbros of Orford area.

In the southwest corner of Sherbrooke map-area, two or three small bodies of very coarse gabbro grade into anorthosite. They seem to have been injected into branches of the great fault that runs through North Hatley.

Silicified Lavas and Gabbros

An unusual and extraordinary silicification has affected both the Bolton lava and the gabbro that cuts it. The phenomenon was first recognized on the eastern slope of Mount Chagnon, about 1,400 feet south of the east end of Orford Lake and some 400 feet west of the road. At that point there are large, clean, glacially polished exposures of the Bolton lava, one section of which contains elliptical areas 12 to 18 inches long and 6 to 8 inches wide, which are liberally sprinkled with coarse crystals of quartz. Some of these crystals attain diameters of 4 to 5 mm., and a number of them display a distinct approach to hexagonal outlines. The quartz-filled ellipses are separated from one another by a few inches of lava containing little quartz or none. In another place, a large body of the lava, some 10 feet wide, is similarly enriched with quartz crystals. Later work proved that much of the lava of Chagnon, Orford, and Baldface Mountains has been silicified in this way; and, where outcrops are not clean, such rocks are apt to be mistaken for intrusives. They can be readily distinguished, however, on freshly broken surfaces, by observation of the groundmass in which the crystals lie, which is always fine grained and lava-like.

The gabbro of the same hills has been similarly altered. The bed of a small creek that flows down the south face of Mount Orford about $\frac{1}{4}$ mile east of Lake Orford displays magnificent exposures swept clean of soil and lichen by the spring floods. These were studied with minute care. In them, the change from gabbro without quartz to gabbro with quartz can be seen repeated many times. The quartzose bodies have widths of the order of 25 to 30 feet. Their edges show no line of demarcation whatever; the quartz simply ceases to be present, and the rock becomes the ordinary gabbro. Without this study, the gabbro thus silicified could readily be mistaken for granite.

Under the microscope the secondary nature of the quartz is clear. Some of it is present in crudely vein-like masses; and the crystals, which range up to 6 mm. in diameter, include fragments of the original minerals, feldspar, altered feldspar, hornblende, and iron ore.

The microscope also shows that the introduction of the quartz was followed by introduction of some chlorite. This forms veinlets averaging about 0·1 mm. in width, that tend to follow around the boundaries of the quartz crystals, but in places cut into or completely across them. These veinlets are confined to the localities specified above; only in one or two instances were they observed to diverge for short distances into the surrounding rock. Also, some of them have, at their centres, exceedingly narrow bands of some highly birefringent mineral, the nature of which was not determined.

CAMPTONITE DYKES

During the summer of 1945 the writer found several basic dykes in the south-central part of Sherbrooke map-area. In the field these looked like rather badly altered lamprophyres, and no particular attention was paid to them other than collecting three samples as fresh looking as possible. When thin sections were cut, however, it was realized that a very unusual rock had been discovered; the samples and sections were accordingly sent to Dr. Eugene Poitevin, mineralogist of the Geological Survey of Canada, for a thorough examination.

The three samples hereafter described were taken from the bed of Moe River south-southeast of Lennoxville. The hamlet of Milby lies close to the junction of Moe and Salmon Rivers about 4 miles south-southwest of Lennoxville. One of the dykes, No. 19, was found on the east shore of the stream, 300 or 400 feet south of the bridge at Milby; a second, No. 22, was found in the stream bed a little more than a mile north of Milby; and the largest, No. 24, about 14 feet wide, is exposed on the west bank of the stream some 5 miles south of Milby, or about ½ mile north of Moe River village in the Coaticook area to the south. All these dykes strike southeast, roughly at right angles to the strata that they cut, and they appear to have near-vertical dips. Similar dykes were observed in the bed of Salmon River, east of the Moe, and in Coaticook River about 1¼ miles southeast of Capelton. They are, therefore, distributed throughout an area at least 8 miles in diameter.

The dykes weather with great rapidity. The largest of them is visible on the rocky shore of Moe River to a height of 4 to 5 feet above low-water level; the upper part of this section is completely weathered to a coarse grit with little cohesion, and even a foot or so above low-water level weathering is so far advanced that collection of even moderately fresh material was impossible. Specimens had to be obtained from only a few inches above this level, where erosion of the rapid stream had kept removing the weathered material, and perhaps the longer periods of submersion had protected the rock from oxidation. In the initial stages of weathering, oxidation progressed along joints, so that the rock was divided into crudely rectangular blocks perhaps a foot or so in length and several inches wide. This primary subdivision into blocks, and the eventual reduction of the material to a coarse sand or grit, is identical with the weathering displayed by the younger olivine diabase of Sudbury district.

Rapid weathering doubtless accounts for the fact that the dykes, although of good size—they average 2 to 4 feet in width and one, as mentioned, is 14 feet wide—are never found in interstream areas, or indeed anywhere except where bedrock is exposed in rapids and when water is low enough to permit examination of such places.

The strata cut by the dykes are the dark impure limestones and limy quarzites of the St. Francis group. This group has been assigned, on the evidence of a few poorly preserved graptolites, to the Normanskill horizon of the Middle Ordovician. The St. Francis beds strike east-northeast, approximately at right angles to the dykes, and have dips that range from 45 degrees to vertical. They are much drag-folded; the argillitic members have developed slaty cleavage; and others are correspondingly metamorphosed. The dykes are entirely undeformed, and they clearly filled fissures entirely unrelated to the regional structure, which was developed at some time during the Devonian period. Obviously, therefore, the dykes are considerably younger, and their freshness and entire lack of metamorphism, other than weathering, suggest that their intrusion may have been fairly recent.

Dr. Poitevin's notes on the material submitted to him are as follows:

"To the naked eye specimens of these dykes resemble basalt, and they range in colour from greyish to greenish black; some are fine grained, and others in addition to this habit display a porphyritic texture. The binocular microscope indicates that these rocks are composed of appreciable amounts of small, elongate, prismatic crystals of hornblende, and that some of the specimens contain phenocrysts of reddish olivine and dark-coloured pyroxene. The magnifying lenses also show that most specimens carry small, disseminated, white, rounded spots. This preliminary examination suggests that these dykes are probably basic lamprophyres. Specimens as fresh as possible collected by H. C. Cooke from the three dykes were numbered by him as Nos. 19, 22, 24, and 24a. The thin sections made from them reveal, under the polarizing microscope, a panidiomorphic structure, which is the tendency of all the constituent minerals to appear as idiomorphic individuals; they also reveal, in the case of the porphyritic types, several generations of the ferromagnesian minerals with the possible exception of olivine. The sections also show that the plagioclase feldspar may be lath-shaped or grouped sheaf-like, and that in some cases the crystals forming the sheaves are somewhat curved. The above are characteristic features generally recognized in lamprophyres.

"Taken individually the corresponding thin sections yielded the following information:

"The groundmass of section No. 19 is composed mainly of idiomorphic crystals of pinkish titaniferous pyroxene, with some elongated brown prismatic barkevicite hornblende in lesser quantities. Also forming part of the groundmass are rounded globules composed of calcite, a little basic andesine, small blades of accessory biotite, and fibrous light-coloured amphibole. Some of the round globules also contain aggregates of very small unidentified spherulites. It may be noted here that this section contains very little feldspar by comparison with Nos. 22 and 24.

"Through the above-mentioned groundmass are disseminated rather abundantly phenocrysts of titan-augite and light greenish yellow olivine, which are far from being uniform in size. The pyroxene, which is the most abundant mineral of the section, is pinkish in natural light and often twinned on *a*(100). It exhibits, in most crystals, a characteristic zonal structure. The cores of the pyroxene crystals are diopsidic in composition, whereas the rims are aegirite. The most common alteration product of the pyroxene is ordinary chlorite and penninite. Alteration of the crystals generally begins in the centre zone.

"Olivine is visible as beautifully shaped phenocrysts, fresh or altered, and also in a few instances as inclusions in the large pyroxene crystals. When fresh the olivine is light yellowish green in colour and the crystal outlines of the individuals are sharp even when altered. Magmatic corrosion is absent or insignificant. Some of the olivine crystals, when totally altered, are replaced by alveolar serpentine, whereas in others iddingsite is the alteration product. Thus, in this section the predominant minerals are pyroxene, hornblende, and olivine. Present in appreciable quantity are serpentine, iddingsite, chlorite, and calcite, and those visible accessory constituents are basic andesine feldspar, biotite mica, apatite, pyrite, and magnetite.

"As the crystals of this rock were unusually good they were carefully measured and the following forms identified:

Olivine: *b*(010), *c*(001), *k*(021), *d*(101), *e*(111), *s*(120), *h*(011).
Hornblende: *a*(100), *b*(010), *m*(110), *c*(001).
Pyroxene: *a*(100), *b*(010), *m*(110), *c*(001).
Apatite: *c*(0001), *m*($10\bar{1}0$).

"As in No. 19, the groundmass of section No. 22 is composed of hornblende and pyroxene, but with the amphibole dominating. The basic andesine almost lacking in No. 19 is rather abundant here. The phenocrysts, somewhat small, are pyroxene and olivine, both species in well-shaped crystals or with corroded outlines. The pyroxene phenocrysts in some instances are grouped to form rosettes. Accessory minerals and alteration products are similar to those of section No. 19.

"Sections 24 and 24a were made from rocks derived from the same dyke, the largest encountered. Section No. 24 represents the central part of the igneous body and No. 24a its marginal phase. Both are mineralogically similar, with this exception—that No. 24 has a porphyritic structure, the phenocrysts being mainly zonal titaniferous augite with a few olivine crystals. Some of the phenocrysts exhibit corrosion. In both sections the groundmass is composed of idiomorphic hornblende, fibrous amphibole, and basic andesine visible as laths or rosettes. Accessory mineral and alteration products are similar to those of the previous sections.

"Thus section No. 19 represents an augite camptonite and sections 22, 24, and 24a are camptonites.

Chemical Composition

"The following analyses of camptonites from Sherbrooke district were carefully made by R. J. C. Fabry, analyst of the Mineralogical Section, Geological Survey of Canada. The difference between them is small considering the wide range of chemical composition this rock may have. For comparison the analyses of two essexites from Mount Royal are also included; they were taken from a report by Bancroft and Howard (1923, p. 32).

Analyses of Camptonite and Essexite

—	19	22	A	B
SiO_2	43·64	40·40	44·66	43·10
TiO_2	1·86	2·50	2·27	2·80
Al_2O_3	13·97	12·30	9·64	13·94
Fe_2O_3	4·58	4·62	4·98	4·92
FeO	6·94	6·94	6·65	6·93
MgO	9·65	12·08	12·83	8·86
CaO	11·97	12·19	13·11	14·65
Na_2O	1·75	0·42	2·07	2·50
K_2O	1·25	1·28	1·17	0·89
H_2O+	2·70	4·40	0·90	0·70
H_2O-	1·09	1·36		
MnO	0·07	0·24	0·19	0·14
P_2O_5	0·61	0·74	0·24	0·27
CO_2	0·39	0·56	0·37	0·64
Cl	Trace	0·02	0·07	Trace
Cr_2O_3	Nil	0·06	....	....
SO_3	....	....	....	None
S	0·24	0·23	....	0·22
FeS_2	....	....	0·22	....
Fe_7S_8	....	....	Trace	....
SrO	....	....	0·03	0·03
BaO	....	0·18	None	0·03
NiO	Trace	0·05	....	....
	100·71	100·57	99·40	100·62
Less O/S	0·09	0·09	....	0·09
	100·62	100·48	99·40	100·53

Norms

—	19	22	A	B
Orthoclase	3·89	0·56	7·23	5·56
Albite	5·24	3·14	8·64	6·29
Anorthite	27·42	29·47	13·34	23·91
Nephelite	5·40	0·28	4·97	7·95
Leucite	2·63	5·25	....	....
Diopside	22·58	23·71	37·52	34·09
Olivine	19·20	9·30	13·70	7·01
Hypersthene	....	12·68	....	....
Magnetite	6·73	6·96	7·19	7·19
Ilmenite	3·65	4·86	4·26	5·32
Pyrite	0·74	0·44	0·22	0·36
Apatite	1·29	1·55	0·67	0·67
Calcite	0·90	1·30	....	....

Name and symbol	Locality	Classification[7]
19. Augite camptonite................ 111.6.4.4.	....	Class III Salfemane Order 6 Portugare Rang 4 docalcic Sub-rang 4 Papenose
22. Camptonite....................... (III) IV.2.2.2.2.	....	Class IV Dofemane Order 2 Scotare Section 2 Pauliare Rang 2 Montrealose Sub-rang 2 Montrealose
A. Montrealite (olivine essexite)...... (III) IV.2.2.2.2.	Cote des Neiges Road, near reservoir, Mount Royal	Class IV Dofemane Order 2 Scotare Section 2 Pauliare Rang 2 Montrealose Sub-rang 2 Montrealose
B. Essexite........................... III.6.(3)4.4.	Lookout, Mount Royal....	Class III Salfemane Order 6 Portugare Rang 4 docalcic Sub-rang 4 Papenose

[1] As the analyses of Montreal rocks used for comparison were already calculated according to the C.I.P.W. Quantitative System, the same method has been followed for the camptonites from near Sherbrooke.

"The information listed in the preceding pages strongly supports the idea that the camptonites from Sherbrooke district are related to the rocks that constitute the Monteregian Hills.

"Brome and Shefford Mountains were the most easterly known Monteregian Hills until McGerrigle (1935, p. 81) reported another occurrence of rocks of the Monteregian type at Megantic Mountain, Compton county, Quebec, some 75 miles to the east of Brome Mountain. The camptonites collected by H. C. Cooke came from a district about half way between these two localities.

REFERENCES

"Bancroft, J. A., and Howard, W. V. (1923): The Essexites of Mount Royal, Montreal, P.Q.; Trans. Roy. Soc., Canada, vol. 17, sec. IV, pp. 13-42.

"McGerrigle, H. W. (1935): Mount Megantic area, southeastern Quebec, and its placer gold deposits; Ann. Rept. Que. Bur. Mines, 1934, pt. D, pp. 63-104."

Dykes of rocks petrographically similar to many present in the Monteregian Hills are found on the shores of Lake Memphremagog cutting the limestones of the Glenbrooke group. They were described by V. F. Marsters in 1895 (61). Augite camptonite constituted six of them, and in addition he found one or two examples of olivine diabase, camptonite, monchiquite, and fourchite. Marsters unfortunately gives little or no information about their geological relations—their size, strike, dip, weathering, and so on; and so far as the writer is aware little or no attention has been given to them since. Marsters also found several granite dykes, which he regards as unrelated to the basic dykes.

Similar rocks are exposed in a railway cut just east of Lake Orford station. Their occurrence was noted by Dresser (27) in 1910, and Fortier (49) has described them more fully as follows:

"The exposure is presumably a composite and complex dyke; it shows many facies grading into one another and also phases that intrude earlier ones. A dark camptonite containing phenocrysts of black amphibole up to 2 inches long and lesser feldspar passes to a hornblende-biotite monzonite with grains up to ½ inch long. The camptonite is exposed at the east and west ends, and also within the outcrop, whereas the monzonite occurs only within the outcrop. Narrow dykes up to 1 foot wide of nordmarkite (?) cut the other phases. Both at the east and west ends of the exposure the camptonite contains many inclusions. These are angular fragments, up to 2 inches long, of greenstone and finely laminated schist. They have very sharp contacts, and apparently no assimilation took place. Thin sections show the plagioclases strongly zoned; dark brown amphibole has reaction rims of biotite and is surrounded by zones of magnetite dust."

No contact of this body with the surrounding rocks is exposed, so that its size is unknown. Fortier also observed another camptonite dyke about 6 feet wide cutting the Caldwell strata about 1,000 feet northwest of the one described.

Dykes of similar character found in Sherbrooke area by the writer strike southeast, approximately at right angles to the strata they cut, and, so far as can be seen, dip vertically. Marsters' map (loc. cit.) suggests that relations on Lake Memphremagog are similar. They, therefore, fill fissures at right angles to the regional structure developed in late Devonian time. This, coupled with their freshness and entire lack of deformation, suggests that they may be of relatively recent age. F. F. Osborne has suggested that the Monteregian rocks may be as late as Tertiary, basing the inference on the poorly developed and immature pleochroic haloes surrounding crystals of zircon and titanite.

CHAPTER III

STRUCTURAL GEOLOGY

FOLDING

Four periods of folding are represented in the region; one following deposition of the Caldwell group, a second after deposition of the Beauceville group, a third subsequent to the accumulation of the Sherbrooke, Glenbrooke, and Lake Aylmer groups, and a fourth after extrusion of the Bolton lavas.

The evidence of post-Caldwell, pre-Beauceville folding is largely found in Orford map-area. On pages 40-42 instances are described in which the Beauceville conglomerate overlies directly the upturned, eroded edges of Caldwell strata. On page 24 it is stated that on the west side of Dudswell map-area the Caldwell beds are thrown into great drag-folds that indicate strong horizontal movement of the southeast side to the southwest. No such drag-folds were recognized in the nearby Beauceville beds, and the inference is that they are of pre-Beauceville age.

The fault breccias found at the Caldwell-Beauceville contact in many parts of the west end of Dudswell map-area, and also in Richmond map-area, are indicative of deposition on a rough erosion surface rather than a smooth conformable plane (*See also* page 43).

An interesting relation, apparently also due to contact faulting, was seen in Dudswell map-area 2 miles northeast of St. Claude. There, a roughly circular mass of thin-banded trachytes, less than ½ mile in diameter, has the structure of a dome, with the trachyte bands paralleling the edges of the mass and dipping steeply outward. A mass of Beauceville slate about 30 feet long lies on the top of the hill, cutting directly across the eroded edges of the trachyte bands. The presence of slate, instead of the basal conglomerate, suggests emplacement by fault movement over a previously folded and eroded surface.

The evidence of a post-Beauceville but pre-Sherbrooke folding lies, apart from the evidence of direct contacts, in the different intensities of folding. The Beauceville and Caldwell beds are closely folded; the crests of individual folds are narrow and swing quickly into the steeply dipping limbs. The Sherbrooke beds, and the Lake Aylmer beds with which they are structurally conformable, have broad, gently undulating crests that may in places be a mile or more in width; and the dips on the limbs, though steep in places, are more commonly around 45 or 50 degrees.

The folding is also proved by direct field evidence, already given in detail on pages 57-59 and 76-78.

The Sherbrooke, Glenbrooke, and Lake Aylmer beds have been folded, thus indicating a third period of orogenic movement. This was presumably the Acadian orogeny, which took place in Middle Devonian time.

Folding of the Bolton lavas and slates is indicated by the fact that in places they now lie at high angles, as indicated by the bedding of the slates and the attitude of pillows in the lava. Possibly, however, these attitudes have been attained through tilting of fault blocks rather than by flexure. It has already been shown (pages 88-89) that they overlie with unconformity the folded and faulted strata of the Glenbrooke group; hence the movement must have been post-Acadian. The only post-Acadian movement of importance known in eastern North America is the post-Pennsylvanian orogeny that raised the Appalachian chain, so that possibly the Bolton lavas were folded at that time. On the other hand, the interval between the mid-Devonian movement and the Pennsylvanian movement was very long, long enough to permit of complete peneplanation of the post-Acadian mountains; but as indicated on page 90, the surface on which the lavas were poured out seems to have been far from peneplaned. Possibly their extrusion and folding took place in their later stages of Acadian movement.

Few of the folds, in any of the geological groups, are traceable far. In the Beauceville group, outcrops are rarely good enough to be certain of their continuity; and in the others it is evident that faults have broken up the folds into a succession of separate blocks.

FAULTS

Faults, both large and small, are numerous in the region. Most of them, including all the larger, trend northeast and cut the rocks into a succession of relatively narrow strips. The number of such faults that have been found wherever they can be recognized from stratigraphic or structural data suggests that numerous others must exist that cannot be recognized because of the lack of suitable horizon markers.

Besides the northeasterly faults that parallel approximately the strike of the beds, others have been recognized that strike about at right angles to it. In most of those instances where the nature of the movement has been determined, the southwest side has moved up. In Dudswell area, a few faults apparently of this type also show the southwest side moving southeast.

PRINCIPAL STRIKE FAULTS

Victoria River Fault

The most easterly strike fault of the region follows approximately the valley of Victoria River in the southeastern corner of Scotstown map-area. It strikes northeast and separates the rocks of the St. Francis group from a group of grey quartzites and light grey slates that, from the brief examination given them, seem petrographically very similar to those of the Caldwell group. Along a road that runs due east from Valracine, about a mile south of the boundary of Scotstown map-area, at a point 9,600 feet east of the village, these rocks are intensely sheared to white and grey mica schists with a northeasterly strike; and a well-developed valley follows the shear zone. Pending further exploration of this district, the writer suggests this zone to be part of a major fault.

Weedon Thrust

The name 'Weedon thrust' was given by Burton (12) to the fault in Disraeli map-area separating the Lake Aylmer group from a band of lavas to the southeast. As the same relations prevail in Scotstown map-area, it is concluded that the fault there is a continuation of the Weedon thrust, although 3 or 4 miles of drift-covered ground intervenes.

The fault first appears about half a mile northwest of the Weedon mine, where limestone of the Lake Aylmer group outcrops close to basic lava. The limestone is intensely sheared and recrystallized. The shearing strikes north 4 degrees east and dips 60 degrees east. At the Weedon mine itself lavas are intensely sheared across widths of several hundred feet on a strike of north 37 degrees east and a dip of 45 degrees southeast.

Three or four hundred feet north of the point where the fault crosses the road from Fontainebleau to the Weedon mine the contact of lavas and limestones is a drift-covered band about 20 feet wide. The lavas are intensely sheared and partly replaced by iron carbonate. Schistosity strikes nearly due north, with a nearly vertical dip; whereas the bedding of the limestone to the west dips about 60 degrees east, into the fault.

About 2,000 feet south of Fontainebleau, the fault lies in a narrow valley some 50 feet deep. On the west side the limestones become more and more intensely sheared as the valley is approached; the lavas across the valley are similarly sheared. The schistosity strikes north 10 degrees east and dips 45 degrees east.

In rge. II, Weedon tp., about 2,000 feet southwest of the Weedon-Gould road, the basal conglomerate of the Lake Aylmer group is more than 600 feet thick, and bedding seems to dip northwest at 60 to 70 degrees. The northwesternmost outcrops, farthest from the fault, are massive, but toward the southeast the rock becomes more and more intensely sheared, and the matrix becomes converted into a paper schist. The lavas to the southeast face southeast, so that the lavas and sediments are back to back. Farther southwest in the same range, the lavas near the contact are both intensely sheared and largely replaced by iron carbonate. At its extreme southwestern end, the lava mass is also veined, and carries some quartz and chalcopyrite. A small pit has been opened on the occurrence.

Southwest of this point, for about 10 miles, very few outcrops are found, and the course of the fault is not definitely known. The fact, however, that the few outcrops northeast of Marbleton are limestones of the Lake Aylmer group, whereas those northeast of Bishop Pond and southward to East Angus are the impure limestones, siliceous limestones, and limy quartzites that elsewhere are referred to as the St. Francis group, suggests that the fault, or a large branch of it, swings west to join the great fault along the southeast side of Stoke Ridge, here termed the St. Francis thrust.

In Scotstown area, the Weedon thrust appears to branch south of Fontainebleau and forms a rather complex pattern of fault blocks (*See* Map 994A). One branch follows the southeast side of the mass of basic lavas in rges. I and II, Weedon tp. The contact of the lavas with the St. Francis group is a deep valley mostly filled with soil; but north of Fisher Hill outcrops of St. Francis strata were found on a low knoll in a swamp, close to the supposed position of the contact. These display recumbent drag-folds, the axial planes of which dip southeast at a low angle. As no similar structure is found farther from the contact, these would seem to be the effect of a low-angle thrust, dipping southeast.

The general southeasterly dip of the shear planes in the Weedon thrust, the direct evidence thus quoted, and the fact that the fault has brought older rocks on the southeast into contact with younger rocks on the northwest, all combine to indicate that the fault is a thrust from the southeast. The branching of the fault, which has introduced a band of lavas between the strata of the St. Francis and Lake Aylmer groups, thus becomes evidence that these lavas, in all probability, are intermediate in age between the St. Francis and Lake Aylmer groups; and it has, accordingly, been suggested (page 57) that they may be of Sherbrooke age.

The age of the Weedon thrust is obviously post-Lower Devonian, as it cuts rocks of the Lake Aylmer group. Probably, therefore, it was formed during the Acadian orogeny of Middle Devonian time, though movement on it may have been renewed later.

St. Francis Thrust

The fault thus named follows the southeast side of Stoke Ridge to St. Francis River, then continues down St. Francis Valley to Lennoxville, along Massawippi River, through Massawippi Lake and Fitch Bay to Lake Memphremagog. Probably it then turns southward in the valley of that lake. At its northeast end it may swing east to join the Weedon thrust.

In Dudswell map-area there is no evidence for the fault, as the contact of the St. Francis rocks with the lavas of Stoke Ridge is everywhere covered with drift. The fault is exposed, however, at the extreme north side of Sherbrooke map-area, $1\frac{1}{2}$ miles northwest of East Angus. High on the flanks of the hill, there, a sheared zone separates rhyolite on the northwest from conglomerate and limestone of the Lake Aylmer group to the southeast. The rock is intensely sheared across a width of 75 feet, and less intensely for 200 to 300 feet on each side. The shear zone strikes northeast and dips steeply southeast. The conglomerate is much sheared near the fault, but farther away is of the normal type. It is overlain by limestone, which is intensely fractured, but numerous fragments are unsheared and carry abundant crinoid stems and other fossils.

As this outcrop lies between rhyolite on the northwest and rocks of the St. Francis group to the southeast, it must be a downfaulted block or graben; and another branch of the fault must bound it on the southeast.

Farther south, in Sherbrooke map-area, bands of rhyolite and associated sediments are repeatedly bevelled by the fault along St. Francis and Massawippi Valleys; and where exposures occur near these rivers, these rocks can be seen to be intensely sheared along fairly closely spaced, parallel belts. One of these places is the valley of a little creek east-northeast of the Aldermac mine; several others are found southwest of Eustis. Cross-sections of the sheared rocks display intense drag-folding for distances of a mile or more from the contact, and similar drag-folds are also numerous in the beds of the St. Francis group southeast of the fault. These are well displayed in the cliffs at the southwest end of Lake Massawippi. The shape of the drag-folds indicates upward movement of the southeast side, so that the fault appears to be a thrust.

This statement may be questioned when the rocks on the two sides of the fault are considered. At its northeast end the St. Francis strata are in faulted contact with rocks of the Lake Aylmer and Sherbrooke (?) groups, and as these are definitely the younger the fault there must be a thrust. Farther southwest, however, some of the strata on the northwest belong to the Caldwell group, which is certainly older than the St. Francis. Ordinarily, therefore, the conclusion would be drawn that the Caldwell side must have moved upward, making the fault a scissors movement; but such a conclusion is contradicted by the southeastward dip and the drag-folding of the cleavage planes.

This apparent contradiction is resolved when the geological history is considered. On the northwest side of the fault are folded Caldwell and Beauceville strata, which were overlaid, after erosion, by Sherbrooke and Lake Aylmer beds. The whole succession was then folded (*See* Figure 20). An overthrust, along the line shown in the figure, could then bring rocks of the St. Francis group into contact with both younger and older strata. It would only be necessary that thrusting be deferred until near the end of the Acadian revolution.

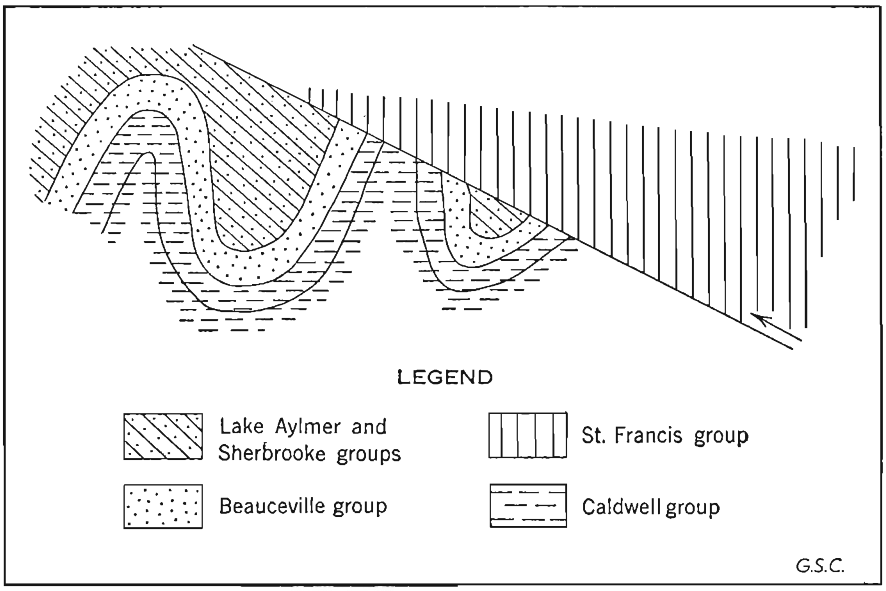

Figure 20. Hypothetical structure-section, showing how rocks of the St. Francis group could be thrust over both older and younger groups.

Richmond Fault

The Richmond fault, in Richmond map-area, follows the valleys of Steele and Salmon Brooks into The Gulf. In Orford map-area it continues through Mud and Bowker Lakes and onward some 2 miles to pass about $\frac{1}{2}$ mile west of the westernmost bay of Stukely Lake. It is believed that it then continues across a 4-mile stretch of heavily drift-covered country to pass through Parker and Eastman Lakes and down Missisquoi Valley. J. W. Ambrose (3) considered that it followed this valley through Memphremagog map-area to cross the International Boundary. North of Richmond map-area, Dresser (37) states that he has traced this fault as far as Little Nicolet Lake.

Evidence for this fault in Richmond and Orford map-areas is largely topographic. The linear succession of straight or gently curving, narrow, steep-walled valleys is highly suggestive of a fault. A dyke-like mass of peridotite, apparently intruded along the fault, sharply separates Caldwell rhyolites on the northwest side from other strata of Beauceville and Caldwell age; and this dyke bevels at a small angle the contact of the latter. South of St. Francis River, the rocks on the southeast side of the inferred fault are so well cleaved that three slate quarries have been opened on them in a distance of 4 miles. The slate was obviously formed before intrusion of the peridotite, as the latter metamorphoses it sufficiently to render it useless near contacts (38).

In Orford map-area, at the south end of Bowker Lake, a peridotite dyke has been intensely sheared, and the sheared zone is traceable a couple of miles farther southwest. Further evidence that the fault follows the valleys of Mud and Bowker Lakes has been gathered by Fortier (49), who states:

"In the northwestern part of Orford map-area there is a narrow, long, deep depression with steep walls, especially to the west. Bowker Lake with deep waters, Mud Pond and The Gulf lie in this depression.

"Schistose quartziferous rocks, sericite-quartz schists and phyllites are found on the west side of the depression. These are apparently derived from more massive quartzites, greywackes, and lesser phyllites which gradually become more schistose and more deformed eastward.

"To the east of the depression are quartzose and chloritic phyllites and rusty slates, which are more deformed on the shore of the lake than farther inland. Small sills of diorite, serpentine, and pyroxenite are also sheared......Along the east shore of Mud Pond a thick sill consisting mainly of massive dunite has a steep slope towards the lake. An exposure of rather massive diorite has a vertical face over 50 feet high along the eastern wall of The Gulf.

"Strata on the west of the depression dip steeply to the east; strata to the east dip westerly as gently as 50 degrees. Examination reveals a discordance of 25 to 40 degrees in trend of structural elements, bedding and schistosity, from one side of Bowker Lake to the other side. Three observations made on grain gradation and one on crossbedding indicate that the strata face eastward on the west side of the depression. Only one top determination was made on the east side of Bowker Lake; pillow structures indicate top to east. Two determinations of easterly tops were made on grain size variation west of Stukely Lake, on the east side of the southerly projection of the depression[1].

"Concordance in stratigraphic attitude of the strata, discordance in dip and strike of the bedding and schistosity, deformation and shearing of the rocks, and topographic depression, are criteria which indicate a zone of faulting."

The writer did not examine the inferred fault zone in Memphremagog map-area, but Ambrose (3) has stated evidence for it as follows:

"The Sutton group consists of schistose sedimentary and volcanic rocks and is folded into a broad anticline that trends north 15 degrees east.

[1] *Note.* Fortier does not draw the inference, but the combination of westerly dips and east-facing tops on the east side of the depression indicates overturning of the strata there—a condition that could have been caused by upward movement of the west side of the fault.

The schists exhibit increasing metamorphism from east to west; secondary feldspar crystals as large as peas, and a noticeable increase in crenulation, first appear along a line that extends northward from a point on the Mansonville-Dunkin highway $1\frac{1}{2}$ miles west of the east contact of the Sutton rocks, to reach the contact near Bolton Centre. ......The more highly metamorphosed belt to the west is evidently truncated against the contact, which must therefore represent either an unconformity or a fault. This conclusion is supported by the observation that bedding, where it can be discerned, and the anticlinal axis, where it can be defined, are nearly or exactly parallel to the trend of the belt of more highly metamorphosed Sutton schists; that is, they too seem truncated by the eastern contact.

"A slaty cleavage is developed throughout the region. This cleavage follows the axial planes of crenulations in the Sutton schists, where such crenulations are developed. The axes of the crenulations, as well as lines of intersection of slaty cleavage planes with planes of schistosity, plunge south into the Sutton schists. Similar axes and lines of intersection in rocks east of the contact plunge north. Since this slaty cleavage forms part of a widespread, uniform system extending far beyond the limits of the map-area, it must be supposed that the slaty cleavage in the Sutton schists and in the rocks east of the contact is of one and the same age and origin. Structural elements dependent on this cleavage should, therefore, have the same attitude on both sides of the contact, but this is not the case. They have been relatively displaced, and apparently the contact is a fault."

The attitude of the Richmond fault, where it has been observed, is nearly vertical. Dips of cleavage developed on or close to the fault average about 85 degrees to the east or southeast.

Relative movement on the Richmond fault was, apparently, upward on the west side. It has been shown (page 22) that the Sutton Mountain schists are, so far as determined, older than the less metamorphosed parts farther east. Also, in Richmond map-area, some areas of Beauceville strata lie on the southeast side of the fault, Caldwell strata on the northwest. The direct evidence cited by Fortier (page 116) seems to indicate upward drag of the northwest side.

If the conclusion is correct, the whole Beauceville fault strip must be a downfaulted block, as the rocks on both sides of it have been faulted relatively upward.

Movement on the Richmond fault appears to have occurred at least twice. The long narrow peridotite dyke, or series of dykes, that mark its position suggest intrusion into a pre-existing fracture zone; and as the peridotites seem to have been injected during the post-Ordovician, Taconic orogeny, such a fracture zone must have been formed during the earlier part of that orogeny, as it brings Caldwell and Beauceville rocks into contact. But it has been shown that the peridotites are themselves intensely sheared along a relatively narrow zone—a fact that undoubtedly accounts for the topographic expression of the fault. Such shearing must have taken place in post-Taconic time, and was, therefore, presumably related to the Acadian orogeny.

Strike Faults in the Beauceville Fault Block

The Beauceville fault block, or strip, contains a considerable variety of formations, hence many faults can there be recognized that would pass unnoticed in the other blocks where the rocks are more monotonous in type. Possibly, too, the structure of the Beauceville block as a downfaulted mass has necessitated greater adjustment by internal faulting than would be required in the others. The faults are too numerous to be all described, but a few of the larger deserve mention.

Memphremagog Map-area. The contact of the Glenbrooke group with the older beds on the east side of Lake Memphremagog is a strong fault. It is well shown in the valley of a small creek flowing into Quinn Bay, at a point about 1,400 feet east of the road. There the contact of Caldwell quartzite and Glenbrooke limestone strikes north 18 degrees east and dips about 60 degrees west. The contact is a fault breccia about 6 feet wide, filled with a rubble of plate-like blocks of quartzite slickensided and gouged on their surfaces. Next to the limestone the matrix becomes more slaty and black, and the fragments are mostly of limestone, 2 or 3 inches in length.

A short distance north of this point, the fault bevels the contact of the Caldwell quartzites with the Sherbrooke grits; and just north of the junction of the main road with the branch into Belmere Point a road cut on the east side displays a zone of intensely sheared, slaty rock, probably either the main fault or a branch passing around a horse. Passing the east side of Macpherson Bay, the surface descends in a very steep cliff, which must be a fault-line scarp; a little farther north, at the point where the map shows the fault finally crossing the road, a branch road runs in to some cottages on the shore. There a cut in the hillside, made apparently to secure road metal, again displays intensely sheared rock.

From the section described, the fault obviously continues south to Lake Memphremagog as the eastern contact of the Glenbrooke is a narrow, rather deep, steep-walled valley. Northward, no direct evidence of faulting was found, but the fact that Glenbrooke limestones are everywhere found at the contact with older rocks is good evidence that the fault continues along the whole boundary.

On the west side of Lake Memphremagog, the writer considers it probable that the west boundary of the same mass of Glenbrooke rocks is also faulted. Admittedly, however, there is no direct evidence of faulting except a strong topographic depression along parts of it.

The northwest boundary of the main mass of Sherbrooke rocks is probably a fault. Strong shearing was noted where the contact is mapped as crossing the two roads in rge. III, Stanstead tp.[1] The manner in which the contact swings to cut across the strike of both the Beauceville and Sherbrooke strata about a mile southwest of Backport can hardly

[1] At the southwestern of these localities the shearing was observed in 1947, in the bottom of a freshly dug drainage ditch beside the road. When the occurrence was checked in 1948, gravel had covered the outcrops.

be explained except by faulting. Just east of the Magog-Ayers Cliff highway, in rge. XII, Magog tp., the contact lies in a steep, narrow valley; and, in Orford map-area, the manner in which the contact angles across the general direction of strike across to Lake Magog is strongly suggestive of a fault.

The southeastern boundary of the same mass of Sherbrooke rocks is certainly faulted in part and may be throughout. A strong fault, marked by a steep valley and pronounced displacement of the rocks crossing it, cuts across Bunker Hill about $1\frac{1}{2}$ miles west of the end of Lake Massawippi. It is lost in the heavily drift-covered area to the north, but may swing to connect with the fault that runs southwest in the continuation of the Magog Lake Valley.

If the conditions outlined in the preceding paragraphs have been correctly appraised, then the eastern mass of Glenbrooke rocks, and the main body of Sherbrooke rocks, are downfaulted blocks, whereas other areas are relatively upfaulted.

Orford Map-area. A large fault undoubtedly underlies the basin of Lake Magog, and extends southward along the valley for an unknown distance. It has brought highly sheared and drag-folded rocks of the Caldwell group, metamorphosed to schist exactly like those of Sutton Mountains, into direct contact with beds of the Sherbrooke group. On the east side of the lake great drag-folds in these schists, by their shape, evidence strong overthrusting from the east, at moderately low angles; and in one place, approximately on lot line 20-21, rge. IX, Hatley tp., the Sherbrooke slates display evidence of having been overridden. The upthrust block extended, apparently, from Lake Magog east to the St. Francis fault. Presumably it was the stresses developed in it when faulted that deformed the beds so highly. The Lake Magog fault must have been formed during the Acadian orogeny, as it has involved strata of Sherbrooke age.

To the south, the fault is lost in an area largely drift covered, though it, or a branch of it, may follow the east boundary of the main body of Sherbrooke rocks, as already mentioned. To the northeast its course is equally uncertain, but it probably swings to form the fault following approximately the course of Magog River.

Sherbrooke and Dudswell Map-areas. The inferred fault along Magog River, just mentioned, continues to separate rocks of the Caldwell group from those of the Sherbrooke group, so that the southeast side is overthrust. The fault has caused intense shearing and drag-folding in the Sherbrooke slates in the western end of the city of Sherbrooke; this is well displayed where the Canadian Pacific railway crosses Magog River, and for 2,000 feet to the west; and also in highway road cuts 1,800 feet north of the railway there.

Farther north, the fault seems to have had the curious effect of dragging the low-dipping beds of the Sherbrooke group northward. This effect has already been described on page 62.

A strong fault has been traced from St. Francis River at a point about $\frac{3}{4}$ mile east of Bromptonville for 10 miles northeast; it then passes beneath a drift-covered area about $4\frac{1}{2}$ miles wide, beyond which it has been traced another 12 miles to the northeast border of Dudswell map-area. The fault separates a strip of Sherbrooke and Lake Aylmer beds from Beauceville strata to the northwest. Throughout most of its length the fault is marked by a straight, deep valley filled with soil, so that the fault was found exposed only in one place, namely, on the west side of Gosford Road about 10,000 feet north of Silver Lake. There the fault appears to fork around a horse of Sherbrooke strata, which is intensely shattered and sheared. Otherwise, the presence of the fault is inferred from the fact that it bevels contacts of Sherbrooke and Lake Aylmer beds, and also truncates structures in these rocks. Thus, in Sherbrooke area northeast of Bromptonville, the general dip is northwest, with Lake Aylmer beds overlying Sherbrooke; this synclinal structure is broken in the middle, so that Beauceville beds abut against Lake Aylmer strata.

Within the 3- to 4-mile strip of beds lying southeast of this fault, many other faults have been found, striking parallel with it so as to cut the beds into a succession of unrelated strips. These are indicated on the accompanying map and will not be discussed in detail. All of these faults obviously formed at the time of the Acadian orogeny, as they involve Sherbrooke and Lake Aylmer beds.

Strike Faults in the St. Francis Fault Block

It has been mentioned on page 113 that a rather complicated pattern of fault blocks is found just southeast of the Weedon thrust near Salmon River; and one of them, that which lies close to the Weedon-Lingwick boundary, has been described. The others are mostly inferred from the abrupt changes taking place along or across the strike of the strata. One, however, which follows roughly the course of Red River, is almost exposed at the road crossing near the mouth of that stream. There the St. Francis sediments become more and more schistose as their contact with the rhyolite breccias is approached, to where, a few feet from that contact, they are converted into a papery schist. Drag-folds in the beds above the dam there, and in the cleavage planes west of the stream, together indicate upward movement of the southeast side.

In Sherbrooke map-area, a fault may lie between the limy and non-limy parts of the St. Francis group. The boundary between the two seems to extend about north up the valley of Coaticook River, across the strike of the bedding. However, the country is so heavily drift covered that the precise relations must remain in doubt.

Faults in the Sutton Mountains Fault Block

No large faults were noted within this block in Orford map-area, though a more detailed study might reveal their presence. In Richmond map-area a complex pattern of faults was found west of Richmond. Most of them are inferred from the distribution of the strata, and quite possibly some of these are not actually present, as it was not then understood that the Waterloo lavas lie unconformably above the Caldwell schists; on the contrary, they were supposed to be interbanded with them, hence any sharp break in strike seemed to imply faulting. Probably some of the small bodies marked as infaulted masses of lava are merely erosion remnants of a larger sheet.

Several of these faults, however, have been directly observed as strong shear zones separating different rock types. In this district, many such shear zones contain much pinkish carbonate. Thus, the fault crossing St. Francis River about 9,000 feet northeast of the west end of the bridge at Richmond contained large amounts of it, and specimens collected there were submitted for chemical analysis to R. J. C. Fabry of the Geological Survey of Canada. Its composition was:

	Per cent
CaO	24·01
MgO	15·27
$(Fe,Al)_2O_3$	4·78
MnO	0·10
CO_2	36·06
H_2O	1·04
Insol.	19·10
	100·36

The insoluble material is probably largely wall-rock, inclusions of which are moderately numerous. The alumina and most of the iron found in the analysis is also thought to be derived from the same source.

If the analysis is recast, it is found that all but 0·39 per cent of the CO_2 present can be accounted for by assuming that all the lime and magnesia are present as carbonate. This carbonate is very close to pure dolomite in composition. The manganese, and perhaps a little iron, is assumed to be also present as carbonate. On this basis the rock consists of:

	Per cent
$CaCO_3$	42·87
$MgCO_3$	32·08
$MnCO_3$	0·16
$FeCO_3$	0·87
Other	24·38

The pinkish coloration may be attributed to the small manganese content.

CROSS FAULTS AND OTHERS

Cross faults are those defined as striking northwesterly roughly at right angles to the general structure. In most instances where the direction of movement can be determined or inferred, the southwest side moved upward, though the mapping suggests that some movements have been of the opposite character. These faults were probably initiated at the same time as the strike faults, because some of the latter change direction to become cross faults for short distances. In addition to the strike and cross faults, there are others that trend in intermediate directions. Some of them approach strike faults in direction and have been discussed with them in previous pages.

It seems unnecessary to list these faults in detail. Few of them have been seen; most of them have been inferred to account for sharp shifts in the position of geological boundaries crossing soil-filled depressions, and the like; the evidence for faulting is, therefore, in such cases, obvious from the maps.

One that was observed, however, forms the northeast end of Stoke Ridge. About 1,800 feet northwest of the school that is situated about a mile west-southwest of the middle of Bishop Pond, the rhyolite of the ridge is faulted into contact with a dark slate. The rhyolite is intensely fractured, and the cracks filled with quartz. Roughly parallel shear zones can be seen in the rhyolite southwest of this contact, and drag-folds in the cleavage indicate upward movement of the southwest side.

In Sherbrooke map-area an important fault with an east-northeast strike runs along the course of Dorman Brook and displaces the bands of rhyolite agglomerate there. It appears to be a right-hand fault with a lateral displacement of about 1,200 feet.

It seems necessary to infer a cross fault of some size along the course of St. Francis River north of Sherbrooke. As the map shows, a wide syncline of Lake Aylmer beds lies west of the river and plunges to the northeast. On the east side of the river no Lake Aylmer beds are found, except a small remnant $\frac{3}{4}$ mile southwest of Beauvoir. Probably the fault following Magog River here has turned down St. Francis Valley.

In Memphremagog map-area, numerous intensely sheared belts are found in the southwestern end of Bunker Hill. They parallel the St. Francis thrust that follows Bunker Brook Valley, and may be subsidiary to it. If so, they should probably be included with the strike faults, but are introduced here because the bedding of the Sherbrooke strata here strikes at right angles to the shear direction. One of the best places to observe these structures is the bed of a small creek on the course of an electric power line across the hill, due south of Lovering Lake. The flood waters of the creek have swept away the soil from its channel so as to afford almost continuous exposure to the top of the hill; and across one zone after another the hard Sherbrooke quartzites are crushed and converted into schists.

The probability of the presence of a number of other faults in Sherbrooke map-area has been dealt with previously and will not be repeated here. Specifically these are the probable fault between the Beauceville and Caldwell groups in the southwestern corner of the map-area, and the probable faults bounding the various strips of rhyolite.

CHAPTER IV

ECONOMIC GEOLOGY

SAND AND GRAVEL

The mineral resource of greatest economic value in the region under discussion is probably its immense deposits of sand and gravel. These have been, and are now being, utilized in great quantities for road materials, railway ballast, making cement, and other purposes, and will undoubtedly be increasingly utilized in the future. Nearly all the stream and river valleys are filled with gravels, deposited there in the closing stages of glaciation. Present streams have done little more than cut away a central channel in these deposits. In addition, eskers and kames are everywhere numerous, so that usually supplies can be obtained fairly near places where they are required, thus reducing haulage costs to a minimum.

COPPER AND PYRITE

The presence of copper ores in the Eastern Townships was noted by Sir William Logan as early as 1847; and during the civil war in the United States (1861-5) the price of copper on the American continent rose to such phenomenal heights, touching 55 cents a pound in July 1864, that a wild mining boom occurred. Every outcrop showing even a trace of the metal was investigated, so that almost all the known occurrences of copper ore were discovered at that time. Very few of them proved profitable, however, and all have now been closed for many years. In 1942 a flurry of interest was excited by the discovery of a new deposit near Sherbrooke by the Aldermac Copper Corporation. This also proved unprofitable, so that operations on it ceased in the summer of 1945.

All the copper occurrences lie in the more or less sheared lavas, usually rhyolites, which are here considered as probably belonging to the Sherbrooke group. All are found in or near the St. Francis thrust or its probable continuation the Weedon thrust, a fact probably of genetic significance.

During the field seasons of 1913-4, J. A. Bancroft was detailed by the Quebec Department of Mines to make a thorough survey of the copper deposits of the Eastern Townships. His comprehensive study (6), published in 1915, reviews all the existing literature and supplements it with his own observations. As little is to be seen now at any of these properties except a shaft full of water and a dump of waste rock, his descriptions of most of them are still the best available. Except where otherwise indicated, therefore, the following descriptions are summarized from his work, which is now out of print and available only in geological libraries.

Aldermac (lot 20, rge. III, Ascot tp.). This deposit was discovered in 1942 by the use of geophysical methods in an area completely covered by some 8 or 10 feet of drift. It has been described by J. E. Hawley and associates (54), from whose paper the following brief description has been extracted.

At the mine, as the map shows, the formations swing to the north; the strike is about north 20 degrees east, the dip about 40 degrees southeast. The orebody is found in a pronounced shear zone that follows a well-defined stratigraphic horizon between schistose rhyolite on the hanging-wall and sedimentary schists on the foot-wall. The horizon and the orebody show pronounced rolls both on the strike and on the dip.

The orebody appears to have formed mainly by replacement of the rhyolite schist of the hanging-wall. It consists of a zone of disseminated sulphides, through which run bands of massive sulphides ranging in width from a few inches to 8 feet. From these bands, which vary in number along the drifts from one to three, many hook-shaped stringers of massive sulphides run off into the hanging-wall. Where they are more than 6 inches wide in the aggregate, values are sufficient to carry a $4\frac{1}{2}$-foot mining width. The massive bands contain, and have largely replaced, many fragments of the mica schist. The ore forms shoots that rake to the southeast, although the minor folds in the strata plunge northwest.

The Aldermac ores, unlike the others in the district, are a complex mixture of pyrite, sphalerite, chalcopyrite, galena, and tennantite. Gangue minerals are quartz, barite, schistose inclusions, and minor amounts of carbonates. A representative sample of a 30-ton carload ran 1·78 per cent copper, 2·20 per cent lead, and 7·07 per cent zinc; and contained also 9·57 per cent of barite. The ores averaged, in addition, about 0·10 ounce of gold and 1·75 ounces of silver a ton.

The deposit was at first developed by a vertical shaft sunk 244 feet, with levels at 156 and 227 feet. Later, an inclined shaft was raised from the second level, which had a depth, on the incline, of 277 feet; and this was later deepened to open a third level at 386 feet. A concentrator, built to treat the ore, commenced operations in July 1944. In 1945, 40,468 tons were milled, and yielded 733,131 pounds of copper, 1,244,446 pounds of lead, 2,887,077 pounds of zinc, 2,206 ounces of gold, and 39,737 ounces of silver. Costs, however, were high, and the mine was closed on June 30, 1945.

Apart from the high smelter charges for treating an ore of this complexity, it was found that the soft schists in which the vein lay were very weak and difficult to support; further, they became sticky mud when disturbed. These conditions led to unusual dilution of the ore by the wall-rocks. The average thickness of the vein material was only 20 inches, and its variable, rolling dip also created difficulties.

Ascot (or Haskell Hill) (W.$\frac{1}{2}$ lot 8, rge. VIII, Ascot tp.). This property, discovered in 1859, has had a chequered career, details of which may be obtained from Bancroft's report. Apparently it was worked at intervals up to about 1910, and some hundreds of tons of ore ranging from 8 to 14 per cent copper were extracted and sold. One shaft is reported to be 340 feet deep, and the underground workings are quite extensive, including some large stopes. Apparently the ore was patchy, as much work seems to have been exploratory. Bancroft states, "Work has progressed upon two very irregular shear zones that traverse the chlorite schists. Locally within these zones, the schists are impregnated with grains of pyrite and chalcopyrite and occasionally have enclosed small 'bunches' of ore. In addition, very irregular lenticular bodies of vein matter composed of calcite, dolomite, quartz, and chalcopyrite have been encountered at irregular intervals. In some instances, such bodies of ore are said to have locally attained a width of 8 feet or more".

Capelton (or Albert) (lots 3 and 4, rge. VIII, Ascot tp.). These properties adjoin the Eustis mine on the northeast, and are situated on the same band of sericite schist. The mode of occurrence, origin, and mineralogical character of the orebodies are the same in both.

The first discoveries were made in 1863, and between that year and 1879 they passed through several hands. In 1879 the properties were acquired by G. H. Nichols and Company, by whom the mines were operated almost continuously until closed in 1907. Mining operations are said to have ceased because the supply of ore was exhausted. At that time the Albert shaft had reached a depth, on the incline, of 2,300 feet; and another shaft, the Walter, of 1,000 feet.

Clark (lot 11, rge. VII, Ascot tp.). This property seems to have been discovered in 1863, and from then until 1866 much work was done on it, including erection of a crusher and concentrator, but since that time it has been idle. The ore appears to have been pyrite with some chalcopyrite, which occurred in irregular patches up to 7 or 8 feet wide, replacing chlorite schists that strike northeast and dip about 45 degrees southeast. The shaft is said to be 73 feet deep, and in addition several shallow prospect pits were dug.

Eustis (lots 2, 3, 4, rge. IX, Ascot tp.). The Eustis mine, discovered in 1865, was operated until 1939; consequently, information on it is more plentiful than on most of the mines of the district (6, 7, 24, 72, 73). The first discoveries, on lot 4, were termed the Lower Canada mine. They were operated, from 1866 to 1872, by American interests under the name of the Hartford mine. In 1872 the property was acquired by the Canadian Copper and Sulphur Company of Glasgow, and operated by them until 1877. From 1877 to 1879 the property lay idle, presumably because the inclined shaft and workings had reached the boundary of the lot. In 1879 the Orford Nickel and Copper Company, which owned lots 2 and 3, leased the property and continued extraction of ore. They operated until 1886, at which time the property was acquired by the Eustis Mining Company and worked by them until 1927. Then the Consolidated Copper and Sulphur Company was organized to take over and operate the Eustis, Albert, and Capel mines. Only the Eustis was worked, however, until it closed in 1939.

The ore consisted of pyrite with varying amounts of chalcopyrite, a small amount of zinc blende and galena, and a little gold and silver. Parts of the ore ran quite high in copper, but mine average would probably have been between 3 and 4 per cent. The high percentage of pyrite made it profitable to produce both pyrite and copper concentrates. The pyrite was shipped for making sulphuric acid; the acid, and phosphate fertilizer, were also made on the ground in a plant erected in 1887 at Capelton by the Nichols Chemical Company.

The ore was a replacement of mica schist, formed by the shearing of rhyolite flows. Ore also replaced the 'greenrock' mentioned on page 54 as a product of the carbonation of the mica schist. The ore contained numerous 'horses' and smaller fragments of wall-rock, in all stages of replacement ranging from those whose character was quite distinct to others whose origin could only be detected by an indefinite banding preserved in the sulphides.

The orebodies consisted of four short, stout lenses arranged *en échelon*. They paralleled the attitude of the enclosing schists, striking northeast and dipping 45 degrees southeast on the average, though rolls in the dip carried it locally from horizontal to 80 degrees northwest (*See* Figure 21). The ore was mined by an inclined shaft that followed the dip of the vein to the 6,350-foot level; and below that by a winze to a depth of 7,416 feet. These distances are measured on the incline; the vertical depth of the mine, when it closed, was about 4,800 feet.

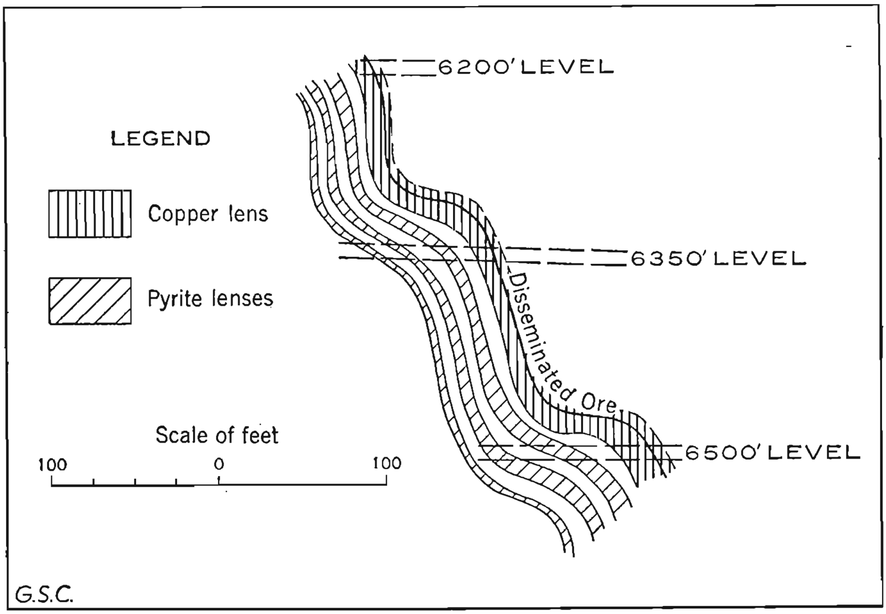

Figure 21. Cross-section, looking northeast, through sulphide lenses at the Eustis mine, between the 6,200 and 6,500 levels. *After* Snow and Brownbill (72).

Of the four sulphide lenses, the southeastern or hanging-wall lens carried most copper, and was, consequently, known as the chalcopyrite or copper lens. It averaged 110 feet in length, and varied in width from 6 to 40 feet. The others, classified as pyrite lenses, are about 250 feet long and ranged in width from 2 to 25 feet. They were separated from each other and the chalcopyrite lens by bands of schist or 'greenrock' 2 to 10 feet thick.

Information kindly supplied by Dr. J. S. Stevenson indicates that the lenses were fairly continuous from the surface downward, but swelled and pinched greatly. On the whole, however, they exhibited a general decrease in size, so that on the 5,800-foot level the chalcopyrite lens was only about 70 feet long and 20 feet in maximum width. The lens was thus a pipe-shaped mass that dipped southeast paralleling the structure of the schists, and raked strongly southwest at about 45 degrees. In four or five places the pipe was broken by small normal faults dipping northwest at angles of 80 to 85 degrees, with displacements of 30 feet or less.

From the surface down to a depth, on the slope, of about 3,200 feet the pyrite lenses contained enough copper to be worth mining. Below that level the copper values faded, and mining was thenceforth confined to the chalcopyrite lens except when additional production of pyrite was desired.

Accurate production figures are lacking for certain of the earlier years of operation, but as nearly as can be estimated some 2,500,000 tons of ore were taken from the mine.

Grand Trunk (lot 6, rge. I, Stukely tp.). At this property, massive beds of marmorized 'dolomitic' limestone intercalated with thinner bands of chlorite schist that originally were shales or fine-grained sandstones are traversed by reticulating veins of quartz up to a few inches in width. The strata strike northeast and dip about 60 degrees northwest, but the veinlets of quartz are nearly vertical. The veins, and the rock nearby, are mineralized with pyrite, chalcopyrite, and bornite. None of the rock, according to Bancroft, will run more than 3 or 4 per cent copper.

The property, which is mentioned in the 1863 report of the Geological Survey of Canada, has been explored by a shaft 60 feet deep. It lies near the boundary between lots 6 and 7, between 100 and 200 yards north of the Canadian Pacific railway. In 1929 this shaft was deepened to 110 feet, and a crosscut run, at the 100-foot level, for 115 feet. In 1931, some 50 feet of drifting was done, and a small mill projected. Work then appears to have been discontinued.

Hepburn (E.½ lot 7, rge. IX, Ascot tp.). This property, first worked in 1880 or 1881, was operated sporadically up to 1910. Sericite and chlorite schists, with the usual northeast strike and southeast dip, are heavily impregnated with sulphides, chiefly pyrite, along a zone about 2 feet wide. This zone expanded into two irregularly lenticular or kidney-shaped bodies of ore, parts of which carried 7 to 8 per cent copper. The ore was removed from these by open-cuts, respectively 40 by 27 feet and 50 by 32 feet, and less than 200 feet deep. In addition, three shafts were sunk and a considerable amount of drifting and crosscutting was done.

Howard (lot 5, rge. XI, Ascot tp.). This mine, under the name of the Cillis, was operated to a small extent in the sixties. In 1889 it was reopened by the Grasselli Chemical Company and worked until 1895. A shaft was put down 300 feet on an incline to the southeast of about 35 degrees, drifts were run some 240 feet northward and 320 feet southward, and considerable stoping was done. Apparently the work investigated a zone of schistose rhyolite some 9 or 10 feet wide, which in places was completely replaced by pyrite with some chalcopyrite, galena, and zinc blende. More commonly, however, the zone comprised ribbons of the sulphides irregularly intercalated with the schists. A few hundred tons of ore were shipped, said to have run from 3 to 5 per cent copper and 7 to 10 ounces of silver a ton.

Huntingdon (lot 8, rge. VIII, Bolton tp.). This mine is situated about 3 miles south of Eastman village, beside the highway from that place to Mansonville. A narrow dyke of serpentine is here in contact on the east with a lava band of the Caldwell group. The rock on the west of the serpentine dyke is concealed by drift, but is thought to be probably the schistose quartzites and slates of the same group. The lavas are partly converted to chlorite schists, and, in the writer's opinion, a narrow band of schistose sediments is also present between the serpentine and the lava. It is difficult to be certain of this, however, as the outcrops are much rusted.

The orebody consisted of schist impregnated, across a width of about 15 feet from the serpentine, with chalcopyrite, pyrite, pyrrhotite, and locally a little zinc blende. The length of this body appears to have been about 150 feet; Bancroft states that on the north it terminates against serpentine, and on the south it gradually dies out. Both the width and the extent of impregnation were variable, as is common in replacement deposits. The body has a strike of north 25 degrees east, and dips steeply, about 70 degrees, southeast.

According to a report made by Charles Robb in 1872, quoted by Bancroft, there was ore also on the west side of the serpentine dyke, which, he says, was richer than on the east side. No further mention is made anywhere of this orebody.

The Huntingdon mine was discovered in 1865, and within a year had shipped 225 tons of ore with a 9 to 11 per cent content of copper. In the following 6 years, from the few figures available, it would appear that from 2,000 to 4,500 tons of ore, of 6 to 12 per cent copper content, was extracted annually and shipped. The property was sold in 1872 to the Huntingdon Copper and Sulphur Company, a Glasgow concern, which increased the output and erected works for concentrating the ore. These were burned in 1875, and although partly rebuilt, further operations were desultory, and closed in 1883. Up to that time the mine had been worked by two shafts, the Huntingdon shaft on the north, said to be 500 to 600 feet deep, and the Wright shaft on the south, about 200.

In 1888 the property was taken up by G. H. Nichols and Company of Capelton. Two years later, the mine was dewatered, and, a short distance south of the Wright shaft, a third shaft was sunk to a depth of 500 feet. This was known as the Nichols shaft. The company carried on prospecting operations until 1893, and a few carloads of ore were shipped.

In the summer of 1912, Pierre Tetreault of Montreal started to erect a concentrating mill with the intention of working over some of the old dumps. Bancroft states that the building was erected, but no machinery installed. Tetreault also sunk a shaft, probably to a depth of about 40 feet, on the western zone of mineralization. After several years of somewhat intermittent prospecting, the property was sold in 1918 to the Eastern Mining and Milling Company, who appear to have completed the concentrator and shipped a considerable amount of concentrates in 1919, averaging 10 to 18 per cent copper. In 1924 they discontinued work and abandoned their lease, although it was said that considerable quantities of low-grade ore still remained in the mine.

Since that time nothing has been done at the mine, except that the British Metals Corporation made a Radiore survey of it in 1929. The buildings have all been removed or have fallen to pieces.

Ives (lot 2, rge. IX, Bolton tp.). The Ives mine, like the Huntingdon, lies in sheared basic lavas of the Caldwell group, near the contact with a dyke of serpentine. The schists strike about north 17 degrees east, and dip east at about 80 degrees. The ores are replacements of the schists, and, from the descriptions, form several pods separated from one another by rock only slightly mineralized. As in the Huntingdon, the ore is pyrite, with a little pyrrhotite, and a larger or smaller quantity of chalcopyrite, which appears to have been introduced after the pyrite and replaced it. Part of the ore also consists of quartz veins mineralized with chalcopyrite.

The mine was discovered in 1866, and most of its development seems to have taken place during the following 6 years. In 1872, T. Sterry Hunt described the workings as consisting of the Brydges shaft, and the Galt shaft 290 feet to the north of it. The Brydges shaft was sunk for 150 feet, of which the last 66 feet were in barren ground. At a depth of 132 feet a drift was run for 102 feet southward, but apparently did not encounter much ore. At a depth of 90 feet a crosscut was driven westward for 54 feet to encounter "talcose schists or soapstone", probably the altered edge of the peridotite dyke. "A portion of rich ore was encountered in the cutting." From here, drifts were run north and south along the dyke contact, for 300 and 150 feet respectively; and in both of these some ore was found. From the end of the north drift a crosscut was run east 48 feet, where "a bed very rich in masses of yellow ore was met with". To reach this, apparently, the Galt shaft was sunk to a depth of 120 feet. At a depth of 72 feet in the Galt shaft, which corresponded to the 90-foot level in the Brydges shaft, drifts were run 60 feet north and 180 feet south along the ore zone, throughout all of which distance good ore persisted.

A third shaft, unnamed, lies about 300 feet north of the Galt shaft. Its depth is unknown, and it has not been mentioned in any of the reports, hence probably nothing of economic value was discovered in it.

About 600 tons of ore carrying 12 per cent of copper are said to have been shipped from the mine in the early days, and a large quantity of lower grade was mined and left on the ground. Little work seems to have been done since 1872, until 1911, when, under the direction of W. A. Cromwell and N. Parker, of Eastman, the Galt shaft was dewatered, and deepened from 110 to 185 feet. J. A. Bancroft examined the property in 1914, when this work was going on. He states that the old workings, at the 100-foot level, showed large stopes developed along the mineralized zone, especially north of the shaft. These stopes varied in width from 7 to 15 feet, and in places were 50 or 60 feet in height.

At the 185-foot level, Cromwell and Parker drifted 22 feet north and 72 feet south. The north drift displayed schist heavily mineralized with pyrite, but little chalcopyrite. The south drift, for the first 26 feet, contained much high-grade ore, 4 to 6 feet in width. The next 8 feet was practically barren schist; the final 38 feet contained considerable chalcopyrite, but over narrower widths. Bancroft states:

"The average width of the sheared zone within which these veins occur is about 5 feet. No statement expressing the relative amount of schist and of veins in any one cross section of the drift would possess worth because such a ratio is extremely variable. The individual veins or stringers of rich ore usually are a few yards, occasionally a few feet, in length; along the strike other similar veins may or may not take the place of a vein that has died out. The veins pinch and swell; one of them, almost solid chalcopyrite, was observed to attain a width of 16 to 18 inches."

Cromwell and Parker made a few shipments of ore, but suspended operations shortly before the beginning of the war in 1914. In 1915 the mine was again pumped out and sampled, and a carload of ore shipped. The reports of the Quebec Bureau of Mines mention that some prospecting or sampling was done in the years 1918, 1925, and 1929, but beyond this no activity is reported.

King (lot 4, rge. XI, Ascot tp.). This property adjoins the Howard in lot 5 to the north, and the Howard orebody extends into the King property. For this reason, development was concentrated near the north boundary of the lot. In the 6 or 7 years prior to 1910 a shaft was put down about 165 feet on an incline of 30 to 40 degrees southeast, and some drifting was done, but only a few tons of ore were shipped. It seems to have occurred as irregularly distributed stringers in sericite schist, one of them, to judge from fragments on the dump, at least 15 inches wide. Assays, presumably of selected samples, are said to have run about 5 per cent copper, from 0·05 to 0·5 ounce in gold, and 5 to 15 ounces of silver a ton.

Lake Memphremagog (lot 28, rge. IX, Potton tp.). This mine is at the northwest end of Hogsback Mountain. The "orebody" is a mass of pyrrhotite with a little zinc blende and pyrite; this material was apparently fractured by movement subsequent to deposition, and thin films of chalcopyrite were deposited along the fractures. Chip samples taken by Bancroft averaged less than 1 per cent copper, though parts of the deposit are said to have averaged 2 per cent, and picked samples may run 4 or 5 per cent.

The body is hour-glass shaped. Part of it is displayed in an open-cut 65 feet long and 35 feet in maximum width. In the central constriction it is only 6 feet wide, but to the south it widens to 20 feet, then narrows to a point about 60 feet from the constriction. North of the constriction the body widens to 12 feet, which is maintained to where it passes under drift at the north end of the open-cut, 40 feet away. About 125 feet north of the open-cut, a shaft, reported to be 90 feet deep, is said to have passed through similar ore into rock, but it has not been proved that the ore is continuous between the two places. Stripping, trenching, and test-pitting some 300 yards to the north of this shaft did not discover anything but rock carrying scattered grains of sulphide.

The orebody lies at the contact of the lava with slates, and dips from 35 to 50 degrees toward the north-northwest. It has been explored by an adit and by an inclined shaft 80 feet deep. Near the bottom the shaft is said to have encountered a slip and passed from ore into rock.

The sulphide body was discovered shortly before 1888, and much development was done in the next 4 or 5 years. Between 1894 and 1907 most of the development above described seems to have been completed, and 500 tons of ore were shipped in 1907, 300 tons at some earlier date. In 1909 the shaft north of the open-cut was completed. In 1918 a third shaft was sunk to a depth of 50 feet (position unknown) and is said to have exposed a body of ore averaging 2 to 3 per cent copper. No further work was then reported to 1929, when some drifting was done.

The writer examined the property briefly in 1948. The workings are now badly overgrown, so that little is to be seen except in the main pit. There it was evident that the orebody has developed at or close to the contact of the Bolton lavas and grey slates that do not effervesce with dilute acid. The sulphides have replaced sheared lava. Shearing strikes almost due north and dips about 60 degrees east. One main and several subordinate zones of shear were seen, in which cleavage arrangements suggest upward thrust of the east side.

Marrington (NE.$\frac{1}{4}$ lot 6, rge. IX, Ascot tp.). This property was worked during the early sixties, probably 1861-6, and reopened for a short time in 1910-11. Chlorite schists striking northeast and dipping about 45 degrees southeast are somewhat drag-folded and impregnated with sulphides, particularly around the nose of the drag-fold. The principal work was done on a streak of massive pyrite with some chalcopyrite, about 3 feet wide at the surface. A shaft was sunk 240 feet on the incline and several hundred feet of drifting done. Two other exploratory shafts, one 135 feet northwest of the main shaft and the other 240 feet southwest of it, were sunk to lesser depths. A few tons of ore have been shipped.

Moulton Hill (lot 23, rge. III, Ascot tp.). The deposit on this property was a body of pyrite, carrying no copper, opened in 1889 by the Grasselli Chemical Company of Cleveland, and worked by them until 1895 to supply pyrites for the manufacture of sulphuric acid.

The deposit lies about 4$\frac{1}{4}$ miles north-northeast of the St. Francis bridge at Lennoxville, on the western contact of the body of granite there with chlorite schist. The edge of the granite is intensely sheared to mica schist; or the rock may be the ordinary sheared rhyolite with the sheared granite close at hand. The sulphide body lies at the contact of the chlorite and mica schist, which strikes northeast and dips 40 to 45 degrees southeast, close to the middle of the north boundary of the lot. It is reported to be a replacement of the somewhat carbonated sericite schist. At the surface it was about 6 feet wide, but the size rapidly increased downward to widths of 40 or 50 feet. The body was mined to a depth, on the dip, of about 300 feet, below which the solid sulphides passed into disseminated ore.

Parks (W.$\frac{1}{2}$ lot 12, rge. VIII, Ascot tp.). On this property veins 14 inches in width or less, composed of pyrite with some chalcopyrite, quartz, and ferrodolomite, cut rhyolite here less sheared than in most of the properties. The veins are supposed to have been explored by two shafts, one said to be 80 feet deep on the dip, the other somewhat more than 100 feet, but very little ore was found.

Silver Star (*Bean, Jackson*) (lot 4, rge. XI, Ascot tp.). On this property an irregular mineralized zone lies in somewhat schistose rhyolite near its contact with sedimentary rocks. The zone does not seem to have been more than 6 feet wide, and followed the cleavage with its usual northeasterly strike and southeasterly dip. Operations appear to have begun about 1898, when a few tons of ore were mined. This was said to have contained appreciable amounts of copper and lead, and to have yielded high assays in gold and silver. Three exploratory shafts were sunk, the deepest 65 feet; it is reported that the bottom of this shaft was not in ore, which may have been lost by faulting.

Suffield (*Griffiths*) (lots 2 and 3, rge. XI, Ascot tp.). The deposit is situated on lot 3 and continues north into the Silver Star property on lot 4. Like the latter, the deposit is a mineralized zone 6 or 7 feet wide in somewhat schistose rhyolite near its contact with sedimentary rocks. Work was done on it at intervals from the early sixties to 1914. Two shafts were sunk, one to a depth of about 250 feet on the incline, the other to 400 feet, and considerable lateral work was done, details of which may be obtained, if desired, from Bancroft's report. The ore is pyrite, with some chalcopyrite, galena, and zinc blende, and was found over a length of some 300 feet. Though some fairly good ore was mined, on the whole values were low, and the ore, if mined, will have to be concentrated to separate the non-metallic constituents. Bancroft expresses the opinion that the blocked-out ore will probably not carry more than 1 per cent copper, on the average.

Victoria (NE.¼ lot 4, rge. VIII, Ascot tp.). This property is situated to the northeast of the Albert, and adjoins it. The Eustis and Albert ore zone, if it extends on strike, should cross it. On the surface a lens of pyrite carrying some chalcopyrite was found; it was about 6 feet wide, in a 20-foot zone of sericite schist heavily impregnated with sulphides and more than 100 feet long. A shaft, sunk on the lens to a depth of 57 feet, is said to have passed out of ore at a depth of about 25 feet. About 300 feet southwest of the shaft, and 50 feet below it, an adit was driven 270 feet into the hill, crosscutting the schists. The face of the adit seems to have reached the mineralized zone, and discovered a stringer of fairly solid sulphides about a foot wide.

Weedon (lots 22a, b, c, d, rge. II, and 22a and b, rge. III, Weedon tp.). This, the only copper mine in Scotstown map-area, has been described by L. D. Adams (2). The following description is from his paper and from reports of the Quebec Department of Mines.

The orebody was discovered by John McDonald in 1908, by sinking pits into a large area of gossan. He sank a shaft for nearly 100 feet; then the property was purchased by the East Canada Smelting Company, which afterwards leased it to the Weedon Mining Company. The ore, after mining, was shipped away and sold, payment being made on the basis of both the sulphur and the copper content. After the first world war, the competition of Louisiana sulphur, and the fall in the price of copper, brought operations to an end in May 1921.

The main orebody was a lens about 570 feet long with a maximum width of about 60 feet. The strike was north 37 degrees east, the dip 45 degrees southeast. The ore was pyrite, with some chalcopyrite and an occasional stringer of galena and sphalerite. Non-metallic minerals included quartz, chlorite, and sericite. The average ore ran 3·62 per cent copper, 0·77 per cent zinc, with a trace of lead and 0·01 ounce of gold and 0·46 ounce of silver a ton. Stoping ceased where the copper content fell below 2·5 per cent.

The ore was a replacement of sericite schist, the metamorphic equivalent of rhyolite or rhyolite tuff; the foot-wall was chlorite schist, the sheared equivalent of andesite. Two veins were found in the chlorite schists paralleling the main vein. One was about 10 feet from the main vein, and consisted of pyrite with low values in copper. The other, 50 feet farther into the foot-wall, had about the same values as the main vein but was too small for mining.

The main shaft was carried to a depth of 965 feet on the dip, or 708 feet vertically. A winze was sunk to a further depth of 205 feet, and a second winze 100 feet more, so that mining was carried to a total depth of 1,270 feet, measured along the dip. The orebody is said to have become smaller with depth, but that this change was partly compensated by its increased content of copper.

Although no other orebodies are known in Scotstown map-area, the intense mineralization of the Weedon thrust and its associated faults by iron carbonate and, in places, by some sulphide suggests that the area might repay prospecting. Geophysical methods would be required, as the thick drift makes ordinary methods impracticable.

CHROMITE

The first discovery of what appeared to be a commercial body of chromite was made in 1845, in lot 23, rge. VII, Bolton tp. Chromite also occurs on lots 13 and 26½ of the same range, on lot 26, rge. VI, and lot 13, rge. IV. Twenty-seven tons of ore containing 49 per cent Cr_2O_3 are said to have been shipped in 1896-7 from a deposit on lot 9, rge. VII. Prospecting during the first world war failed, however, to find any large body of chromite in this township (23).

In Brompton township, a chromite pit about 1,200 feet west of the south end of Little Brompton Lake yielded some 200 tons of ore in 1916-8.

On the west side of Webster Lake, in rge. XII, Orford tp., chromite has been extracted from many pits. Denis (23) reports that during the first world war some 600 tons, ranging from 32 to 60 per cent Cr_2O_3, were taken from two pits on lot 4. During the second war, operations were mainly confined to one pit on cadastral lot 690 (lot 7, approximately), though small amounts were obtained from ten others. Up to July 1942, some 2,000 tons were mined by the Orford Mining Company. The chromic oxide content of the ore averaged 30 to 35 per cent, and the chrome-iron ratio was 3:1 or better. At the close of open-cut operations, the main pit had a maximum depth of 90 feet. The company then agreed, with the financial help of the Dominion Government, to attempt the recovery of more chromite by sinking below the bottom of the pit. A shaft, inclined at an angle of 20 degrees, was sunk a distance of 134 feet, and 206 feet of drifts and crosscuts were run beneath the pit. Although several pods of chromite were encountered, none proved large, and the total recovery of chromite was only 385 tons.

The Orford Mining Company also carried on operations both north and east of Little Brompton Lake, but no information is available as to the results obtained.

The geological features of these deposits have been interestingly described by Y. O. Fortier (48). As elsewhere in the Eastern Townships, the chromite occurs both in disseminated bands an inch or less in thickness, that alternate with bands of serpentine, and in solid masses with sharp boundaries, many of which appear to fill fissures in the serpentine. His observations mark very precisely the time at which the massive chromite bodies were formed. In two instances he found them cut by small dykes of pyroxenite, in another by a vein of chrysotile asbestos, and in still another by a veinlet of antigorite. The relation to pyroxenite shows that the chromite was formed before all the magmatic constituents had solidified. That the bulk of the rock had solidified, however, is shown by the occurrence of the mineral in fissures, some of which have slickensided walls; and by the inclusion in the chromite of olivine crystals, whose presence indicates that crystallization of olivine was well advanced, or complete, before that of chromite became important.

In Richmond map-area, chromite was discovered in 1916 by Douglas B. Sterrett in lots 7 and 8, rge. X, Cleveland tp., and in 1917 he organized the Quebec Asbestos and Chrome Company to operate the property. According to T. C. Denis[1] the deposit was a series of elongated lenses, *en échelon,* ranging in width from a few inches to 18 feet, with a general strike of north 25 degrees east. The first work was a series of open-cuts and open stopes over a length of 1,400 feet, but in 1918 a shaft 196 feet deep was sunk, with levels at 109 and 184 feet. Operations ceased on March 1, 1919.

In 1940 Chromite Limited was organized to resume operations on the Sterrett property. During 1941 only crude ore was mined and marketed, but a concentrator was completed early in 1942. The concentrate is reported to have run 48 per cent Cr_2O_3 or better. The shaft was deepened to 400 feet and lateral work done at lower levels until operations ceased in 1945. No production figures have been published, but they are said to be large. The provincial report for 1943 states that production at times amounted to 1,500 tons a month. That for 1944 states that the production of this mine for that year was 46 per cent of the total production of the province, which would be 12,444 tons.

No observations were made by the writer at this property. When he visited it in 1946 the shaft was filled with water, and the mill and buildings were dismantled.

NICKEL

An attempt was made to mine nickel many years ago in lot 6, rge. XII, Orford tp. The writer has been unable to find the exact date of the operation, but it was probably about 1880, because when the property was visited by C. W. Willimott in 1882 the mine buildings were still standing and in charge of a caretaker. Fortier states that the operators were the

[1] Mining Operations in the province of Quebec, 1917; Rept. of the Dept. of Colonization, Mines, and Fisheries, Quebec, p. 27.

Orford Nickel and Copper Company, which afterwards shifted their operations to Sudbury, eventually becoming the International Nickel Company.

The property was examined by Y. O. Fortier in 1943. According to his description (48), the deposit was a calcite vein some 9 feet wide, situated at the contact of a serpentine sill with siliceous schists. The ore was millerite, the sulphide of nickel, and with it were associated masses of diopside, the chrome garnet uvarovite, and chromite. According to Ells (43), the amount of millerite present was less than 1 per cent of the vein matter, so that operations were soon discontinued.

Fortier cites evidence indicating that the calcite-bearing solutions attacked and dissolved some of the serpentine from one side of the vein fissure, and some silica from the other side, thus obtaining the constituents needed for the formation of diopside. The uvarovite present always has residual cores of chromite, which under the microscope show evidence of solution and replacement. Evidently, therefore, it has been formed through the action of the silicated vein-forming solutions on lumps of chromite present in the serpentine.

ASBESTOS

J. G. Ross' report (66) on Chrysotile Asbestos in Canada contains the following references to the occurrences in Memphremagog and Orford areas:

"A good deal of exploratory work was done in 1906, 1907, and 1908, around Eastman . . . . . . The serpentine belt south of this locality was prospected, but so far no operations have been on a commercial scale.

"In Bolton township, range XI, lot 2, two bands of parallel asbestos stringers, $\frac{1}{8}$ inch up to $\frac{3}{8}$ inch thick, occur in a dark green massive serpentine on the side of a precipitous mountain, not far from Orford Lake. Three prospect pits show two similar occurrences, in one of which fair milling material may be seen.

"In Bolton township, range VII, lot 6 (Parker lot), prior to 1910, the Brome County Asbestos Development Company did some prospecting work and laid the foundations of a mill. In an open cut a much fissured fibrous serpentine can be seen in which asbestos stringers are frequent.

"Bolton township, range VII, lot 10 (Benoit lot). The serpentine formation outcrops west of Trousers Lake in the shape of several parallel, rocky and steep ranges. On the western side of a ridge is an adit 15 feet high, 12 feet wide, and 20 feet deep. The serpentine is of a dark green and grey colour; is harder than the ordinary run of serpentine; and contains, occasionally, some small veins of asbestos.

"Among the other asbestos outcrops in the vicinity is the John Carpenter deposit on cadastral lot 948, north of St. Etienne. About 80 feet of blasting has been done along the brow of a hill, in a dark green serpentine, which, on the surface, is in a crushed and foliated condition, but which becomes massive at a depth of a few feet. The exposed rock exhibits asbestos in a number of veins measuring from $\frac{1}{16}$ inch to $\frac{3}{8}$ inch thick. The asbestos, though in places silky, is to some extent brittle.

"Asbestos has been discovered on cadastral lots 967, 744, 768, and 971; all located west of Lake Nick, near Bolton Centre.

"Near Mansonville, not far from the Vermont boundary, asbestos outcrops occur on a number of properties; but with few exceptions the veins are not of sufficient size to encourage actual development work."

CALCITE

In lot 5, rge. XVI, and lot 11, rge. F, Sherbrooke tp., the Orford Marble Company is quarrying a pink calcite. The locality is just south of a small pond about halfway between the most northerly of the Chain Ponds and Bowker Lake. At this place a sheared zone cuts peridotite, striking about north 67 degrees east and dipping vertically. Where shearing is intense, the width of the zone is about 20 feet, but to the east it passes into a much wider fracture zone. Calcite has been introduced along the fractures, altering the peridotite, or in places the pyroxenite, to a dark red product locally called marble. Thin sections show it to be nearly all calcite. It is being extracted and crushed for making terrazzo, and experiments are in progress for utilizing polished blocks as ornamental stone.

LIMESTONE

A flourishing lime industry has been carried on at Lime Ridge by Dominion Lime, Limited, for some years. According to M. F. Goudge (50) this company commenced operations in 1890 on a quarry about 1¾ miles south-southwest of Lime Ridge; but as the limestone there was not wholly satisfactory they purchased their present plant and property from the Dudswell Lime and Marble Company. The quarry described by Goudge was abandoned in 1938, and a new quarry has been opened about ¼ mile north-northwest of the old. The limestone is a high-calcium blue or white variety averaging 97 to 98 per cent $CaCO_3$, and drill-holes indicate that this material extends to a depth of at least 200 feet. Quicklime of various types is the main product of the company, but crushed limestone, poultry grit, and other products are also sold.

MARBLE

A small quarry was opened for marble on lot 22, rge. VII, Dudswell tp., but apparently the stone was unsound and the project abandoned. The marmorization and its causes have already been discussed on pages 75-76.

FLAGSTONE

More than 30 years ago several quarries lying half a mile or so north-east of the south end of Bishop Pond produced flagstones, tombstones, and foundation stone in considerable quantity from evenly bedded siliceous limestones of the St. Francis group. These workings have been described in detail by Goudge (50) and W. A. Parks (63). All have been idle for years. According to an analysis by Goudge, the rock runs 31·14 per cent silica, 62·79 per cent $CaCO_3$, 3·79 per cent $MgCO_3$, and 1·11 per cent alumina.

SLATE

Slate has been quarried only in the east half of Richmond map-area, and none of the quarries there has been worked for many years. The best known is the New Rockland quarry in lot 23, rge. IV, Melbourne tp., which was worked almost continuously from 1868 to 1921. It produced a dark bluish grey slate of excellent quality. The quarry lies close to the dyke of peridotite that underlies the valley of Salmon Brook, and the dyke may have had a slight effect on the slate, metamorphosing it sufficiently to give it greater strength. Dresser (38) states that close to the contact the slate becomes nearly a hornstone, and is penetrated by dykes and quartz veins. A chemical analysis of this slate, and its character as brought out by various physical tests, are given by Ells (43).

Other slate quarries operated for longer or shorter periods during the last half of last century are the Walton, in lot 22, rge. VI, Melbourne tp.; the Steele or Bedard, in lot 6, rge. XV, Cleveland tp.; a quarry in lot 24, rge. II, Melbourne tp., about which no mention has been found in the literature, and a quarry in lot 4, rge. I, Kingsey tp.

In 1921 a quarry was operating in lot 14, rge. IV, Melbourne tp., for the manufacture of green crushed slate. Operations were discontinued in 1923.

GRANITE

In Scotstown map-area sporadic attempts have been made to quarry granite, apparently without great success. One quarry, on the north side of Moose Pond in lot 22, rge. VII, SW., Stratford tp., was opened in 1928 by the Plamondon Granite Company and has been operated intermittently. The rock is a medium-grained, light grey mica granite.

A second quarry lies about a mile northeast of Scotstown, in lot 40, rge. D, Lingwick tp. It was opened in 1920 by the Scotstown Granite Corporation, succeeded in 1929 by the Scotstown Granite Company. The rock, which had been much used for building stone and paving blocks, is a grey, medium- to coarse-grained biotite granite.

At some time prior to 1900 stone was quarried for bridges on the Canadian Pacific railway from lot 17B, rge. I, Lingwick tp., about 2 miles northeast of Scotstown. The rock is dark and fine grained, presumably through contamination by adjacent sediments; and as the quarry lies in rather low swampy ground it has not since been operated.

The Stanstead granite in the south part of Memphremagog map-area is the site of very extensive quarrying operations described in detail by F. R. Burton (13). Operations there were begun by Jonathan Haselton, who came to the province from Massachusetts about the end of the civil war in the United States, and are still vigorously prosecuted. The stone is a medium-grained biotite-muscovite granite ranging from light grey, almost white, to very dark grey in colour. It is marketed under various trade names, of which the best known is Stanstead Grey. The composition has a considerable range, varying along with the colour. Burton furnished the following figures for percentage composition, by volume, of various types:

Mineral	Stanstead Light	Stanstead Grey	Stanstead Dark	B. and R. Dark	House Hill
Quartz	32·7	20·0	31·4	23·1	23·6
Feldspar	62·3	71·2	58·0	62·9	66·0
Micas, etc	4·1	8·3	10·1	13·8	8·9
Accessories	0·9	0·5	0·6	0·2	1·5

At the time Burton studied the area, thirty-five quarries were in operation, though several were small and equipped only to produce curbstones and paving blocks. A large group were of intermediate size and produced monument stone, curbstone, paving blocks, and occasional stone for small buildings. Two, Stanstead Granite Quarries and Brodie's Limited, were large and equipped to produce stone of any size for building or monument work.

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