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COATICOOK - MALVINA AREA, ELECTORAL DISTRICTS OF STANSTEAD AND COMPTON

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GEOLOGICAL REPORT 69

COATICOOK-MALVINA AREA

ELECTORAL DISTRICTS OF

STANSTEAD AND COMPTON

by

H. C. COOKE

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COATICOOK-MALVINA AREA

ELECTORAL DISTRICTS OF STANSTEAD AND COMPTON

by H.C. Cooke

INTRODUCTION

This report outlines the geology of two adjacent map-areas in the Eastern Townships of the Province of Quebec. The study is essentially a continuation of the writer's work of 1930-1948. During that period the work was done under the direction of the Geological Survey of Canada.

Location and Access

Coaticook map-area lies between longitudes 71°30' and 72°00' West. It is bounded on the south by the State of Vermont and on the north by latitude 45°15'. It is sixteen miles from north to south and twenty-four miles from east to west, or approximately 400 square miles in area. Malvina map-area lies immediately to the east. It includes a rudely triangular sliver of territory lying between Coaticook area (71°30') and the New Hampshire border. Its area is roughly 60 square miles.

Sherbrooke, the largest city of the Townships, is about a dozen miles north of the western half of Coaticook map-area. From this city the area may be reached by automobile or autobus over good roads, and by the Montreal-Portland line of the Canadian National Railways. The eastern shore of lake Massawippi, in the extreme northwestern corner of Coaticook map-area, is followed by the Quebec Central Railway line connecting Sherbrooke with Newport, Vermont. Formerly, a branch of the Canadian Pacific railway followed the valley of Hall stream, but this has been abandoned. Within the area, travel is made easy by a network of roads, most of which have a gravel surface.

Inhabitants

The district is widely but not thickly settled. The lower ground has been cleared for agricultural purposes. Dairy farming is the principal occupation. The chief crops are hay, potatoes, turnips, and grain. The hillier parts of the district, where the soil is poor and access difficult, have been left in timber. These sections have been logged at least once and are now thickly covered with second growth. Pulpwood and also hardwood for lumber and firewood are still produced.

The chief centre of population is Coaticook, a busy industrial village located on Coaticook river, near the middle of Coaticook map-area. Electric power is generated at a large falls on the river here. Other villages, dotted over the area at intervals of five to eight miles, serve as shopping and postal centres.

Field Work and Acknowledgments

The field work leading to the present report was done in 1949. As originally planned only the west half of Coaticook map-area was to be mapped. However, unusually good weather, coupled with the rather monotonous character of the geology, permitted the extension of the mapping. Time proved insufficient, however, to cover Malvina area as thoroughly as Coaticook area; in particular, the northeast corner of Malvina has been only hastily examined. The field work was done on a one-inch to one-mile scale, topographic sheets of the Department of National Defence, Ottawa, being used as base-maps. Efficient assistance was given in the field by Côme Carbonneau, Keith Bell, Félix Couture, and André Laurin, all of whom were of student-assistant rank at the time.

Previous Work

The present area was examined by R.W. Ells (7)[x] as part of his project of mapping the whole Eastern Townships' region in 1885-90. This work was done on a scale of one inch to four miles. F.R. Burton (1), in 1931, described the granite quarries of the area and studied the economic possibilities of the granite of the region in general. H.W. McGerrigle (11), in 1935, reviewed the placer gold occurrences on some of the streams in the area as part of a study of gold placers in the Eastern Townships as a whole.

PHYSICAL FEATURES

The area under discussion is part of the dissected plateau surface which N.M. Fenneman (8) has termed the 'New England Upland'. In Coaticook area its general slope is northwest. Maximum elevations on the sedimentary rocks of the southeast corner of the map-area range from 1,700 to 2,100 feet above sea level, whereas the corresponding elevations in the northwest corner are only about 1,000 feet. Monadnocks of resistant rock rise considerably above the general surface. Thus, Hereford mountain, a mass of granite, attains a height of about 2,750 feet above sea level, and along the International boundary hills of granite and quartzite rise to elevations of 2,400 feet.

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[x]Numbers within brackets refer to the bibliography at the end of the report.

Most of the region drains northward by small streams to St. Francis river, and through it to the St. Lawrence. The largest is Coaticook river, which rises in the United States and flows north through the middle of this map-area. Moe and Salmon rivers in the east, and Tomifobia and Niger rivers in the southwest, are the chief streams of smaller size. The south-eastern part of Coaticook map-area, and nearly all of Malvina map-area, drain southward to Connecticut river, which, in turn, flows southward to empty into the Atlantic ocean at Long Island sound. The chief tributary in the district is Hall stream, a large creek which, over most of its length, is the boundary between Quebec and New Hampshire.

There are few lakes in the area. Part of lake Massawippi occupies the extreme northwest corner of the map-area; Lyster lake, about a mile and a half long, lies in the southwestern corner, and Wallace pond, of similar size, in the southeastern. A few smaller lakes, most of them about a quarter of a mile in diameter, are scattered here and there.

Most of the streams follow the general slope and flow north to northwest. The smaller are consequent streams of postglacial age, as their valleys are poorly developed and are cut mainly in drift. The larger, on the other hand, occupy valleys obviously of preglacial age, cut several hundred feet below the general plateau level. These valleys are graded; that is, falls and steep rapids have disappeared, except in a few places which are described later; valley bottoms are moderately wide and flat, and in them the development of meanders has begun. The true width of these valleys is considerably greater than their apparent width today, because the present sides are kame terraces of sand and gravel, laid down along the sides of the stagnant glaciers that occupied the valleys during the closing stages of glaciation. Tributaries to the larger streams have gullied these deposits and have thus made it possible to estimate their width; Coaticook valley, for example, appears to have a true width, from rock wall to rock wall, between a quarter mile and half a mile more than its present width.

The valleys of Coaticook, Moe, and Salmon rivers are of the type described. Their widths and graded bottoms place them in the stage of topographic development termed late youth or early maturity.

In a few places, however, these valleys have anomalous youthful characteristics. The town of Coaticook, for example, is built at a place where the river passes through a deep, narrow, rock gorge with a considerable falls; at Dixville a similar, though much smaller, gorge is found; and at Moe River village there is a similar gorge on Moe river. Such gorges, which will be discussed in more detail later, are comparatively recent features. At some time during the Pleistocene, the original wide channels of these streams became blocked by drift, thereby forcing the streams to develop the present channels past the obstructions.

The courses of these streams have a further peculiar feature. Moderately mature streams might be expected to show a considerable degree of adjustment to the underlying structure, that is, to be parallel to the strike of the beds over much of their courses, because valleys develop most easily on the less resistant beds. None of these streams, however, is so adjusted; on the contrary, each of them cuts across the general strike of the formations at a large angle; the course of each is relatively straight; and each runs fairly directly down the slope of that part of the upland surface on which it lies. Such stream valleys may have originated in either of two ways. The original streams may have flowed across a peneplain, a surface so low and flat that adjustment to the underlying structure would have been unnecessary; when uplift began, it may have been so gradual that the larger streams were able to maintain their courses. Such streams are termed antecedent. On the other hand, the present folded strata may have been covered by beds of later age but somewhat different structure, to which the drainage was adjusted; if, upon uplift, this cover were removed by erosion, the streams would still maintain the courses thus acquired. Such streams are termed superimposed. So far as the writer has been able to observe, there is little in this area to determine whether these streams are antecedent or superimposed. However, work in other parts of the Eastern Townships (3, 5) appears to indicate that the region is an uplifted peneplain.

Careful consideration was also given to the possibility that these main streams might have been established on fault zones, which would, of course, have been zones of easy erosion, but no evidence to substantiate this could be found. In the bed of Moe river, for example, both in Coaticook map-area and in Sherbrooke map-area to the north, there are reasonably long areas of exposed rock, but the few faults observed cut across, rather than along, the stream bed. Evidence of this sort is about all that can be obtained, for the monotonous character of the sedimentary beds makes it impossible to determine whether they have been displaced where they cross the valleys.

Another interesting feature of the topography is the relative youth of the larger valleys compared to the rather mature dissection of the rest of the plateau. Although the valleys, as noted, are in a stage of late youth of early maturity, the remainder of the surface is a succession of rolling slopes, characteristic of a mature state of dissection. This condition is suggestive of a double rejuvenation; after the first stage a surface approaching maturity was established, and after the second the present valleys were cut, while the general surface became, of course, still more mature. If so, between 1,000 and 2,000 feet of rock must have been removed from the original peneplain surface in developing the present surface.

In contrast to the valleys described, that of Hall stream, in Malvina map-area, slopes southward, against the general slope of the upland. It has the same characteristics as the others — a rather narrow flood-plain and a nearly graded course without falls or steep rapids — indicating that it is in the physiographic stage of late youth or early maturity. But to attain this condition Hall stream has had to cut much deeper into the plateau than the other streams, and the sides of its valley are correspondingly steeper. The average depth of the valley is 800 feet or more, whereas that of Coaticook river, the largest of the others, is only about 400 feet.

About three-quarters of a mile north of the International boundary, outcrops on the west side of Hall stream and fairly close to it are intensely sheared, suggesting that this valley has been developed on a fault. Probably, therefore, this tributary of Connecticut river has extended itself headward on the easily-eroded material of the fault. Connecticut river, at this point, is only 1,100 feet above sea-level, whereas the plateau north of it rises to 2,000 feet in about two miles. A tributary flowing down this steep slope would have high erosive power, and would cut away schistose fault material with rapidity.

The valley of Hall stream having been cut so deeply below the surrounding upland surface, the stream's tributaries flowing down the steep valley sides would also have strong erosive power; hence the stage would appear to be set for piracy of the waters of streams flowing over the higher surface of the plateau. The topography suggests that this process has been active. The tributary joining Hall stream at East Hereford appears to have stolen most of the water of the stream entering Lindsay pond at its southeast end, for between the head of this stream and that of the tributary mentioned is a narrow wind gap, some 400 feet or more in depth. Similar wind gaps, although not so deep, are found in range X, lot 19, and range XI, lot 16, of Hereford township. What appears to be another wind gap is seen in Malvina map-area, crossing ranges IV and V of Auckland township. It is a narrow valley some 300 feet deep between the headwaters of Clifton river and a branch of Hall stream, traversed by the now abandoned line of the Canadian Pacific railway.

The stream entering the northwest end of Wallace pond appears to be similar to Hall stream in its history, although it is much less developed. Established apparently on an important fault, this stream, though small, has already cut its bed nearly to grade and along its lower reaches has developed a narrow flood-plain. Between this stream and another that flows west to Dixville, there is a wind gap some 200 feet deep in range IV, lot 4, Barford township. This suggests that the west-flowing stream once extended either into or completely across the area now drained by the stream flowing into Wallace pond, and that the latter has diverted southward some of the water formerly flowing westward.

Glaciation has modified profoundly most of the original drainage of this region. Although the larger valleys are undoubtedly of preglacial age, the present streams have not yet been able to remove from the valleys all the glacial and glaciofluvial deposits; hence the valleys are in general much narrower than in preglacial time. Most of the smaller streams follow random courses over drift in which they have cut fairly deep, narrow valleys. Where such channels intersect higher parts of the underlying bed-rock surface, falls and rapids commonly are found; between such barriers, the coarser parts of the drift will, of course, remain until the barriers are cut away.

GENERAL GEOLOGY

GENERAL STATEMENT

The work of T.H. Clark (2) and the writer (3) has shown that the rock formations of the Eastern Townships are broken into segments by great through-going faults with general north-northeast strikes. Thus the segments, or fault blocks, are long, comparatively narrow strips trending in the same general direction. Most of these faults were overthrusts from southeast to northwest, and probably movement of many miles was involved. In one case, at least, an overthrust of thirteen miles has been measured (4). Some of the faults were probably initiated during the Taconic orogeny of late Ordovician time, but much of the movement appears to have taken place during the Acadian orogeny of the Devonian period.

The rocks of Coaticook and Malvina map-areas all belong to the easternmost fault slice in Quebec, which the writer has termed (3) the St. Francis slice. It is bounded on the west by the St. Francis overthrust which runs northeast from Fitch bay of lake Memphremagog through Massawippi lake and river, and thence follows St. Francis river and the east side of Stoke ridge. The eastern boundary is not known with certainty, but it may be Hall stream which, as some evidence suggests, may mark an important fault.

About nine-tenths of the area mapped is underlain by beds of the St. Francis group, supposedly of Middle Ordovician age. Near lake

Massawippi these beds are mainly impure limestones, but farther southeast quartzites appear and gradually increase in amount until little or no limestone is found. Thence, for several miles, quartzites with thin interbeds of slate are the only rocks to be seen. East of these, slates and argillites appear in increasing proportions and underlie most of the eastern side of the map-area except the extreme southeast corner, where the quartzite member of the group again appears, apparently beneath the slate member.

The Sherbrooke group of rocks overlies the St. Francis group with great angular unconformity. In this district it consists wholly of argillaceous rocks with some beds of rather fine grit. It underlies a small part of the southeast corner of Coaticook map-area and a larger part of Malvina map-area. The Sherbrooke beds contain no fossils so far as observed, but structural and stratigraphic relations suggest (3) that they are probably of Lower to Middle Silurian age.

Along the International boundary, and on Hereford mountain, bodies of granite have intruded and metamorphosed the rocks of the St. Francis group. A few dykes of granite, almost all in Barnston township, were also found. The granite is petrographically identical with the Stanstead granite a few miles to the west, and, like it, presumably was intruded during the Acadian orogeny.

Dykes of camptonite, rarely more than six feet thick, are common. They weather very rapidly, and for this reason are not exposed in interstream areas. However, there are few places where streams have cleaned the overburden from the rock surface for any considerable distance without exposing one or more of these dykes. Several are to be seen in the Coaticook gorge, and also in the bed of the stream flowing down the side of Coaticook valley in range IV, lot 14, Barford township. The dykes commonly strike east to southeast. They vary a great deal in composition, but in general appear related to the camptonite-essexite rocks of the Monteregian hills, and may be of Tertiary age.

In structure, the St. Francis beds are unusual in that they are generally overturned, most of them facing to the southeast but dipping northwest. The overturning appears to have occurred during the Taconic orogeny. At some later period, presumably during the Acadian orogeny, the overturned beds again underwent folding, although not extreme. The double movement has produced puzzling and apparently contradictory effects.

The structure of the Sherbrooke beds is much simpler. The only disturbance to which they were subjected was the Acadian, which does not seem to have been severe. Commonly, the beds have rather gentle dips, though locally the dips become steep and in a few places even vertical. In no place were overturned dips observed.

TABLE OF FORMATIONS

Quaternary		Ground moraine, fluvio-glacial sands and gravels, stream deposits, etc.
	Unconformity	
Tertiary ?	Intrusive contact	Camptonite dykes
Devonian	Acadian orogeny: Intrusive contact	Folding, intense faulting Granite
Silurian ?	Sherbrooke group	Fine grit, argillite, slate
	Unconformity	
Ordovician	Taconic orogeny:	Intense folding, faulting
	St. Francis group: Slate member	Argillite, slate, minor quartzite
	Quartzite member	Quartzites of varying purity, minor slate and limestone
	Limestone member	Impure limestone, minor quartzite and slate

ORDOVICIAN

St. Francis Group

The rocks of the St. Francis group underlie nearly all of Coaticook map-area and two thirds of Malvina map-area. The group appears to be very thick, but actual measurements have not been possible in view of the sharp folding and absence of good transverse sections. The succession is from oldest to youngest going from west to east through the three general subdivisions of impure limestones, impure quartzites, and slates. The limestones are restricted to the western five to six miles of the area mapped, and a roughly equal area on the eastern side is occupied mainly by dark slates. The area between (averaging fourteen miles wide) is underlain by the phase or subdivision characterized by impure quartzite but with associated greywacke, siltstone, and minor amounts of slate. The three subdivisions are shown on the accompanying map. However, as their lithologies are gradational, the positions of the separating lines must be classed as arbitrary and subject to personal interpretation.

Lithology

Limestones.- The limestones are fairly dark grey rocks which are everywhere rather poorly exposed, presumably because they are both soft and easily soluble in rainwater. Where outcrops are found, they are usually covered with a brown crust a quarter of an inch to one inch thick, about the consistency of hard clay. This is the residue of insoluble impurities remaining after the calcium carbonate was dissolved by weathering.

The impurities are mostly small sand grains with minor amounts of other materials. The proportions of impurities to calcium carbonate vary greatly. Some of the beds approach quartzite in composition and even the purest limestones of the group are not much more than half carbonate. Seven analyses of limestone from this formation in Vermont are given by Doll (6, p. 24), and show a $CaCO_3$ content ranging from 20.99 to 61.1 per cent. Analyses of limestones from quarries opened many years ago near Ayers Cliff and North Hatley are given by M.F. Goudge (9) as follows:

Analyses of Limestone

	Ayers Cliff	North Hatley
SiO_2	40.36 per cent	43.06 per cent
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 "

Analyst: C.L. O'Brian

Most of the limestone beds are finely crystalline due to flowage during folding. In places, the flow lines, brought out by weathering, are oriented like the cleavage of slates; in other places they simulate cross-bedding. In still other places the flow lines are arranged in complex whorls and swirls, suggesting large movements of the soft limestone. Flow lines are commonly visible only in creek beds, where erosion has formed clean, smooth surfaces of considerable size.

Quartzites.- The rocks thus termed are hard and grey to dark grey in colour. The beds range in thickness from a fraction of an inch to several feet, but beds about two feet thick are most common. Where not interbedded with much limestone or slate they are well exposed and form many of the higher hills of the district.

The original constituents appear to have been quartz, feldspar, mafic minerals, and, presumably, clay minerals. A few beds contain as much as 75 to 80 per cent of quartz, but more commonly the proportion is smaller, down to a few scattered grains. These less pure varieties were commonly called greywackes. Thin sections show that the quartzites have been much recrystallized. Original boundaries of quartz grains have entirely disappeared, very largely by crushing. Much, if not all, of the feldspar appears to be secondary oligoclase-albite. Most of the mafic minerals have become biotite and chlorite; and muscovite, present in most thin sections, is probably secondary after feldspar and clay minerals.

In spite of the recrystallization, the bedding has not been destroyed, and on clean surfaces cross-bedding can occasionally be observed. Few of the beds have any cleavage or directed texture. In the southern part of the map-area, near bodies of granite, many of the finer-grained and more basic beds contain small metacrysts of biotite.

Slate.- The slates of the district are all dark grey to black, with a well-developed slaty cleavage. Beds range in thickness from a fraction of an inch to five inches, but thicknesses of an inch or two are most common.

More or less slate is present throughout the district, interbedded with limestones or with quartzites. The top of the succession consists almost wholly of black slate interbedded with a more massive and harder siliceous argillite or siltstone. The slate-argillite band, which is only about a mile wide at Wallace pond, widens on the northeast to four miles or more. This widening and the fairly consistent plunge to the northeast which was observed in the field together suggest that the structure of the slate band is broadly synclinal. If this is true, the quartzites to the east and west must lie beneath the slates. In fact, it was directly observed in the field that the quartzites west of the slate band face east, but on the quartzites east of the slate band very few reliable structural observations could be obtained.

Structure

Folding.- The structure of the St. Francis rocks is determinable on nearly every outcrop of any size, usually by cleavage-bedding relations, less commonly by cross-bedding, and in a few places by the presence of rill marks. Drag folds are also very common, and support the conclusions drawn from the other data. In many places beds of impure limestone have developed flow textures that parallel the cleavage of the slaty beds, and thus can be used for structure determination.

These observations indicate that the St. Francis beds are almost everywhere overturned. Throughout most of Coaticook map-area they strike northeast to north-northeast and dip northwest at angles ranging from 55 degrees to near-vertical, although in a few places dips are as low as 20 degrees. The tops of almost all beds face southeast. This extraordinary structure is maintained from Massawippi lake to the slate formation northeast of Wallace pond, a distance of more than 20 miles at right angles to the strike. Over at least fourteen miles of this distance — the width of the quartzite member — exposures are sufficiently numerous to render it certain that the structure is monoclinal and that no reversals of dip or top are present.

Within the westernmost six miles of limestones, one or two places were found where, over short distances, the beds face northwest, and it is therefore possible that other northwest-facing beds are hidden by drift. Thus, beds on Hall brook face west and dip 35 degrees east. About half a mile north of Lyster lake, all the beds dip about 75 degrees northwest, but face, successively, southeast, northwest, and southeast again, within a distance across the strike of about half a mile. Thus there are here two isoclinal folds, a syncline followed by an anticline, each about a quarter of a mile across. At both places the reversals are short, and the structures may be classed as large drag folds. Even if others are present — and it is unlikely that many are, as structure determinations are reasonably numerous — they would not greatly decrease the apparent thickness of the limestone member.

In the slate member northeast of Wallace pond, outcrops are widely spaced and reliable determinations of structure are difficult to obtain. Those that were obtained suggest that the slate lies in rather closely spaced, tight folds, so that probably its thickness is not great though it covers several miles laterally.

The preceding descriptions have brought out the following points:

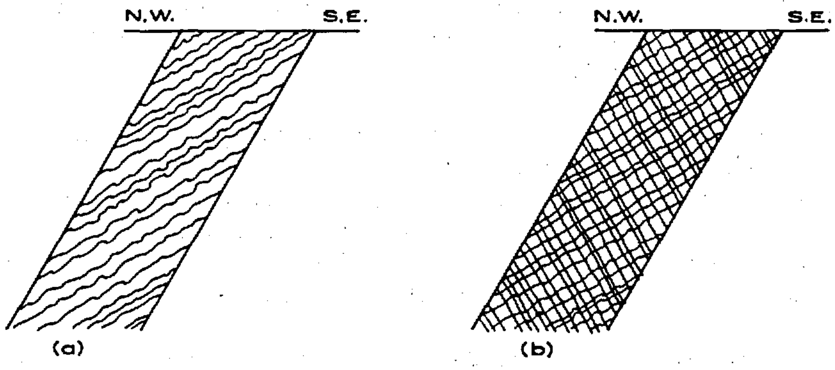
(1) That across a distance of more than twenty miles a gradual change takes place in the composition of the sedimentary rocks. On the northeast, the rock is a siliceous limestone, which passes gradually, by decrease in the number of limy beds, into impure quartzites with minor amounts of slate; and these, in turn, into almost pure slate and less slaty argillite.

(2) Both the limestones with their high content of fine sand, and the quartzites with their cross-bedding, indicate deposition in fairly shoal water. Rill mark suggests that sub-aerial conditions prevailed at times. Maintenance of these conditions throughout the deposition of several thousand feet of sediments indicates that the sea bottom was sinking about as fast as accumulation went on. Such a condition points to accumulation in a geosyncline.

(3) The outcrop width of the sedimentary beds, from lake Massawippi to the centre of the syncline northeast of Wallace pond, is more than twenty miles. The quartzites, so far as could be observed, are not repeated by folding, and if there is no repetition by faulting an average dip of 60 degrees northwest would indicate a thickness for them of about twelve miles; an average dip of 50 degrees, eleven miles. Reversals have been noted in the limestone member, and if it be assumed that they have increased the width of the band by one-half, that is, from four miles to six, the thickness of limestone is still three miles or more. No estimate of the thickness of the slate member is possible, but even without it a total thickness of more than 14 miles of sediments is indicated.

Thicknesses such as these are unusual. Measurements in other

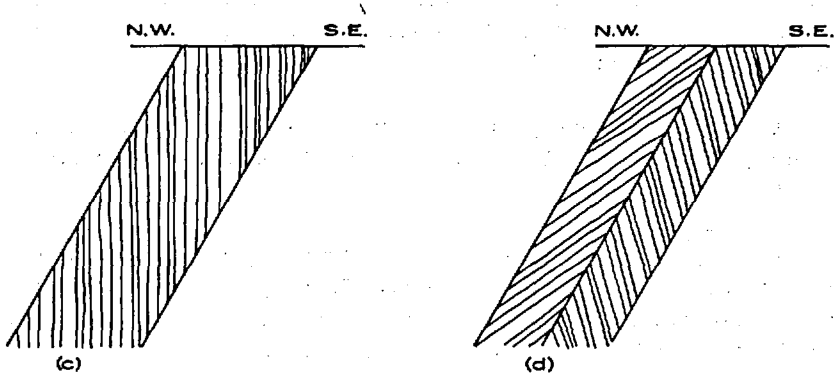
FIGURE I



Cross-sections illustrating disturbances of older cleavage (dipping northwest) by Acadian movement.

(a) Corrugation of older cleavage into minute drag folds.

(b) Development of a coarse fracture cleavage making a large angle with the bedding. In most places the older cleavage is destroyed, but in some, as in diagram, it can still be recognized.



D.M.Q. 1955 No. 1103

(c) New flow cleavage developed.

(d) New flow cleavage developed in right half of bed while old flow cleavage still remains in left half.

geosynclines have indicated that, when thicknesses of eight miles or so have accumulated, folding takes place and the region is raised above sea level. It seems probable, therefore, that strike faulting must have caused repetition of beds, though no evidence for it, topographic or otherwise, has been found.

Acadian Folding.- Many puzzling features characterize the structure of these map-areas. In the course of the field work it was established that these are the result of a second folding of the previously overturned beds. The earlier, and principal, folding took place during the Taconic orogeny toward the end of the Ordovician period; the later folding is ascribed to the Acadian movement of the Devonian.

One result of the second folding was the formation of drag folds that indicate relative uplift on the northwest. These folds have amplitudes ranging from a few feet to forty feet, and usually they plunge northeast at moderately low angles. As the movement on these folds was the exact opposite of those caused by the earlier folding — in which the southeast side moved up — they have clearly been formed after the strata assumed their present positions. One drag fold of this type was found in the creek bottom near the road junction, range IX, lot line 26-27, Barnston township. A much larger one lies east of the road running north through lot 25, range VIII, Barnston township. Quite probably many of the very low northwesterly dips shown on the accompanying map are the result of large drag movements of this type.

Drag folds of the above type are relatively few. Much more widespread and important is the disturbance of the earlier cleavage. Several effects have been produced, some or all of which may be found within a single area of outcrop:

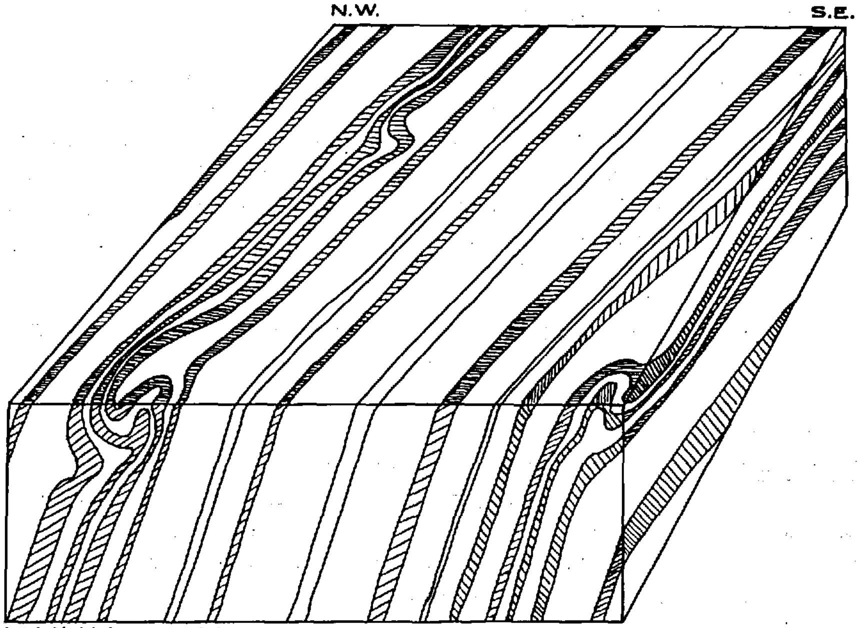
(1) The older cleavage may be corrugated into a multitude of minute drag folds (Figure 1a). Closely associated with such corrugation in many instances is

(2) Development of a rather coarse fracture cleavage crossing the earlier cleavage, as shown in Figure 1b. In some places, the later fracture cleavage has completely destroyed the earlier flow cleavage; in others, both may still be seen, as in the Figure.

(3) Development of a new flow cleavage (Figure 1c). This usually intersects the bedding at a rather small angle, whereas the fracture cleavage intersects it at a large angle, about 70 degrees.

It is quite common to find the older and both of the newer cleavages not only in the same area of outcrop, but even in adjoining beds.

FIGURE 11



Drag fold and cleavage relations as actually observed in the same outcrop.

Beds lettered a, a, a, are slate beds dipping northwest but displaying older cleavage indicating that they face southeast. Some of them are involved in a drag fold formed by the same movement. Beds b, b, b, display direction of cleavage reversed by a later uplift of the northwest, and are involved in a drag fold caused by movement of the same type. Bed c is involved in the same drag fold, but retains the older cleavage.

It is also not uncommon to find, within a single bed, the old cleavage abruptly reversed in a band parallel with the bedding, as illustrated in Figure 1d.

An effort has been made (Figure 2) to illustrate the observed drag and cleavage relations as they may be seen on the vertical and horizontal planes, respectively.

It is obvious, in a district where relationships are so contradictory, that the utmost care must be used if structures are to be interpreted correctly; and it is not improbable that some of the observations noted on the accompanying maps are incorrect. However, it was soon recognized that the presence of corrugated cleavage and large-angle cleavage are indicators of later disturbances of earlier structures, and where these were found especial care was exercised.

Disturbances in the cleavage were seen only in the slates. Cleavages in harder beds were not affected.

Summary of structural peculiarities

Areal Changes.- The area underlain by overturned strata extends west from Coaticook map-area into Memphremagog map-area, almost to the St. Francis fault. It leaves the vicinity of the fault near the south end of lake Massawippi, but occupies the southeast part of Sherbrooke map-area (3, Figure 2, p. 32) and finally ends in Scotstown map-area about a mile and a half from the southern border. Beyond these limits, the St. Francis beds have normal dips, commonly steep.

Near the St. Francis fault the dips of the strata are mostly vertical or near-vertical. To the southeast they become progressively more and more overturned until, near the east side of Coaticook map-area, the overturned dips average about 50 degrees northwest.

Faulting

Dixville fault.- In addition to the St. Francis fault, which has been described in an earlier publication (3), and the numerous small strike faults, the existence of which is inferred, a large fault has been recognized in the southern part of Coaticook map-area. It passes about three-quarters of a mile south of Dixville, and has been traced about four miles westward, where it passes under drift. It was also traced some four and a half miles east of Coaticook river, to the creek entering the northwest end of Wallace pond. The deep, steep-sided valley of the creek suggests that the fault swings southeastward along the valley and through Wallace pond, though actually none of the few outcrops found in the creek displays any shearing.

The fault is easily recognized by the fact that south of it the quartzite beds strike a few degrees east or west of north, dip steeply east, but face west, whereas north of it the beds have normal north-northeast strikes, dip steeply west, and face east. It would seem that the beds south of the fault must have been shifted westward, relative to those on the north, a distance of at least ten miles, so that the beds south of the fault correspond to those lying east of the slate in the central part of the syncline north and northeast of the fault. Throughout its course this fault is marked by a prominent valley, in most places some 200 feet deep.

Hall Stream Fault.- In the extreme southeast corner of Coaticook map-area, outcrops along the highway, about three-quarters of a mile north of Hereford Station, and fairly close to Hall stream, show evidence of faulting. Some of the rocks were impure quartzites or greywackes that have been converted by intense shearing to mica schists in which all trace of bedding has been destroyed. The schistosity strikes N.25°E. and dips fairly steeply northwest. Beds of black slate found a short distance south of the greywackes are intensely contorted, more so than anywhere else in the district; their cleavage planes give the impression that the rocks were broken into fragments which were then individually rotated before pressure caused re-cementation. It is believed that these features could only be induced by a strong fault following the valley of Hall stream.

In the creek bed about three-quarters of a mile to the north-northwest, wide, closely spaced shear zones that may be branches of this fault were found. They strike N.25°W. and dip steeply west. They cut hard, more or less impure quartzites that strike a little east of north, dip about 70 degrees east, and face west; some of the beds may be very thick for, in places, no bedding could be discerned over considerable widths. In the shear zones, the quartzites have been converted to a mica schist containing plate-like, unsheared fragments of quartzite. Near the surface, the schist is much rotted, almost to clay in places.

Small Faults.- Only a few small faults were observed. In Coaticook gorge, at Coaticook, three were seen, two of which strike about north, have near-vertical dips, and show downward movement of the east side. The third strikes northwest, dips 60 degrees southwest, and beds crossing it are displaced laterally about 25 feet, the northeast side to the northwest. In Moe River canyon, north of Moe River village, the sedimentary beds are strongly drag folded, and the drag fold is broken at the crest by a fault striking about N.30°E. and dipping 25 degrees northwest. This fault is obviously due to fracturing of the beds during drag folding, and is therefore of Taconic age. In the creek bed in range X, lot 15, Barford township, a fault that strikes due east and seems to dip about 45 degrees south is evidenced by a zone, some fifteen feet wide, of weathered, limonitic breccia. From the bending of beds bordering the fault it is concluded that the south side moved west and up, so that the fault is a thrust.

Correlation

The St. Francis group, on the Vermont side of the International boundary, includes what was formerly known as the Waits River formation. Below the Waits River are two formations not found on the Canadian side, the Northfield slate and the Shaw Mountain formation. The Northfield slate is mainly dark grey to black slate with occasional interbeds of sandy or calcareous materials. Locally, pebbles are found near the base. Its contact with the Waits River formation is a thrust fault (6, p. 20). The Shaw Mountain, which underlies the Northfield unconformably, is said to consist of tuffs and crystalline limestones, commonly rather strongly sheared. The base is a rather thick conglomerate, made up mainly of quartz pebbles, with a few slaty and other types, in a schistose sericitic matrix. These formations appear to have been faulted off where they encounter the southern continuation of the Saint Francis-Fitch Bay fault.

The area in Vermont lying south of the east half of Memphremagog map-area (Canada) has been studied in detail by Dr. Charles G. Doll, State Geologist of Vermont (6). In that area he subdivided the Waits River into three new formations, named (by him) the Ayers Cliff at the base, followed successively by the Barton River and Westmore formations. The Ayers Cliff, so called because particularly well exposed at Ayers Cliff at the south end of lake Massawippi, is composed almost entirely of impure limestones that range in their content of calcium carbonate from about 20 to 60 per cent. A few beds of dark grey slate and phyllite are also present, becoming more numerous toward the top of the formation.

The Barton River formation is described by Doll as separated from the Ayers Cliff by the Irasburg conglomerate, which is discussed in detail on a subsequent page. Otherwise, the lower part of the formation consists of about 1,600 feet of (dominantly) slates and phyllites intercalated with lesser amounts of limestones and calcareous schists. The middle and upper parts of the formation are more calcareous, but toward the top there is a pronounced increase in siliceous and argillaceous types.

The Westmore formation, in the area studied by Doll, is described as largely phyllites and schists, with smaller amounts of limestones and quartzites. The phyllites of this formation appear to be light-coloured, recrystallized, impure quartzites, whereas those of the Barton River are described as darker rocks, distinguishable with difficulty from slates.

The lithological differences between these three formations, it must be realized, are rather delicate. In fact, Dr. Doll has told the writer that he appreciated them himself only after some years of study of the area. Had Doll's work been published before the mapping of Coaticook area, it might have been possible to carry his boundaries northeastward into Canada, in spite of the few and widely separated outcrops of the limestone-bearing formations. Under the existing circumstances, however, no such subdivision has been attempted; the only subdivision made is that between parts in which limestone beds are moderately numerous and that in which they are rare or completely lacking. Obviously, this division must take place well above the base of the Westmore formation. It does not appear to have been noted by Doll in any part of the area studied by him. The area mapped by the writer as containing limestone beds therefore includes all of Doll's Ayers Cliff and Barton River formations, together with at least a considerable part of his Westmore formation. If the Westmore is required, as defined by Doll, to contain limestone beds, then the quartzite-limestone boundary shown by the writer would mark the top of that formation. In that case, the writer's quartzite and upper slate subdivisions should probably be given new names.

Age

The St. Francis group underlies the Sherbrooke group with great angular unconformity. As shown in an earlier publication (3), the Sherbrooke group appears to be Lower to Middle Silurian in age. The St. Francis group must therefore be older than the Taconic orogeny that preceded deposition of the Sherbrooke, and is therefore considered to be Ordovician in age.

The St. Francis group was first recognized and described by T.H. Clark (5) in Disraeli map-area, more than 60 miles to the northeast. There, a few graptolites were found indicating the age of the beds in which they lie to be Normanskill (Middle Ordovician). The formation has since been traced southwest along its strike to the International boundary. From this study it has become better known, and its great thickness is now recognized. Apparently, deposition continued until ended by the Taconic orogeny, and the thickness of the series suggests that it was probably forming during much of the Ordovician period prior to that orogeny.

These conclusions differ sharply from those drawn by Doll from his recent study of the neighbouring area of Vermont. A main point of difference is the weight placed by him on the Irasburg conglomerate, which was first described by Richardson in 1906. The type locality of this conglomerate is south of Irasburg village, Vermont. Doll (6) places this conglomerate at the base of the Barton River formation, and regards it as proof of unconformity between the Barton River and Ayers Cliff formations. Accordingly, he considers the Barton River to be of Silurian age. In a mottled limestone stratum in his Westmore formation, which corresponds to the quartzite member of the St. Francis group, he found "fossils that have been identified as cystoid and crinoid calyces whose structural features indicate genera belonging to the Middle Silurian or possibly the Lower Devonian" (6, p. 34). Doll adds, however, "there is some disagreement amomg authorities concerning the true nature of the specimens". Nevertheless, he classifies the Westmore as Silurian or possibly Lower Devonian, partly because of the fossils, partly because it overlies the Barton River, which he has also classified as Silurian because of the presence of the Irasburg conglomerate. It is pertinent, therefore, to examine in some detail the facts on which his conclusions are based.

The Irasburg conglomerate is described by Doll as having a limestone matrix which strongly resembles the limestones of the underlying Ayers Cliff formation. In it, pebbles and boulders are numerous in some places but in other places they are sparsely distributed. "Indeed, in places, only single cobbles betray the presence of the conglomerate" (6, p. 32). The pebbles and boulders are well rounded to sub-angular, and consist of granite, andesite, diorite, diabase, serpentine, chlorite and sericite schists, sericitic marble, and micaceous quartzite, with a few of dark crystalline limestone, black mudstone, and phyllite. The largest boulder recorded is nine feet long and three feet wide.

These facts are most suggestive. Limestone is commonly considered to have been deposited in warm, fairly clear seas. This limestone, as analyses show, contains some mud and very fine sand, and hence the water in which it was deposited was stirred by currents, gentle indeed but strong enough to transport the fine-grained sediment; thus, it was probably only a few hundred feet deep.

How could boulders, one of which weighs several tons, have been brought into an environment of this sort? It may be pointed out that the boulders have been brought from a great distance, as they cannot be matched in any of the St. Francis beds; their haphazard distribution is also very odd. Only one agent could bring in boulders from a distance and drop them here and there on the bottom of a warm, moderately deep sea; that agent is floating ice. Greenland icebergs melting in the warm waters of the Gulf Stream are undoubtedly making deposits of exactly the same sort today.

A conglomerate with such an origin is, however, merely an accident of nature; it implies no break whatever in the normal processes of sedimentation, and cannot therefore be held to indicate unconformity. No other evidence suggesting a break between the Ayers Cliff and Barton River formations has been found, and no reason therefore exists for assuming the Barton River to be later than Ordovician.

The fossils reported to have been found in the Westmore formation fall into a different category. The writer has seen them, though not the locality where they were found, and they certainly appear to be fossils. If the rock from which they were taken is truly a part of the Westmore formation, and if their characteristics have been correctly determined as those of Silurian forms, such evidence is, of course, final. All the general structural evidence, however, suggests that an error exists somewhere. From Thetford to the International boundary, a great angular unconformity separates the rocks of Ordovician age from those of Silurian and Devonian age. Below the unconformity the Ordovician rocks have been intensely deformed by the Taconic orogeny; north of Scotstown they have near-vertical dips everywhere, and south of that place they are overturned to the southeast. In contrast, the rocks above the unconformity are much less deformed; large parts have low dips and their fossils have not been destroyed, though in places they are considerably deformed. Outside of the parts with low dips, only in rare instances do the dips exceed sixty degrees, and they are commonly less, except in the Lake Memphremagog area, where they are nearly vertical.

All the St. Francis beds, including Doll's Westmore formation, form a sequence in which no visible break appears, and all have suffered the same intense deformation, with overturning to the southeast. They are overlain by much less deformed rocks which the writer has identified as belonging to the Sherbrooke group. It therefore seems impossible that any beds lying below this great angular unconformity can be other than Ordovician; and the writer would suggest that the fossiliferous rocks found by Doll, if Silurian, are either an erosion remnant or an infaulted block of one of the younger sedimentary formations.[x]

LOWER-MIDDLE SILURIAN (?)

Sherbrooke Group

Rocks of the Sherbrooke group underlie only some four square miles in the extreme southeast corner of Coaticook map-area, together with possibly one-third of the Canadian territory in Malvina map-area. They consist largely of argillite in beds ranging from three inches to a foot or even more in thickness, with occasional beds of the characteristic grit of the group. No conglomerates or coarse grits were found. Most of the argillite has been deformed sufficiently to develop a slaty cleavage, but where

[x]See Appendix, page 35.

bedding has remained horizontal or nearly so cleavage is either slightly developed or not at all.

Petrography

The grits are grey rocks characterized by the presence of numerous white or light grey platy chips. The microscope shows them to contain fairly numerous fragments of quartz and smaller grains of feldspar more or less altered to calcite. The material of the platy chips is extremely fine-grained and appears to be largely feldspar with some secondary chlorite. It may have been an acidic lava such as rhyolite or trachyte.

In the map-areas to the west and north, the Sherbrooke grits, in many places, become coarse enough to be small-pebble conglomerates, with fragments as large as peas. No beds of the sort were found in the map-areas here described; the largest fragments are rarely more than 1 mm. in diameter.

No special study was given to the argillites and slates. They are dark grey rocks weathering to brownish tints.

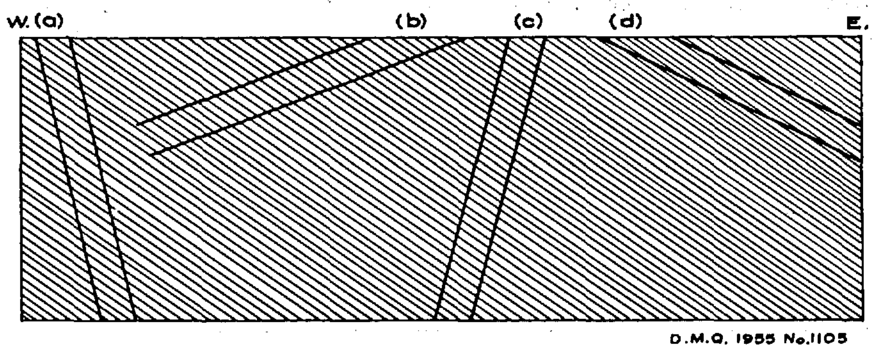
Structure

Throughout much of the area these rocks have been tilted so that they now have dips of 45 to 60 degrees, and locally, over short distances, the dips are nearly vertical. In some places, as along the road north and south of Paquette, Malvina map-area, the beds are nearly horizontal or have low dips. In some places, however, the beds are apt to display sharp bends, with the dip changing abruptly from low to steep and back again within a few feet. But nowhere were beds found overturned — a feature useful in distinguishing slaty beds of this group from slaty beds of the St. Francis group.

In Malvina map-area, between East Hereford and Paquette, outcrops are reasonably continuous in some sections, and structural study there shows that the folds are closely spaced; in one place there is only about 700 feet between the axis of one syncline and that of the next; in another, the distance is only a quarter of a mile. It would seem, therefore, that the formation resembles a flat sheet that has been somewhat wrinkled. Such a conception would appear to imply that, during folding, the Sherbrooke strata slid laterally along their plane of contact with the St. Francis group.

In addition to the cleavage that normally is related to the folding,

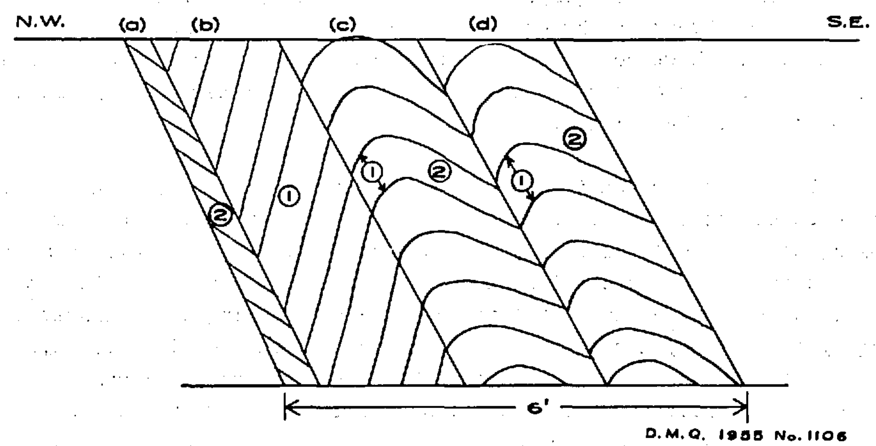
FIGURE III



Cross-section showing late, east-dipping regional cleavage observed in Malvina and east part of Coaticook map-areas.

This illustrates how it may lead to erroneous determination of structure. Beds like a above, dipping east more steeply than the cleavage, or like b, dipping west at angles less than 45 degrees, may be determined as overturned, whereas other criteria indicate that they are not. No error, however, arises, in the case of beds like c and d.

FIGURE IV



Cross-section showing relations observed on southeast side of small anticline in Sherbrooke beds, Hereford township, range VI.

Bed a is slate; b, c, d, are thick beds of quartzite, in which the folding developed a normal fracture cleavage (1) above. In beds c and d this has been bent by later movement into positions (2), as indicated. In slate bed a, a flow cleavage (3) has been developed by the later movement.

a later cleavage has been formed in these rocks, striking approximately north and dipping about 45 degrees to the east. Where this is well developed, if care is not taken wrong determinations of structure may be made. Figure 3 shows how this may occur if the strata are dipping east at an angle steeper than the later cleavage, or west at angles less than 45 degrees. At such places, strata may be incorrectly determined as overturned.

In Malvina map-area, a mile and three-eighths northeast of East Hereford, a farm road runs south from the highway for nearly half a mile. On the hillside east of the road the Sherbrooke beds are bent into an anticline followed by a syncline, with a distance of about 650 feet between their axes. On the east side of the anticline the relations shown in Figure 4 were sketched. Three of the beds are impure quartzite and one is slate. In the quartzite beds a fracture cleavage has developed, and in two of them this is bent by the later movement so as to give rise to a pseudo-dragfold. In the slate bed, a flow cleavage has developed, making it look as if the bed is overturned. The beds at this point strike N.30°E., dip 65 degrees east, and face east.

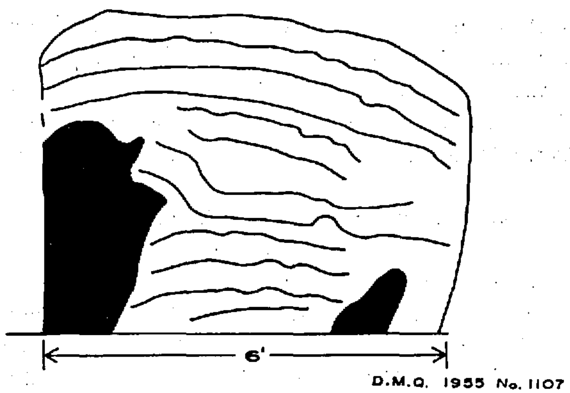
It will be recalled that the St. Francis beds to the west have also been affected by an uplift on the west which formed a few drag folds in the overturned strata, corrugated the old cleavage, and in places even destroyed it entirely with formation of a new cleavage. The movement was ascribed to the Acadian orogeny. The occurrence of similar disturbances in the folded Sherbrooke rocks enables one to date the movement with more certainty. The Sherbrooke beds were folded during the Acadian disturbance and, from what has been said, it is clear that the later cleavage must have developed after the folding.

In an earlier publication (3) it was shown that, after the Silurian and Devonian rocks of Memphremagog map-area had been folded and partially eroded, the Bolton lavas were poured out on them, and, in their turn, were somewhat folded. No good evidence from which to date their folding is known, but the writer suggested it may have been during the Pennsylvanian orogeny or possibly during the closing stages of the Acadian orogeny. Be that as it may, the existence in both Memphremagog and Coaticook map-areas of a movement after the Silurian and Devonian rocks were folded certainly suggests that the age of the movement was probably the same in both places.

Relations to St. Francis Group

No sharp contact between the Sherbrooke and St. Francis rocks such as occurs in adjoining map-areas (3) was found in this district, and hence relations must be inferred from the general areal relations and structural

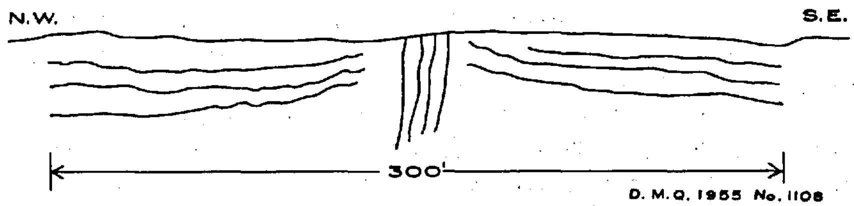
FIGURE V



Cross-section of observed relations between Sherbrooke rusty grit and St. Francis argillitic quartzite, Hereford township, range II, lot 6.

Masses of St. Francis rock in solid black, Sherbrooke grit lined. The irregularity of the lines is much greater in the outcrop than is indicated in the sketch.

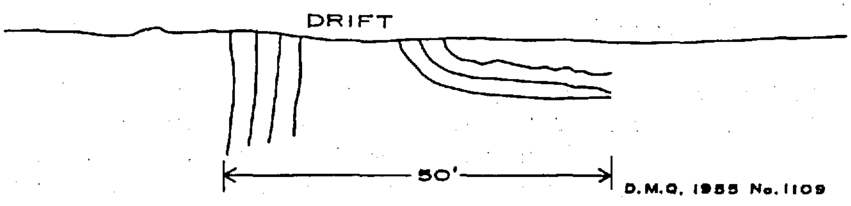
FIGURE VI



Cross-section showing observed relations about two and a half miles north-northeast of Paquette, Malvina map-area.

The nearly horizontal beds are Sherbrooke argillites. These appear to arch over a spine of vertically-dipping slates, which may therefore belong to the St. Francis group.

FIGURE VII



Cross-section to illustrate sharp bending of Sherbrooke beds (on right) near contact with vertically-dipping St. Francis beds (left).

differences. It is obvious, for example, from the manner in which the contact between the two groups strikes, in places, at a large angle to the strike of the bedding, that the contact must be either unconformable or faulted; the relations previously determined are such as to indicate an unconformity, although faulting is not excluded as an explanation.

About the middle of range II, Hereford township, outcrops found about three-quarters of a mile west of the east boundary of Coaticook map-area are St. Francis quartzites, striking N.10°E., dipping vertically, and facing west. Overlying these for a distance of thirty or forty feet are some rusty grits, without any definite structure, but which, from observations next described, appear to be the basal beds of the Sherbrooke group. Some bands of the grit are much rustier than others, and, if these differences are due to original bedding, they indicate large angular unconformity, as the rustier bands dip west at low angles, about 15 degrees.

About half a mile east-northeast of the above occurrences is an isolated, almost circular mass of Sherbrooke rocks about 500 feet in diameter. On the east side, a farm path leads north to the base of the hill. On the hillside, outcrops of St. Francis quartzites strike N.10°E., dip vertically, and face west. About half way up the hill such quartzites are found on the path, and five or six feet away, uphill, rusty Sherbrooke grits appear. Although the actual contact was not seen, Figure 5, sketched from a face about six feet long, appears to illustrate contact relations. The masses in solid black in the Figure are argillitic quartzite, similar to many St. Francis types though not to the quartzites immediately below. The remainder of the face consists of Sherbrooke beds — rusty, loose-textured grit, containing numerous thin, brownish bands, quite irregular in shape and outlines. The lines in the diagram are an attempt to represent these bands, though the actual irregularity is much greater than is indicated in the sketch. Some of the bands display breaks such as are often seen in sand beds in a gravel pit.

It seems quite clear, from the proximity of the Sherbrooke beds, that the loose-textured grits must lie at the base of the group. The masses of argillitic quartzite, the writer considers, were probably irregular blocks lying on the contact surface when the grits were deposited.

In Hereford township, range VIII, about three-quarters of a mile east of the west boundary of Malvina map-area, a bay-like mass of St. Francis beds is almost surrounded by Sherbrooke beds. The St. Francis strata are thin-bedded quartzites and slates that strike N.20°E., dip 80 degrees west, and face east. About 500 feet to the south, on strike, thick-bedded greywackes appear, dipping north at very low angles. Lithologically, these are typical Sherbrooke beds, and the conclusion seems unavoidable that they overlie the St. Francis with large angular unconformity.

In Malvina map-area, just south of the Hereford-Auckland boundary line, and on the east side of the road between Malvina and Paquette, the Sherbrooke rocks are well exposed. The rocks are greywackes in beds up to two feet thick; the bedding is generally nearly horizontal but displays sharp bends in which the dips, for a few feet, are steep or even vertical. Through the centre of the area runs a spine of vertically-dipping beds as illustrated in cross-section in Figure 6. It is difficult to avoid the conclusion that the vertically-dipping beds belong to the St. Francis group, but unfortunately the contact between the Sherbrooke beds and those with vertical dips is hidden.

Just north of the Hereford-Auckland line and on the road mentioned above, indubitable St. Francis beds are exposed. These are thin-bedded slates and quartzites that strike N.30°E., dip vertically, and face east. The contact between them and Sherbrooke beds is in a low depression about 30 feet wide, striking northeast. Southeast of this depression the flat Sherbrooke beds are bent sharply upward as if they had been downfaulted against the St. Francis (Figure 7). On the west side of the road, scattered outcrops of the Sherbrooke beds occur between others of the steep-dipping St. Francis beds. The relations are such as to indicate that the Sherbrooke patches are remnants lying on an old erosion surface.

Along range-line V-VI of Clifton township, about a mile south of the north boundary and six miles west of the east boundary of Coaticook map-area, three outcrops of Sherbrooke rocks were found; these appear to belong to a single mass. The beds here have low dips and are relatively undisturbed, whereas the nearest outcrops of St. Francis rocks (less than half a mile to the north and south) are overturned, dipping steeply northwest and facing southeast.

While searching for evidence of faulting along Hall stream, a brief trip was made along the east side of the valley. Since the topographic map was surveyed, a good road has been built from Beecher Falls northward for five or six miles. Most of the few outcrops along this road are vertically-dipping slates and slaty greywackes which have no pronounced lithological resemblance to St. Francis beds. On the east side of the road, at a point about four miles from the southern border of Malvina map-area, a patch of Sherbrooke grit lies on the older rocks. The latter strike N.15°E., dip vertically, and face west, whereas the Sherbrooke beds dip west at angles of about 30 degrees. Uphill, beyond the boundary of the latter, a place was found at the south end of an outcrop of older rocks where a hole eroded into them for a depth of about two feet below the present surface is filled with the Sherbrooke grit. Unconformity between the two is therefore undubitable.

Age

The Sherbrooke strata overlie the St. Francis beds with great angular unconformity. As the latter appear to be Ordovician, and to have been folded during the Taconic orogeny near the end of Ordovician time, the Sherbrooke beds must have been deposited after sufficient time had elapsed for the Taconic folds to be eroded to a new level. They could hardly have been laid down, therefore, before some time early in the Silurian. In an earlier publication (3) their age was placed, tentatively, as Lower to Middle Silurian.

In Memphremagog map-area, Sherbrooke strata are intruded by the Stanstead granite (3), and in Sherbrooke map-area are overlain with erosional unconformity by beds of Lower Devonian age. Thus, the age there assigned to them seems approximately correct.

INTRUSIVE ROCKS

Granite

A mass of granite extends for fourteen miles along the International boundary west of Wallace pond and reaches northward for distances up to a maximum of two and a half miles. Another body, about two and a half miles in diameter, outcrops at the crest of Hereford mountain. In addition, a few dykes occur outside of these main masses; most of them are in Barnston township.

The larger bodies are very coarse-grained, rather light grey, biotite granite. Thin sections show that orthoclase, microcline, and quartz are the principal constituents, with some albite, 4 or 5 per cent of biotite, and a few crystals of muscovite. The composition is thus identical with that of the Stanstead granite, and presumably the two rocks are of the same age and origin. The Stanstead granite is known (3, p. 102) to have been intruded during the Acadian orogeny, in Devonian time.

Granite intrusion has metamorphosed rather strongly the surrounding sedimentary rocks. The slaty types have been particularly affected; they have been converted into hornfels, with a hardness of about 4, and with numerous black metacrysts of biotite. In places, large crystals of other secondary minerals, such as staurolite and sillimanite, have developed. Such alterations are particularly well seen in the creek bed in Barford township, range III, lot 13, and in Barnston township, range VIII, north of the big bulge in the granite contact.

Camptonites

The camptonites are mostly medium- to coarse-grained, porphyritic, very basic rocks which, in this area, occur as small dykes. Under weathering they disintegrate quickly and hence are never found outcropping except at places of rapid erosion, such as in stream beds where rapids or falls occur. There are a few of these dykes in Coaticook canyon, and several in the bed of the creek in range III, lot 13, Barford township. Others were noted at various places in the area. All the observed dykes are less than six feet wide; they have east to southeast strikes and steep to vertical dips.

As such dykes have been studied in considerable detail by others (10, 13), no particular attention was paid to them. Previous work has shown that they have a considerable range in composition, depending on the proportions of the individual minerals present. Of these, the main ones are olivine, titanaugite and other pyroxenes, hornblendes, and a small amount of basic andesine feldspar. Biotite, apatite, pyrite, and magnetite are accessory.

The strong petrographic resemblance of these dykes to the intrusives of the Monteregian Hills renders it highly likely that they originated from the same magmatic source and were injected at about the same time. F.F. Osborne (12) has advanced the suggestion, based on the poor development of pleochroic haloes, that this time may have been as late as Tertiary.

PLEISTOCENE

The surface of the region is mantled with till, commonly more or less clayey. As a rule it is only a few feet thick, but in some places, presumably old valleys, thicknesses of 100 feet or more may be observed where the deposits have been dissected by post-glacial streams. The drift appears to be largely or entirely ground moraine; no pronounced recessional moraines were observed.

In addition to the morainic deposits, all the larger valleys contain large amounts of glacio-fluvial material — gravels and sands interbedded here and there with clays that must have been deposited in temporary bodies of standing water. Commonly, these clays contain pebbles and fragments which, in places, are both numerous and large, so that the lakes must have contained many blocks of floating ice carrying morainic debris.

The presence of such deposits on the sides of the larger valleys points to the conclusion that ice lingered in these valleys after it had largely disappeared from the general upland surface. Melting of this ice would give rise to streams along the sides of the valley glaciers, streams that were obviously ponded, in places, to form temporary lakes. In these streams and lakes the deposits now found were laid down. One side of such streams would be the valley wall, the other the glacial ice.

In a few places the distribution of the ice was such as to permit deposition of glacio-fluvial and other material completely across the pre-existing valleys, choking them so that, after final disappearance of the ice, the streams were forced to find new channels. One of these places is at Coaticook. Here the preglacial channel, which ran through the eastern part of the town, can still be recognized where a tributary creek cuts through the glacio-fluvial sands and gravels in the northern limits of the town. The blocking of the old channel has forced the present stream to cut a rock gorge there. A smaller gorge of similar origin has been cut at Dixville, five miles to the south. Below Moes River village, Moe river has cut a rock gorge about half as long and half as deep as Coaticook gorge. In Clifton township, range V, lot 1, a gorge about fifteen feet deep and a few hundred feet long has been cut in rock by the small creek there.

Coaticook gorge is three-quarters of a mile long and about 100 feet deep, with near-vertical sides. It is cut in hard quartzites of the St. Francis group. Moes River gorge, though smaller, is similar in character. It has been the writer's experience, on the Canadian Shield, that post-Wisconsin erosion has been negligible, even by fair-sized streams and in rapids. To him, therefore, it seems incredible that such gorges could have been cut by insignificant streams, such as the Moe and Coaticook, during the few thousand years since the end of the Wisconsin stage of glaciation. Also, as these are north-flowing streams, it cannot be assumed that their volume was temporarily increased by additions from the ice sheet to the north.

If the above premise is correct, it follows that the stream valleys must have been blocked by the fluvio-glacial accumulations of some pre-Wisconsin stage of glaciation, so that gorge-cutting could go on, not only in post-Wisconsin time, but also throughout at least one earlier interglacial stage.

If this hypothesis is correct, then Wisconsin drift should be found overlying the accumulations of fluvio-glacial gravels; and it is a fact that thin remnants of moraine are found to overlie them in many places where good sections are available. They may be seen, for example, on the sides of the creek valley just north of the cemetery on the eastern limit of Coaticook; in a gravel pit in range VIII, lot 15, Barnston township; on the north side of Salmon river a short distance east of Gosselin Mills; on the east bank of Moe river south of the bridge, in range IX, lot 10 of Compton township; and in many other places. This drift is nowhere more than a few feet thick, and in many places is only a few inches deep or is altogether lacking. If this drift was deposited by the last sheet, the ice in this area must have been thin and almost stagnant — a conclusion strengthened by the fact that the glacio-fluvial deposits have not been removed or even much disturbed.

An interesting characteristic of the glacio-fluvial deposits is that pebbles and boulders of the St. Francis limestone in them are now completely rotted, even those several inches in diameter, so that they disintegrate into soil within a few weeks after being exposed to the weather. However, as no information could be found as to how rapidly this rotting proceeds, the peculiarity affords no reliable information as to the age of the deposits.

The fluvio-glacial deposits should be underlain by an older till, but at no place was this observed.

In the bed of Moe river in range X, Barford township, about four feet of a stiff blue clay containing a few small pebbles and an occasional boulder can be seen. As no bedding was detected, the material is considered to be till. It is overlain by coarse, bedded gravels. As these are obviously part of the flood plain of the stream, however, they really afford no evidence as to the relative ages of the till and the fluvio-glacial deposits.

Eskers are uncommon in the area. One, about four miles long, is found just west of Coaticook; it has been extensively utilized for road and building material. Its course is a little east of north, as if it had been formed in a channel that drained to the Coaticook valley through, or under, stagnant ice.

A much smaller deposit of sand that lies about half a mile to the west in range III, Barnston township, is similarly elongated. Other deposits of sand and gravel are fairly numerous; some of them appear, from their irregular knob-like shape, to be kames, but most of them lie on the side of some valley, and therefore most probably were laid down by streams following the borders of ice masses.

Glacial striae are not numerous within the area mapped. Those found indicate that the ice movement was from the northwest toward the southeast.

ECONOMIC GEOLOGY

Sand and Gravel

The large deposits of sand and gravel probably constitute the most valuable mineral resource of the district. They have been used extensively for road metal and for concrete aggregate. The esker just west of Coaticook provides a very large and conveniently located deposit. This is some four miles long and up to a quarter of a mile wide. It has been largely removed over a length of about a mile and a half.

Other deposits include apparent kames or kame terraces on the valley sides of Niger river some two miles north-northeast of Lyster lake. There is a deposit of sand on the west valley side of Moe river, a mile and a quarter east of Boudreau Corners. The valley sides of many of the streams, particularly the Coaticook and the Moe, show well developed terraces along many sections. These are cut in glacial and post-glacial materials and could provide gravel in many places. Sand and gravel bars at or a little above the level of the present stream are particularly common along Coaticook river.

Granite

The economic possibilities of the granites of this area have been reviewed by Burton (1). Production at the present time is restricted to the Gingras & Frères quarry. This is located about a mile and a quarter north-northwest of Stanhope (lot 26, Range X, Barnston). Here 1,000-2,000 tons of building stone are produced annually. The quarry has been operating since 1930, and stone from it may be seen in such buildings as the Royal Mint, Ottawa; Banque d'Economie de Québec (Maple Ave. and Ste.Foy Road); the Roman Catholic Church in Cowansville; and in the sanitoria at Ste.Germaine de Dorchester, at Macamic (Abitibi), and at Mont-Joli (Matane).

Other, and smaller, quarries have produced some commercial granite. These include principally the quarry operated by Frontenac Quarries, Limited, located three miles northwest of Stanhope in parts of lots 21 and 22, Range X, of Barnston. This quarry produced a total of some 60,000 cubic feet of building stone and curbstone during its period of operation, 1927-28. A third quarry (lot 27, Range X, Barnston; near the Gingras quarry) was operated only in 1931 and produced a few monument bases.

The above mentioned quarries have produced granite classed by Burton (1, p. 69) as of good quality and particularly suitable for "monument bases, hammered dies, and small size building-stone". It is known in the trade as Stanhope — intermediate in colour between Stanstead Grey and Beebe White.

Some twelve miles east-northeast of Stanhope, in the Hereford Mountain granite area, a quarry was operated in the 1890's. The location (lot 21, Range V, Hereford township) is poor in regard to transportation but a "large supply" of "good quality" granite is available here. "Rough ashlar from this quarry was used in building the church at St. Herménégilde and made a very attractive building" (1, p. 78).

One potential site for large-scale quarrying operations was singled out by Burton (1, p. 75). This was on the Barford-Hereford township line, 2,000 feet north of the International boundary. Here the stone "is lighter in colour than the average Stanhope and appears to be of good quality. The sheets dip gently to the east, range from five to twelve feet in thickness, and do not appear to be closely jointed". The locality is about ten miles from a railway.

Placer Gold

According to McGerrigle (11), placer gold is present in some of the streams of Coaticook area, particularly the Moe. Interest in the placers of Moe river goes back at least to 1908, although there is no indication that any extensive work was done and no record of any production. McGerrigle (11, pp. 34-35) panned gold from the Recent alluvials along the Moe from Milby upstream for some fourteen miles. "The best results were obtained between Milby and the first road crossing the stream above Moe River village... In this distance (about seven miles), several bars occur, in which gold to the value of 50 cents (a yard) was indicated by panning. It was common to have 20 colours and flakes to the pan at the most favourable points of the bars, but such showings were not generally uniform and the indicated values usually decreased with depth... Nevertheless, some of the individual bars tested to a depth of no more than four feet — the depth of the tests being limited by water — contain a quantity of gold estimated on the basis of our panning and weighing, to have a value of $600 or thereabouts" (11, pp. 34-36).

The actual possibilities of this stream are not known. However (McGerrigle, personal communication), it is possible that a small operation, involving the use of a mechanical pan, might successfully work the bars of the stream. The terraced gravels on the valley sides are reported to carry gold. Some tests have been made on these in earlier years but they appear to have been inconclusive.

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APPENDIX

In September, 1955, the writer, guided by Dr. Doll, visited the locality where the fossils had been found. The locality is close to the head of Lake Willoughby, fifteen miles south of the international boundary, in the bed of Stony brook. The fossils are contained in a bed of limestone striking north-northeast and dipping 18° northwest. The beds are close to a body of Late Devonian granite, and the limestone has been rendered rather coarsely crystalline, perhaps by the heat of the intrusive. Beds of dark, micaceous, very fine-grained sandstone, termed phyllite by Doll, outcrop nearby, and are considered by him to belong to the Westmore formation, of Silurian or Lower Devonian age. The Westmore, at the international boundary, seems to lie in the middle, or just above the middle, of the succession termed St. Francis by the writer, and considered by him to be Ordovician.

The preservation of echinoderms in limestone so completely recrystallized is rather remarkable. However, most palaeontologists who have seen the specimens agree that they are crinoids or cystoids. As crinoids are found in the Ordovician, and cystoids even lower, their presence does not prove a Silurian or Devonian age. Dr. Goldring, however, considers them Silurian, perhaps younger.

The writer's earlier suggestion that the fossils might have been found in some rock of later age, brought by faulting into its present position, does not seem possible. Also, although the phyllites, with which the limestone is interbedded, are lithologically quite unlike any of the St. Francis rocks north of the border, it seems impossible to deny that they are part of the Westmore, in view of the very careful, detailed work done by Dr. Doll in the area. Hence the question must await a more satisfactory determination of the age of the crinoids.

In 1947 W.M. Cady found corals of probable Middle Ordovician age in the Waits River formation (equivalent to the St. Francis group) in a number of places east of Montpelier, Vermont, some 25 miles south of Doll's locality. These, he states, were found throughout a zone between 2,000 and 12,000 feet above the base of the formation (discounting repetition). The greater figure should be close to the base of the Westmore.

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ALPHABETICAL INDEX