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GEOLOGY OF THE EASTMAN-ORFORD LAKE AREA

I

MINISTÈRE
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ET DES RESSOURCES

DIRECTION GÉNÉRALE DE
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ET MINÉRALE

GEOLOGY OF
EASTMAN-ORFORD LAKE AREA

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by

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INTRODUCTION

General Statement

In 1956 and 1957, the writer was directed by the Quebec Mineral Deposits Branch to undertake a detailed study of the structural relations and stratigraphy of the above area with the view to investigate possible exploitable mineral deposits.

The Eastman-Orford Lake area lies within the southeastern portion of the Appalachian physiographie province of Quebec. Its topographic Divisions include the Sutton Mountains in the west, flanked by the Eastern Quebec Uplands to the east.

The area is underlain by a thick assemblage of intensely folded Bonsecours schists succeeded eastward by steeply dipping clastic rocks of the Ottauquechee, Miller Pond and Beauceville formations of Cambrian and Ordovician age.

Zoning of the intrusives, underlying Orford and Chagnon mountains, suggests differentiation in place through gravitative crystal settling.

The structural features consist of the Sutton-Green Mountain anticlinorium and a profusion of minor structures. It is suggested that two contrasting sets of folds represent two stages of deformation, accompanied by corresponding early and late phases of metamorphism.

The mineral occurrences of the area consist of copper and iron sulphides and other materials of economic importance. The mineral deposits and mining operations of the Quebec Copper

Corporation are described in some detail.

Location and Means of Access

The Eastman-Orford Lake area lies in the southern part of the Eastern Townships, about 22 miles southwest of Sherbrooke. It comprises approximately 44 square miles and is bounded by latitudes 45°15' and 45°20' and by longitudes 72°15' and 72°25'.

The area includes about 32 square miles of the northern part of Bolton township in the county of Brome, 11 square miles of the southern part of Stukely township, Shefford county and about 1 square mile of Orford township, Sherbrooke county (Fig. 1).

The most important road serving the area is the Montreal-Sherbrooke Highway No. I. The Sherbrooke-Montreal line of the Canadian Pacific Railways crosses the northern part of the area, closely paralleling Highway No. I. In addition, an old North Stukely-Eastman Railway crosses the area from north to south and a network of good secondary gravel roads covers the district making the area easily accessible. (Introduce Fig. 1).

Field Work and Methods of Study

In the summers of 1956 and 1957, the writer completed two 5-minute quadrangles for the Quebec Department of Mines, the St. Etienne-de-Bolton and the Lake Orford map-sheets, respectively. In 1958, the writer spent part of the summer rechecking the structural data collected in previous summers. In addition, a small area, a few miles east of South Bolton, comprising about ten square miles, was mapped by the writer in late 1958.

Areal mapping was done at a scale of one inch to 500 feet. An accurate base map was prepared with the aid of plane table methods. All the roads and railroads were surveyed by plane table and telescopic alidade, and pickets were placed at intervals of 300 feet or less to increase mapping accuracy. Several base lines were cut and chained, including two north-south lines across Chagnon and Orford mountains.

The ground was systematically covered by pace and compass traverses spaced 500 feet apart, supplemented by an examination of all the outcrops along the roads.

Aerial photographs at 1000 feet to one inch were used in the open country to ensure complete coverage of rock exposures in critical parts of the area.

The field data were then transferred to a final map at a scale of 1500 feet to 1 inch.

Acknowledgements

The field work was carried out under the auspices of the Mineral Deposits Branch of the Quebec Department of Mines. The writer is greatly indebted to Dr. A.O. Dufresne, Deputy Minister of Mines, to Dr. I.W. Jones and to Dr. J.E. Gilbert, Chief of the Mineral Deposits Branch for permission to use the information collected in this report.

Dr. P. Grenier of the Quebec Department of Mines visited the area on several occasions and greatly assisted the writer in the solution of many problems. The writer is indebted to him for suggestions during the writing of the preliminary reports.

In 1958 and 1959, the writer had the opportunity to participate on two field trips organized by Dr. W.A. Cady of the United States Geological Survey. The suggestions by Drs. W.A. Cady, P.H. Osberg and M. Rickard greatly benefitted the writer.

Dr. J.E. Gill visited the map-area, and offered valuable advice and criticism.

Able assistance in the field was given by G. Duquette, Y. Bellefleur and J.L. Piccard in 1956, and R. Arbour, R. Gregoire, G. Mathurin and G. Bédard in 1957.

The research work was made possible by scholarships awarded to the writer by the Quebec Department of Mines for 1955 and 1956, and by the Quebec Department of Industry and Commerce for 1957 and 1958.

The writer is grateful to the Mineral Deposits Branch for the supply of approximately 300 thin sections, innumerable prints of field exposures, as well as four full chemical analyses.

Previous Work

The first accounts of the general geology of the region were by Sir W. Logan in the early reports of The Geological Survey, and these he later compiled and included in his 'Geology of Canada' in 1863. Logan inferred (1863) that the Sutton Mountains are made up of lower Silurian rocks and that they are part of a synclinal structure that extended from St. Armand to St. Mary on the Chaudière river. On both limbs of this synclinal structure, he indicated 'magnesian strata', possibly referring to dolomitic sediments on the west and serpentinized peridotites and talcose rocks on the east of the axis (i.e. in the vicinity of Missisquoi river and Orford lake).

S. T. Hunt suggested that the rocks along the Sutton axis are of Huronian age.

A. R. C. Selwyn (1818), reversed Logan's structure and considered the Sutton axis a simple anticline with a central core of Huronian rocks flanked on each side by belts of successively younger Paleozoic formations.

In 1882 and 1883, F. D. Adams submitted a detailed petrographic description of some 30 samples of Orford mountain and Owl's Head 'diabases' and 'highly feldspathic graywackes', and separated the intrusive serpentine series from the layered sedimentary rocks.

Between 1885 and 1894, R. W. Ells wrote several reports on the structure and stratigraphy of the Eastman-Orford Lake area. He offered an elaborate interpretation that, in general, confirmed Selwyn's views. Ells stated that the Sutton Mountains were the site of a great anticlinal of Huronian schists (Bonsecours in this report), bordered on the northwest by Cambrian black and grey slates (possibly the writer's Ottauquechee) that are overlain by red and green slates, sandstones and grits of the Sillery formation (corresponding partly to the writer's Miller Pond formation). The latter are, in turn succeeded by Cambro-Silurian and Silurian rocks.

In 1907, the Geological Survey issued a special report by J. A. Dresser on the copper-bearing rocks; it was followed in 1913 by a report on the serpentine belt in Southern Quebec by the same author. According to Dresser, the rocks that border the serpentinites consisted of a coarse feldspathic sandstone or greywacke, and red and green slates (Sillery), underlain by quartzites and dark schists of the L'Islet formation (corresponding to Rosaire or Ottauquechee) and overlain by black slates of the Ordovician Farnham formation (Beauceville in this report). The quartzose and sericitic schists exposed northwest of the L'Islet rocks were termed 'undifferentiated Paleozoics', the greater part of which, he thought to be meta-volcanics. Intrusions of serpentinites within the Farnham led Dresser to believe that all the igneous rocks of the Orford Lake area were post-Ordovician.

R. Harvie (1911) continued southward and eastward the work undertaken by Dresser and mapped the Orford Lake area and vicinity. He generally agreed with Dresser's theories and upheld his view that the rocks of the serpentine belt are, in the main, parts of one consanguineous instrusion, having been separated from one another during the progress of cooling. He maintained however, that the 'Sutton Mountain series' was Precambrian and made up of 'porphyries and greenstones'. In 1913, however, Harvie expressed the view that the core of the anticline is made up of recrystallized arkoses and greywackes. He also suggested that most of the hills on the eastern margin of the Eastman-Orford Lake area are made up of quartz-diabase.

In 1915, J. A. Bancroft made a detailed study of the copper deposits and prospects in the Eastern Townships, including the Ives Bolton, Huntington, Grand Trunk mines and others.

From 1923 to 1936, T. H. Clark, assisted by H. W. McGerrigle and H. W. Fairbairn, mapped the area underlain by the Sutton range and the region west of Memphremagog lake.

He came to the conclusion (1934) that the schists represent not only the Oak Hill series, but also a younger body of sediments of Upper Cambrian and possibly Ordovician age. He implied that the 'Bolton igneous series' (Chagnon mountain and the greenstones south of Eastman are included) lies with structural unconformity on the Magog slates.

The unconformity between volcanics and Magog slates was also emphasized in a report of 1936 by T. H. Clark and H. W. Fairbairn.

Chemical changes in metabasalts of the Bolton igneous series have been investigated by H. W. Fairbairn in 1933. He presented some evidence that the volcanic rocks north of Mansonville are characterized by two types of alterations.

In 1941, J. W. Ambrose mapped the Mansonville map-sheet immediately to the south of the area discussed in this report. His investigation of pillow structures in the Bolton volcanics conclusively proved that the Bolton volcanics are interbedded with Beauceville sediments and therefore of similar age as the sediments, i.e. Middle Ordovician.

In 1945, Y. O. Fortier described the geology of the Orford map-sheet and adjacent areas to the east and northeast. He concurs with Ambrose's contention that the volcanic bodies are interlayered with the sedimentary strata and places the extrusives of the greywacke-slate sequence into the same lithological group. According to Fortier, the rocks of the Orford-Chagnon-Baldface complex are later than the ultrabasic rocks of the Orford Lake region.

In 1950, the Geological Survey published a report by H. C. Cooke. He discarded both Mansonville and Magog and adopted Caldwell and Beauceville instead. He maintained that the Beauceville group overlies the Caldwell group with structural and erosional unconformity, and emphasized the fact that there is 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 the Sutton Mountains. Following Clark, he also concluded that the Beauceville was unconformably overlain by volcanics. He restricted, however, the term 'Bolton group' to the extrusives that make up the hills west of Memphremagog lake, and to patches of volcanic rocks that unconformably overlie both, the Caldwell and the Beauceville.

In 1956 and 1957, P. H. Osberg made a detailed survey of a large area that extended from Danville, Richmond county, to Bolton Pass, Brome county, and that included the western part of the area discussed herein. He suggested that the schists of the Sutton Mountains (Bonsecours) are equivalent to parts of Clark's Oak Hill series. In 1958, during a field trip in the vicinity of Richmond, Quebec, Osberg showed that the Tibbit Hill schist was overlain by Pinnacle greywacke and Bonsecours schists in what seemed to be an anticlinal structure. These, in turn, are succeeded by Sweetsburg slates.

DESCRIPTION OF THE AREA

Settlement and Resources

The area is widely settled and cleared land devoted to agriculture and cattle-raising is extensive. The chief agricultural crops are hay, potatoes , and corn.

The principal villages of the area are South-Stukely, St. Etienne-de-Bolton and Eastman. The latter has a native population of about 650, mostly French speaking, and serves primarily as a shopping and postal center for the neighbouring farmers and prospectors.

The chief active industry of the area is lumbering. In addition to lumber camps,there are many independant operations of local inhabitants, who, on their own farms cut fir and spruce for pulp, and pine for construction. Poplar and birch are relatively scarce; local growths of cedar are quite common in wet and swampy grounds. Extensive stands of maple, as a source of syrup and sugar, provide the farmers with additional income.

Some trapping is done, although fur-bearing animals such as fox, lynx and bear are not plentiful. Fish appear to be scarce.

Streams within the area do not carry a sufficient flow of water to be of any great significance as a source of water power.

Topography

The Eastman-Orford Lake area includes two of the physiographic units of the Appalachian Province in the Eastern Townships: The Sutton Mountains and the Eastern Quebec Uplands.

The Sutton Mountains traverse the map-area from its southwest corner to a point west of Eastman lake and thence northward to Bonsecours (North Stukely). It is a moderately undulating ridge underlain by intensily deformed and metamorphosed schists and averaging 1000 to 1100 feet in elevation. The dominant topographic feature is St. Etienne mountain, rising to an elevation of 1750 feet above sea level. Northeastward from St. Etienne mountain, the ridge becomes progressively lower at Libby pond (925 feet), then gradually rises to a small plateau at 1150 feet south of Eastray (Fig. 2). An east-west transverse valley (800 feet), connecting Orford lake with Waterloo, separates the latter plateau from a rolling plain that maintains a constant elevation of 900 to 1100 feet west and north of Eastman lake. (Introduce Fig. 2).

Extending east of the Sutton Mountains and separated from them by the prominent Missisquoi River valley, lie the Eastern Quebec Uplands, a moderately flat plateau with gentle slopes that rarely exceeds 1000 feet above sea level. Rising abruptly above the upland is the three to four-mile wide Orford Ridge, a line of lofty hills that in the area under consideration includes Chagnon (2000 feet) and the western slope of the Orford mountains (2725 feet). This ridge is part of the 'Serpentine Belt' and is underlain by a vast assemblage of extrusive and intrusive rocks that range in composition from acidic to ultrabasic.

Adjoining this range to the east is the strongly marked valley of Lake Memphremagog at an elevation of 683 feet.

The topographic divisions are lithologically controlled and strike northeast in harmony with the gross structural trends of the region as a whole.

Drainage

The Eastman-Orford Lake area is, in general, well drained. The greater part of the country is drained via the Missisquoi valley to Lake Champlain. Along the eastern boundary of the map-area, however, most of the streams that descend Orford mountain in a radial pattern, empty into a series of small lakes that dot the country side in the southeast corner of the map-sheet.

The most important river is the Missisquoi, which originates west of Stukely lake, flows southward along a prominent, lithologically controlled valley and eventually cuts across the Green Mountains in a deep gorge (2 miles south of the International Boundary) to discharge into Lake Champlain.

Of special interest are the numerous streams that flow east- or westward across the regional structure; examples are found in the northern extension of Castle brook, the stream connecting Orford with Eastman lakes, the creek that flows westward through South Stukely, and many others. Cooke (1937) and Fortier (1946) called attention to this marked alignment of small transverse streams. Fortier presented a a logical interpretation, when he said that the Orford gap "is a vestige of an ancient transverse stream that antedated the formation of the ranges" (p. 38). It is quite probable that this also applies to Bolton Pass, west of South Bolton.

There is some indication that the major lake basins of the area originated by piracy or damming, or both. Both, Eastman lake (formerly Silver lake) and Long pond (Etang Bonne Allée), are elongated bodies of water at similar altitudes (800 feet) that lie in an important southeasterly trending subsequent valley. Both owe their origin to damming by glacial debris. This is evidenced by the abundant glacio-fluvial deposits that occur at their northern extremities.

Orford lake and Libby pond, on the other hand, are probably remnants of the old east-west trending river system discussed above. Piracy and damming as a result of glaciation probably controlled their present locations and shapes.

There are only a few swamps in the map-area, and their origin is probably similar to that of the above-mentioned lakes.

Glaciation

Depositional Features

A large blanket of morainic material covers most of the northern part of the St. Etienne-de-Bolton map-sheet, west and northwest of Eastman lake. It forms an undulating plain marked by gently sloping swells and basins broken here and there by bedrock that projects through it. Information from wells and bore holes indicates that the drift here is from ten to twenty feet thick.

The morainic material consists largely of till. The coarse-grained fraction, made up of pebbles, cobbles and boulders, is largely of local provenance. The fine-grained fraction, consisting of sand, silt, and clay, may be of more distant origin and may have been ground up by mechanical wear en route. At some places, there is a heavy concentration of boulders free of any matrix of till. Either sheet erosion on gentle slopes or deflation could have removed the fine sizes.

Most of the cobbles and boulders are composed of greywacke and schist, but some are made up of boulders of ultrabasic intrusives and tuff and lava fragments, embedded in, and quite frequently cemented by, fine-grained sandy material and minor clay. This suggests that the source rocks were predominantly sandstones and minor slates, as well as schists. The relative scarcity of clay also reflects differences in erodibility of the source rocks.

Although there is some cementation of sand grains and pebbles due to a small amount of clay-sized particles, the compactness of the morainic material is, in general, slight. It is apparently structureless and shows no fissility or stratification. The sub-rounded shapes of the stones suggest that they have been carried by glacial meltwater before being picked up by the ice and incorporated in the till.

Glacio-fluvial deposits are very abundant in the map-area and in the immediate vicinity, where they form broad, gently sloping outwash planes or kames. The most extensive ones may be found east of St. Etienne, north of Eastman lake, approximately one mile north of Foster, Brome township, and on the southeast slope of Orford mountain.

The stram-built stratified drift is made up of interlaminated coarse-and fine-grained, well-sorted beds showing marked cross-bedding. The thin foreset laminae are commonly steep and have little continuity, because each is partly cut away by younger beds, thereby indicating deposits of the outwash delta type. Generally, the beds consist of alternating pebbly and sandy layers with the silt and clay fraction very small or non-existent. Variations in grain-size are sharp and numerous. The particles, for the most part of local derivation, are rounded and lack striations.

Most of the beds have a gentle dip to the southeast, suggesting that the meltwater flowed southeastwardly. This is also corroborated by the attitude of the cross-bedding.

Erosional Features

Abundant glacial striae provide additional proof that the area has been overrun by the Laurentian ice-sheet. Most of the readings indicate a S. 20° E. to S. 40°E. direction of ice movement. Divergence in trend of the striations may be observed immediately east of Orford lake, where shallow grooves on polished and rounded intrusives, indicate an east-west movement of ice flow. In the Memphremagog Lake valley, the striae run in a north-south direction. From this it may be concluded that, where an ice-sheet flowed across a much-dissected terrain, the ice tended to follow the valleys even though the trends of the depressions departed from the general direction of ice flow by a wide angle.

Evidences of glacial plucking are apparent throughout the area. Unsymmetrical bosses with gentle slopes facing northwestward and steeper sides facing southeastward may be observed in an area west and northwest of the St. Etienne village. Examples of plucking action of ice may also be found on the southeast escarpment of Orford and Owl's Head mountains. About two miles southeast of St. Etienne, a knob underlain by intrusive diorite, has a comparatively gentle slope on the northwest side and a 50-foot high cliff on the east side.

Ice Movement

There seems to be enough evidence to state that there are two main trends in the movement of ice-sheets in the area.

The presence of boulders of Beauceville and Miller Pond rocks west of their source area, in the region underlain by the Bonsecours schists and Oak Hill series, indicates a westward or northwestward flow. However, no examples of striae, stream-lined forms or plucking can be cited to support this contention. It is possible that such northerly or westerly movement of ice was caused by changes in direction of flow of a single lobe of a sheet as a result of topographic irregularities or shift in the position of the center of outflow of ice.

Quite apparent, on the other hand, are the evidences for a southerly or southeasterly movement of the ice-sheet. Although striations did not provide sufficient information as to the direction of ice flow, (no asymmetrical grooves or chatter marks were seen) plucked lee surfaces clearly indicate a glacier flow in a S. 20°E. direction. The divergencies from this trend in valleys and on the slopes of Orford mountain reflect the adaptation of local lobes to ridge and valley trends.

The writer is of the opinion that a northerly or northwesterly glacier movement preceeded a southeasterly ice flow.

Physiographic History

The first stage in the physiographic history of the area was probably the evolution of a surface of fairly low relief upon which a system of westward flowing, consequent streams eventually developed. This erosion surface was uplifted "in late Tertiary, perhaps about mid-Pliocene, time" (Cooke, 1950, p. 8), resulting in a mature east-west drainage pattern with antecedent streams superimposed on the structural elements of the area.

Erosion and dissection of this uplifted surface eventually resulted in the outlining of the harder and more resistant rock types and structures, such as the Sutton Mountains, the Stoke Hills and the Megantic Hills, rising above northeasterly trending valleys of the Missiquoi river and the Memphremagog lake.

As the subsequent rivers, such as the Missiquoi and Salmon brook adjusted themselves to the prevailing northeasterly trending structures and cut deeper channels, they intersected and eventually captured the headwaters of the east-west flowing streams. Fortier indicated that "streams were developed along structural lines in structural valleys" and that erosion along them "resulted in the capture of the waters of the transverse 'Orford-Waterloo River' " (1946, p. 39). The 'Bolton Pass' is probably another example of a gap that was originally the site of a captured transverse stream. Libby pond may, too, have been the vestige of an ancient, westward flowing river.

Glaciation interrupted the normal development of geomorphic processes. The glaciers scoured the existing valleys, polished and rounded off the hill tops and left the country covered with abundant till, stratified drift and glacio-fluvial deposits. The valleys of the Missisquoi river and Lake Memphremagog were choked with glacial debris; this resulted in the formation of such lakes as Parker and Eastman,and the swampy and drowned areas north of Long and Parker ponds.

Present day streams are removing the unconsolidated glacial and pre-glacial debris, and are reorganizing a topographically and structurally controlled drainage pattern.

GENERAL GEOLOGY

General Statement

The Eastman-Orford Lake area lies in the western part of the deformed belt of the northern Appalachian Mountain System.

The area is underlain in the west by rocks of the Bonsecours group consisting of a thick assemblage of strongly folded and plicated quartz-sericite-graphite-and quartz-sericite schists interbedded with chlorite schists and greenstones.

The schists are succeeded to the east by quartzites, quartz-sericite-graphite schists and phyllites of the Ottauquechee formation of apparently Upper Cambrian age. The latter, in turn, pass transitionally into the Miller Pond formation, composed of Cambro-Ordovician greywackes, slates, quartz-sericite-chlorite schists, rhyolite and spilitic greenstone interstratified with discontinuous sheets of greenstone and tuff beds.

In the map-area, the Beauceville formation overlies the Miller Pond rocks conformably. It consists of a thick metabasalt at the base, succeeded by an assemblage of dark slates and minor quartzites farther east.

All the intrusives are located in the central and eastern part of the map-area; they comprise serpentinized peridotite, pyroxenite, gabbro, and 'acidic rock', granite-and quartz-diorite breccia and lamprophyre dikes. By far the largest intrusive mass underlies parts of Orford and Chagnon mountains. Zoning of the latter suggests differentiation in place through gravitative crystal settling.

The structural elements are manifold and reflect the complicated characteristics of the Appalachian Mountain System. The controlling structure of the map-area is a broad anticlinorium, the axial plane of which strikes northeast and dips vertically or steeply to the east.

There are indications that the area was subjected to stresses that resulted in two different fold patterns. Various minor structural features, which may generally be distinguished by their characteristic styles, accompany these folds.

Evidence for both major and small-scale faulting has been found in the map-area. West of Orford lake, a continuous breccia zone, made up of disordered fragments of Miller Pond schists, extends across the map-area in a northeasterly direction and probably represents a major zone of dislocation.

There is no paleontological evidence for the age of the rock units mentioned in this report, except for the Beauceville formation, which is Ordovician. The age assignments in the following table of formations are therefore tentative.

Bonsecours Group

General Statement

Various terms have been assigned to the vast assemblage of schists that constitute the Sutton Mountains in southeastern Quebec. The following names: Sutton Mountain series (Harvie, 1911), Sutton Mountain (Dresser, 1911), Bennett Schists (Harvie and Knox, 1917; Cooke, 1937; Benoit, 1958), Sutton Schists (Clark, 1934, 1936), Sutton group (Ambrose, 1942), Sutton Mountain group (Fortier, 1946), Bennett Schist formation (Gorman, 1956), Bennett group (Béland, 1957), Sutton-Bennett Schist (Riordon, 1957), Sutton facies (de Römer, 1957, 1958), have been used at one time or another.

In this report, the writer has adopted 'Bonsecours group' for the schists that make up the Sutton-Green Mountain anticlinorium in the map-area. The term has been coined by P. H. Osberg (personal communication, 1958) and named after Bonsecours (North Stukely) village, six miles north of Eastman lake.

The writer has subdivided the group litholigically into two main units: the quartz-sericite-graphite schist-and the quartz-sericite-schist divisions. The latter is made up of four units, each of which will be described in the following sections.

The rocks of the divisions and of the individual units have transitional contacts and grade into each other both, across and along the strike. The absence of horizon markers and the highly folded and altered nature of the schists are other factors that make the determination of the true stratigraphic succession very difficult, if not impossible. There seems to be no doubt, however, that in the map-area, the quartz-sericite-graphite schist division is the lowermost unit of the Bonsecours group.

Distribution and Extent

Broadly speaking, rocks of identical lithology as the Bonsecours can be traced intermittently to the northeast and along the axis of the Sutton-Green Mountain anticlinorium for at least 150 miles (Map No. III). Southwest of the map-area, various schists, similar to the Bonsecours rocks can be followed across the International Border into Vermont for an approximately equal distance. The width of this belt is very variable throughout its length.

The rocks of the Bonsecours group take up the western half of the map-sheet and cover an area of approximately 24 square miles. The belt is bounded on the east by a contact with the Ottauquechee formation, a fairly straight line that connects Parker and Eastman lakes with a point 0.5 mile west of Trousers lake. Its western extremity lies two miles bayond the limits of the map-area. Hence, at this latitude, the belt underlain by the Bonsecours group is some 6.5 miles wide.

Quartz-sericite-graphite Schist Division

A northeasterly trending 4000-to 5000-foot wide belt of quartz-sericite-graphite schist comprises the oldest rocks of the map-area. It extends from St. Etienne mountain to north of Libby pond, where it gradually merges into quartz-sericite schists. Excellent outcrops of quartz-sericite-graphite schist are exposed

Table of Formations

Age	Group	Formation	Lithology
Recent and Pleistocene			Till, glacio-fluvial and outwash delta deposits
Ordovician and Post-Ordovician			Lamprophyre dikes Granite-and quartz-diorite-breccia 'Acidic rock' Gabbro Pyroxenite Serpentinized peridotite Metasomatic dolomite
Ordovician		Beauceville formation	Black slate and interbedded quartzite Massive metabasalt
Cambro-Ordovician		Miller Pond formation	Spilitic greenstone division Rhyolite division schist division: quartz-sericite-graphite schist; green and purple slate; greenstone; quartz-sericite-chlorite schist Greywacke-slate division: siliceous limestone; greenstone; green and purple slate; arenite and quartzite; slate and argillite; massive greywacke and grey slate
Upper Cambrian?		Ottauquechee formation	Phyllite, grey siltstone, quartz-sericite-graphite schist Bedded, impure quartzite, some interbedded slate
Cambrian?	Bonsecours Group		Quartz-sericite schist division: quartz-sericite-albite-(chlorite) schist; quartz-sericite-chlorite-(albite) schist; quartz-sericite-graphite schist; chlorite schist and greenstone; marble Quartz-sericite-graphite schist division: quartz-sericite-graphite schist.

on St. Etienne mountain, on lot 10, range V, and on lot 3, range VII, Bolton township. At the latter locality, numerous bands of graphite schist, from 50 to 300 feet wide, are intercalated and interfinger with quartz-sericite-and quartz-sericite-chlorite-schists. In many cases, the writer was able to prove that the repetition of such schist lenses was actually due to disrupted and disconnected fold limbs.

The graphite schist is steel-grey in colour and usually shows rusty weathering due to oxidation of porphyroblasts of pyrite up to one inch in size. A 12-ounze sample of a typical quartz-sericite-graphite schist analysed 0.77 per cent carbon. Most rock sections examined indicate substantial amounts of albite. The latter occur as dark euhedral porphyroblasts that owe their colour to included streaks of carbonaceous material. The crystals generally lie among micaceous minerals that occupy the spaces between laminae of granulated quartz; they commonly transect the primary schistosity. Quartz constitutes 15 to 50 per cent of the rock. It commonly occurs either as irregular grains with sutured boundaries, or as lens-like granular aggregates flanked by laminae of schistose minerals. Although the original clastic character of the quartz may be preserved in a few cases, most of the grains are wholly recrystallized. Sericite is very abundant and is usually segregated along sub-parallel schistosity planes that enclose quartz-filled lenses. Also present are a few muscovite laths lying at all angles with the schistosity. Chlorite is commonly associated with sericite and imparts a greenish tint to the rock; it is rarely more abundant than the sericite. Locally, apatite, ankerite and tourmaline, as well as epidote and iron ores are observed.

Quartz-sericite-Schist Division

This variety of schist is the most abundant rock type of the Bonsecours group. It conformably overlies the main carbonaceous belt with transitional contacts and extends diagonally across the area in a zone that, in the northern part, has a width of about five miles. In the central and southern parts, it is exposed on the west and east sides of the quartz-sericite-graphite-schist belt and on both flanks of the Sutton-Green Mountain anticlinorial axis.

The writer subdivided this division into the four following units: quartz-sericite-albite-(chlorite) schist, +) quartz-sericite-chlorite-(albite) schist, chlorite schist and greenstone, and dolomitic marble.

Quartz-sericite-albite-(chlorite) Schist

The greater part of the quartz-sericite-albite-(chlorite) schist is a heterogenous unit with a wide range in composition. It is typically a silvery to pale-green rock made up of segregational layers, 1/16 to 1/18 of an inch wide, of quartz, mica, albite and minor chlorite (Plate IA); it grades imperceptibly into thin-bedded quartzites and graphitic phyllites. In many instances, monor differences in lithologic characteristics along strike, as well as the apparent discontinuity of the individual schist varieties, suggest a sedimentary facies variation.

Excellent examples of a typical quartz-sericite-albite-(chlorite) schist may be seen in the southern and northern parts of lots 10 and 11 respectively, range I, Stukely township, and on lot 5, range VII, Bolton township (Plate IB). Characteristically, massive and irregular veins of white, milky quartz, ranging from a fraction of an inch to one foot in width, parallel the general trend of the schistosity or cut across the segregational layering; disconnected, pod-or hook-shaped quartz lenses of all sizes are commonplace. Original bedding is very rarely detectable. In many outcrops, however, the quartz-rich granulite layers, commonly thinner than the micaceous bands, parallel the schistosity for considerable lengths and probably represent original stratification.

The lenticles of quartz and feldspar are tightly folded and are usually thicker at the crests of the folds. Horizontal sections of these minor folds show drawn-out S-shaped flexures, the crests of which are offset along sub-parallel shear-surfaces; as a result,

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+) Names in parenthesis refer to minerals that may or may not be an important part of the particular mineral assemblage.

the limbs of the elongated minor folds are generally obliterated by the prevalent schistosity. The traces of the crests on the schistosity surfaces form rod-like aggregates of quartz that are parallel to axes of steeply plunging minor folds. The thickened crests and quartz linticles are, in turn, folded about shallow, northeasterly plunging axes.

Commonly, the micaceous layers show extremely well-developed slip cleavage resulting from small-scale crumpling and differential movement along limbs of microflexures.

Compositionally, the rock is a typical albite-bearing quartzo-feldspathic schist, in which almost all the clastic grains have been eliminated. It is apparent that quartz, sericite and albite together make up 85 to 90 per cent of the rock. Quartz constitutes 40 to 50 per cent of the rock and occurs as a mosaic-like aggregate of small (0.05-0.5 mm) clear grains, showing undulose extinction. At places, the grains are traversed by minute strings (0.0003 mm) of an unindentified material. No preferred orientation or elongation of the individual quartz grains was observed.

Albite porphyroblasts characterize particularly the region of the axial zone of the Sutton-Green Mountain anticlinorium, where they appear in the more micaceous or chloritic beds. The percentage of albite present in the rock is very variable; occasionally, there is a gradation, within a few feet and on the same horizon, from a mica schist almost free from albite to an albite schist in which the crystals make up a high percentage of the rock.

The porphyroblasts are roughly equidimensional in shape that rarely exceeds 1 mm across. Simple carlsbad twinning was noted in a few cases, while local development of lamellar twinning is not uncommon. At many places, larger albites enclose irregular blebs of quartz and parallel contorted strings of carbonaceous material, that show evidence of slight rotation. The feldspar was identified as $Ab_{95}\ An_{5}$.

Although strings of albite porphyroblasts are commonly parallel to, and follow micaceous layers around noses of minor folds, they clearly transect the principal schistosity (Fig. 3). There is no clear indication as to the relationship of slip cleavage and albite porphyroblasts; generally, however, the albite crystals appear to have formed prior to the development of slip surfaces that commonly curve around the grains. (Introduce Fig. 3).

Hematite seems to be a frequent constituent of porphyroblastic albite schists. It occurs in string-like forms parallel to the main schistosity and as thin, wavy lines concurrent to the slip cleavage. Hematite commonly pigments the line of junction between adjacent albites or between albite and quartz; there is no doubt that patchy hematite-staining accounts for the pink colour of the albites in some hand specimens.

Magnetite is locally abundant and occurs as small octahedra disseminated throughout the rock. Muscovite is relatively coarse and its elongated slabs (up to 5 mm. long) are unoriented and commonly transect the prevalent schistosity (Plate II A and B). The mica is usually accompanied by tiny flakes of colourless or very pale-green chlorite; the distribution of the latter is very sporadic in that chlorite-rich rocks may pass into chlorite-poor schists on the same horizon.

In the schists north and east of South Stukely village, several chloritoid-rich beds were encountered. The ottrelite occurs in randomly oriented porphyroblasts, enclosing trains of inclusions. Apatite, epidote, graphite, zircon, garnet, and tourmaline are relatively common accessory minerals. Partial chemical analyses of a quartz-sericite-albite-(chlorite) schist are given in Table 1. (Introduce Table 1).

Quartz-sericite-chlorite(albite) Schist

Interfingering with the schist varieties described above, are discontinuous, narrow interbeds of a relatively chlorite-rich schist. Excellent exposures are found in the western part of lots 9, 10 and 11, range IV, Bolton township.

It is, generally, a highly foliated, pale-green rock of very heterogenous composition, exhibiting contacts that are everywhere transitional across and along the strike. The mineral composition of the quartz-sericite-chlorite-(albite) schist differs from that of other schists of the area, by its slightly higher chlorite and albite, and lower quartz contents. Albite porphyroblasts are particularly conspicuous in the vicinity of the axial zone of the Sutton-Green Mountain anticlinorium, where segregations of albite crystals form leucocratic patches that consist almost entirely of albite.

The textural and structural aspects of the quartz-sericite-chlorite-(albite) schist are in many ways similar to those of other schists of the area. The well-defined segregational layers consist of an alteration of thin quartzitic laminae and relatively wide micaceous layers striking northeast and parallel to the regional trend (Plate III A). At places, the micaceous bands exhibit micro-folding and a later, relatively rectilinear slip cleavage that intersects and displaces the crinkles; the resulting, well-defined lineation has a consistent northeasterly or southwesterly plunge. Partial chemical analyses of typical quartz-sericite-chlorite-(albite) schists are given in Table 1.

Chlorite Schist and Greenstone

Chlorite schists and relatively massive greenstones are interbedded with other schist varieties in many parts of the belt underlain by the Bonsecours rocks. They commonly form elongated, lens-like bodies, 100 to 500 feet wide and traceable for a few hundred to several thousand feet. Their contacts with the other schists are generally gradational, and their longer dimension and schistosity are everywhere parallel to the structural trend of the surrounding schists.

Chlorite schist lenses are concentrated on both flanks of the anticlinorium and are distributed at irregular intervals along the whole length of the Bonsecours belt in the map-area. Although some evidence in the adjacent schists indicates that the intercalated chlorite-rich lenses are tightly folded, no actual noses of folds were discovered in the field. Shearing and slippage along the axial plane cleavage of tight isoclinal folds may result in the disruption and isolation of fold fragments; this may, under certain conditions, lead to total obliteration of any traces of folding. Such mechanism may also explain the relative narrowness of the individual chlorite-schist lenses and their marked discontinuity along strike.

Megascopically, the chlorite schist is commonly, but not invariably, a schistose, dark-green rock containing scattered octahedra of magnetite. It is generally stratified with wide chlorite-rich bands separated by thin (1/16 of an inch) layers of albite, calcite and occasionally quartz. Such typical chlorite schists are best exposed on the road leading eastward from St. Etienne village.

Chlorite gives the dark green to yellow-grennish colour to the rock and occurs as long, lath-shaped crystals or as scaly aggregates elongated in the plane of schistosity. The depth of colour and strength of pleochroism are quite variable; some larger crystals wrap around opaque iron ores and acquire a deeper colour and stronger pleochroism. Occasionally, the chlorite forms stumpy porphyroblasts set across the schistosity. Its relatively high refractive index indicates that the chlorite is probably a member of the prochlorites. Sericite is much less plentiful than in the other schist varieties. Muscovite, on the other hand, is a frequent, but generally not important, constituent occurring in minute, randomly oriented flakes.

Invariably, the feldspar is albite; it occurs as rounded crystals showing considerable variation in size and shape. Aggregates of albite porphyroblasts and equigranular grains are commonly associated with quartz. Albite also forms minute interstitial grains (0.03 - 0.1 mm) that are irregular, untwinned and lack cleavage, and are then difficult to distinguish from quartz. In most specimens, however, the crystals show a well-developed albite twinning; some of the larger crystals exhibit cloudy inclusions, and a trace of zoning can occasionally be seen. The amount of epidote varies widely. It may occur as aggregates of yellow-green granules or as idioblastic prisms elongated in the direction of the schistosity and lineation. At places, the irregular distribution of epidote in streaks and bands is a characteristic feature of the rock. A variable and often large percentage of quartz (18 per cent) is seen in most sections; the crystals are arranged in clots and stringers paralleling the contortions of the foliation.

An almost omnipresent constituent of chlorite schists are sharply crystallized octahedra of magnetite up to 1/8 of an inch in diameter, scattered at random throughout the rock. Among the accessory minerals are rounded grains of granular clusters of sphene and prismatic crystals of apatite. Well-twinned calcite occurs locally in stringers paralleling the schistosity. Partial chemical analyses of chlorite schists are given in Table 2.

Chlorite schists, as described above, grade at places into massive and apparently structureless actinolite-bearing greenstones on one hand, and into quartz-sericite-chlorite-(albite) schists on the other. Mineralogically, the greenstones differ from the chlorite schists in that the rock contains appreciable amounts of actinolite. This mineral takes the form of slender prisms and needles that either bend around noses of microfolds or cut across the crenulations of the schistosity. Lenses of a typical actinolite-bearing greenstone crop out in a 200 to 800-foot wide belt that skirts the western shore of Eastman lake. Here, a massive actinolite-greenstone is flanked on the east by a uniformly banded rock made up of continuous and alternating segregational layers of feldspar- and chlorite-epidote-actinolite-rich material.

~~Another massive actinolite-greenstone is exposed in the upper centre of the St. Etienne-de-Bolton map-sheet, and 1.5 miles north of Libby pond. This 200-foot wide and 6000-foot long lens exhibits clusters of well-shaped actinolite crystals that evidently formed in the late stages of metamorphism.~~

A northeasterly trending, 1500- to 3000-foot wide zone of banded greenstone is exposed immediately west of South Stukely. It is in conformable contact with quartz-sericite-(chlorite)-albite schist on the east, while its western margin is masked by a heavy blanket of glacial drift.

There is little doubt that the greenstones at South Stukely represent a folded tabular body intercalated in the rocks of the quartz-sericite schist division.

Interbedded with the greenstone are five lenses of cream-coloured marble and several interbeds of phyllite (Table 2).

The general appearance of the greenstone at South Stukely is that of a bluish-green banded rock that is schistose in some places and massive in others. The continuous layers range from

1/16 to 2 inches in width and are commonly light or dark green, grey, black, reddish or yellow, and simulate bedding. This is due to the relative abundance and segregation of chlorite-epidote-actinolite on one hand, and quartz and albite on the other. The structural features of the greenstone, such as tight drag folding and intense shearing of the micaceous layers are comparable to the deformational porperties of the surrounding mica schists. Numerous quartz-epidote veinlets and elongated epidote-feldspar knots, 1 to 12 inches in length, are commonly present along schistosity planes. The rock is at places highly amygdaloidal, with the small, closely-spaced amygdules arranged in strings and drawn out into flattened forms. The majority of the oval amygdules are elongated in a N. 10°E. direction, which at the particular South Stukely locality, coincides with the trend of the late axial plane cleavage (slip cleavage). Evidence in thin section suggests that the recrystallized contents of the amygdules have rotated into the latter plane. The amygdules themselves generally consist of an aggregate of secondary feldspar and calcite or hematite. Optical properties and crystal form suggest that staurolite or ottrelite may be the unidentified minerals.

Albite has usually a 'caries' texture and seems to be an early constituent; it is usually associated with actinolite and epidote, the latter occurring as inclusions. The distribution of quartz is very erratic. It may make up 18 per cent of the rock and is generally associated with feldspath-bearing veinlets. Chlorite occurs as interstitial material in form of narrow veinlets containing small crystals of albite and in fan-shaped aggregates everywhere associated with hematite and albite. Actinolite occurs as well-crystallized colourless to pale-green rhombs and rods (0.4 mm long) enclosing numerous small grains of albite, and showing a marked sieve structure; disrupted large actinolite porphyroblasts with matching walls are frequently cross-out by tiny feldspar veinlets. Other instances, however, point to a late development of actinolite.

Hematite is readily observed in hand specimen; it takes up approximately 4 per cent of the rock and occurs as dark plates and scales 0.05 to 3 mm in diameter. At places, it fills amygdule cavities and then occurs in slightly aligned beads (0.3 mm in the longest dimension). Irregular patches of hematite frequently replace quartz, feldspar and chlorite, and suggest that hematite is probably the last-formed of the greenstone mineral assemblage. Four full chemical analyses of South Stukely greenstones and interbedded phyllitic horizons are given in Table 2. (Introduce Table 2).

Marble

Five linses of marble, varying from 15 to 500 feet in width, are present within the belt underlain by the South Stukely banded greenstone. Single and scattered outcrops of similar crystalline limestone are exposed at intervals along strike from about 2 miles southwest of, to 11 miles northeast of, South Stukely. A small, isolated 10-foot wide marble bed, containing streaks of fuchsite and specks of pyrite, is also exposed in lot 3, range IV, Bolton township, in the area underlain by quartz-sericite schists.

The contacts with the greenstone are gradational over a 5 to 10-foot wide zone that shows variable amounts of calcite, talc, chlorite and clay minerals. The individual lenses in the South Stukely area strike northeasterly and dip to the northwest at an angle of 60 to 70 degrees. Their thickness varies from 10 to 450 feet, but averages 200 feet. Conformable and gradational contacts with the surrounding rocks suggest that the originally continuous carbonate beds were subjected to similar stress conditions as the adjacent greenstones and mica schists of the Bonsecours group. It is also probable that the carbonate beds were disrupted and drawn out into their present lenticular shape by plastic flowage.

The rock, wherever exposed, is highly crystalline and fine-grained, but varies in colour, being light-grey in one locality and light-blue in another, and is in many places mottled with green, yellow and mauve. Numerous calcite and milky quartz veins cut the marble in an irregular pattern, and scattered crystals of pyrite and copper sulfides are noticeable in hand specimens.

In general, the rock consists almost entirely of white calcium carbonate; at some places, however, the marble is made up of dolomite bands containing considerable amounts of impurities. Concentrations of such impurities along subparallel and continuous lines probably represent traces of original bedding.

The marble averages 88 per cent calcite, 2 per cent quartz and feldspar, 8 per cent dolomite, 1 per cent chlorite and traces of opaque minerals.

Calcite commonly occurs in interlocking crystals, showing no noticeable elongation of the grains. Minor chlorite and graphite are sparingly dispersed throughout the rock, or occur as sub-parallel, wavy stringers simulating relict bedding. Quartz and feldspar form small, elongated and interconnected aggregates that suggest vein material.

Metamorphism

Bonsecours Quartzo-feldspathic Schists

It is everywhere apparent that the Bonsecours quartzo-feldspathic schists are of sedimentary origin. Although many of the original textures and minerals have since disappeared because of recrystallization and reconstitution of the rocks, the occurrence of bedded quartzites within the schists, the gradation of quartzites to quartz-sericite-chlorite-albite schists interstratified with chlorite schists and greenstones, the widespread distribution of graphite and phyllitic beds containing relict detrital grains, as well as the chemical composition of the schists, suggest that the area underlain by the Sutton-Green Mountain antriclinorium was originally an actively subsiding and mobile basin into which thick series of argillaceous and clastic material accumulated.

Bonsecours schists originating from argillites are richer in potash than in soda (Table 1, Nos. 1, 3, 4), whereas the reverse is the case for schists derived from greywackes (Table 1, Nos. 2, 5). It is seen from Table 1 that the silica and alkali contents of a Bonsecours quartz-sericite-(albite)-chlorite schist (No. 3) compare favourably with the chemical data for grey Miller Pond slates (No. 8). Similarly, the alkali content of a quartz-sericite-albite-(chlorite) schist (No. 1) is comparable to the soda and potash values found in Beauceville shales (No. 9). Some relatively chlorite-rich quartzo-feldspathic schists have a low potash-soda ratio (No. 2).

It is difficult to account for soda enrichment in the Bonsecours schists, except locally by small-scale metamorphic differentiation, since there is no trace of an igneous intrusion which could be held responsible for albitization of sediments concerned. The fact that albite is apparently not associated with quartz veins, suggests that the formation of albite schists was not attended by considerable impregnation of material from without.

Though migration has certainly occurred, it is inferred that it was only on a small scale and intraformational in nature. The general increase in grain size with increasing metamorphism and the development of albite porphyroblasts in the axial zone of the anticlinorium are evidence of some diffusion. On the other hand, the metasomatic changes that have occurred, would probably fall within the known limits of variation in original composition of the sediments.

Bonsecours Chlorite Schist and Greenstone

The Bonsecours chlorite schists and greenstones of the Eastman-Orford Lake area have undergone low-grade regional metamorphism and contain mineral assemblages characteristic of the greenschist facies. However, it was not possible to trace directly textural, mineralogical and chemical changes from chlorite schists to the parent unmetamorphosed rocks within the map-area. The original nature of the chlorite schists must therefore be inferred from their mineral and chemical compositions and from comparison with chlorite schists in the Thetford, Disraeli and Warwick areas, and in Vermont.

In the Eastman-Orford Lake area, some of the more massive-looking chlorite schists are filled with small, grennish-white nodules, resembling amygdules. At some places, the rock has a pitted appearance, due to sub-circular cavities, in which residues of epidote and calcite are still discernible.

Both, greenstones and chlorite schists, were probably derived from rocks of similar composition; whereas greenstones retained many of their original textures, the chlorite schists are entirely recrystallized, probably as a result of more intense dynamic metamorphism.

Chemical data on Bonsecours greenstones and interbedded phyllites, consisting of four full and four partial analyses, are in close agreement with petrographic studies. When the calculated molecular proportions of the greenstones and the dark, crenulated phyllites are plotted on the diagram, they have the distribution shown in Fig. 4. It is seen that No. 5 and No. 6 fall within the epidote-actinolite-chlorite field. The plotted composition of No.6 is in agreement with the following data obtained by modal analysis of the greenstone: actinolite 47 per cent, epidote 21 per cent, and chlorite 10 per cent. (Introduce Fig. 4).

The general field and microscopic characteristics, the prevalent mineral assemblage, as illustrated by the ACF diagram, the surprisingly low $\frac{Na_2O}{K_2O}$ ratio and high magnesia content (Table 2, No. 8), all point to the assumption that the phyllite layers are volcanic ash beds or admixtures of sediments and pyroclastics.

Quartz Veins

Veins and stringers of quartz are widely distributed in the Bonsecours and Miller Pond schists, and appear to be related mineralogically to the immediately adjacent rocks. It is maintained that quartz, filling crests and troughs of minor folds or paralleling schistosity planes in form of stringers and nodules, is due to leaching of silica from the surrounding rock and subsequent deposition of quartz in areas of least stress.

Most quartz veins in the schists of the map-area do not suggest derivation from a magmatic source; it appears that they are mainly products of metamorphic differentiation involving solution and recrystallization of silica and were derived from the rocks in which they occur. Quartz stringers, paralleling schistosity S_1, are commonly truncated and at places offset by the late axial plane cleavage S_2, indicating that at least some mobilization of silica had taken place prior to the late period of deformation. Field observations and thin sections suggest, however, that diffusion of silica was to a large degree a late phenomenon, as evidenced by quartz-filled S_2 fractures and cross-cutting relationships with schistosity S_1.

Thickness

The total outcrop width of the Bonsecours group, measured across the regional trend, is 6.5 miles, of which 5.3 miles are within the area under study. Since the width represents two limbs of a major, slightly inclined anticline, the apparent thickness of one limb would be of the order of 16,000 to 17,000 feet. It would be very difficult to apply a correction factor that may compensate for the duplication of beds due to folding. However, the writer is of the opinion that 12,000 feet is probably closer to the true value.

The maximum width of the quartz-sericite-graphite-schist division is approximately one mile. A little over three miles south of the southern margin of the map-area, the graphite-bearing horizon reappears in a southeasterly trending belt reaching a maximum breadth of eight miles. It is quite probable that the graphite division is not uniformly thick along its strike due to original sedimentary and tectonic thickening and thinning of the beds. Although its base is not exposed in the map-area, and the upper boundary rather indistinct, the writer feels that the thickness of the graphite division is probably in the order of 2000 to 3000 feet.

On these assumptions, the estimated thickness of the quartz-sericite-schist division would therefore be 9000 to 10,000 feet. Crude measurements of the South Stukely banded greenstone indicate an approximate thickness of 400 to 500 feet, while the apparent thickness of the marble lenses varies from 10 to 450 feet and averages 200 feet.

Although variations in thickness of the Bonsecours group may be in part due to original deposition, shearing shows that tectonic forces played an important part in altering the apparent thickness. There can be no doubt, however, that the Bonsecours group is very thick. In view of the many assumptions made, the thicknesses given above may be in error by several thousands of feet and represent only an approximation at best.

Age and Correlation

The age of the Bonsecours group has long been a controversial matter. The writer agrees with Osberg (personal communication, 1959) that the Bonsecours rocks overlie the Tibbit Hill chlorite schists and the Pinnacle greywacke, and underlie the Sweetsburg slates; the latter have been traced around the nose of the Sutton-Green Mountain anticline into the Upper Cambrian Ottauquechee formation exposed on the eastern limb of the Green Mountain anticlinorium in Vermont. These facts indicate a Lower and/or Middle Cambrian age for the Bonsecours group.

Corroborating evidence from Vermont suggests a similar age for the Bonsecours rocks. The quartz-sericite-schist division, which in the writer's area overlies the graphite schist, is similar in lithology and structure to, and may be easily traced into, the Jay Peak-Pinney Hollow formations in northern Vermont; the latter succeeds and grades into the Hazens Notch graphitic quartz-sericite schist (Cady, 1960, p. 548).

The writer concludes that the quartz-sericite-graphite and the quartz-sericite rock divisions of the Bonsecours group are equivalent to the Hazens Notch and the Jay Peak-Pinney Hollow formations, respectively. Both, Hazens Notch and Jay Peak-Pinney Hollow overlie the Pinnacle greywacke and underlie the Sweetsburg slates; fossil evidence from Quebec's Oak Hill Series and from Vermont therefore suggest a Lower and/or Middle Cambrian age for the Bonsecours group.

Ottauquechee Formation

General Statement

Rocks of the Ottauquechee formation are exposed in a northeasterly trending wedge-shaped belt that is 0.7 miles wide at its southern extremity and a little over 1000 feet at the northern margin of the map-area. D

Two rock types in intimate association are typical of this formation: a massive, slate-grey quartzite and a dark-grey to black m phyllite; minor interbeds of siltstones, quartz-sericite-graphite schist and calcareous quartzites, chlorite schists and dolomitic marble beds are characteristically part of the formation. Several lenses of uralitized gabbro and numerous bodies of serpentinized peridotite are frequently encountered within the quartzite-phyllite succession. Three small plugs of a diorite breccia are apparently the only intrusions that show unconformable contacts with the enclosing rocks.

Apparently the formation is in conformable contact with the underlying Bonsecours and the overlying Miller Pond rocks. It grades into the former through a transition zone about 300 feet wide, that is made up of alternating horizons of impure quartzites, phyllites and quartz-sericite-chlorite-(albite) schists. Lenses of serpentinized peridotite are intermittently exposed along this zone. At several localities, however, the contact between the Ottauquechee and the underlying Bonsecours was located within a few feet.

West of Eastman lake and north of Parker pond, an actinolite-bearing greenstone underlies a grey, crystalline dolomite, which probably represents the base of the Ottauquechee formation in the map-area. North of Parker pond, a similar lens of marble consists predominantly of calcite and criss-crossing quartz veins.

The upper contact of the Ottauquechee with feldspathic greywackes and argillites of the Miller Pond formation is even more transitional and ill-defined. This transition zone is marked by an upward gradation from interlayered graphite schists, grey phyllites and greenish quartzites to a feldspar-rich, impure sandstone, siltstones and argillites. Since there are only a few outcrops of Ottauquechee and Miller Pond in the Missisquoi River valley, south and north of Eastman lake, the boundary between the two formations cannot be precisely located; it has been drawn as near as possible to the outer limit, in which the black phyllite and the grey-blue quartzite together are 90 per cent of the rock exposed.

Quartzite

The quartzite occurs in sharply defined beds from a few feet to 100 feet in thickness, interstratified with phyllites and the quartz-sericite-graphite schists, which make up the major part of the formation.

Excellent outcrops of a tough, blue-grey Ottauquechee quartzite are exposed on an east-west road, 5000 feet east of Libby pond. Half a mile south of this locality, a succession of six parallel quartzite ridges spaced at intervals of 500 feet strike northeast and dip vertically. Structural relations with the intervening phyllites and siltstones in the valleys indicate that the regular repetition of the quartzite horizons is due to folding. On account of their superior hardness and resistance to erosion, as compared with the associated phyllites, some of the quartzite ridges may be traced for thousands of feet.

Commonly, the rock shows a faint layering made up of regularly spaced and continuous bands of black colouring matter that resembles bedding. At places, concentration of such graphitic material in the quartzite results in a dark, massive and tough rock that strikes a sharp colour contrast with criss-crossing, one half to two inches wide veinlets of granulated white quartz. The veins in the quartzite are of such uniform distribution and persistent occurrence as to be characteristic of the formation everywhere. A system of jointing parallel with the strike and at right angles to the bedding is occasionally present; it contributed greatly to the reduction of the beds to small blocks; these, a foot or more in cross-section, are very common in the glacial drift of the region.

In thin section, the quartzite is composed of granulated quartz and various amounts of muscovite and black colouring matter. The latter is concentrated in different proportions in successive layers, so that some of the rock is laminated. The sub-rounded and sorted quartz grains range from 0.1 to 0.4 mm in size and are embedded in a generally quartzitic and, at places, silty or calcareous groundmass. The dark grains are coated and welded by thin carbonaceous matter. In some sections, the quartz grains are aligned and strained, and show effects of dynamic metamorphism. Most of the compact and massive quartzites have been consolidated by quartz cement, so that their detrital grains are tightly locked together by secondary quartz or carbonates or both together. Considering the high proportion of quartz, such rocks may appropiately be called impure quartz arenites.

In one thin section the writer observed impure quartz grains surrounded by rims of clear quartz. This suggests secondary outgrowth or enlargment of detrital grains tightly lockes together by authigenic or secondary quartz so as to fill completely the available pore spaces in the rock. Another section showed a granular sement of calcite filling pore spaces between quartz grains.

The feldspar content is low and albite porphyroblasts are rare. In schistose quartzites, alteration of thin quartzo-feldspathic layers (1.2 mm wide) with laminae of chlorite and sericite (0.02 mm wide) imparts a marked schistosity to the rock. Tourmaline, zircon, epidote and iron sulfides are common minor accessory minerals.

Phyllite and Quartz-sericite-graphite Schist

Phyllites and graphite-bearing schists underlie areas of low to moderate relief; particularly good exposures are found in the low areas north of Trousers lake and along the road, east of Libby pond. Excellent outcrops of a quartz-sericite-graphite schist on the east shore of Parker pond testify that the Ottauquechee belt, although attenuated, is a continuous one.

The phyllite is generally a black, shiny and fine-grained rock that shows a marked tendency to cleave into thin sheets or slabs. Schistosity is at places accentuated by thin, but macroscopically visible segregation bands of alternating quartzo-feldspathic and micaceous or carbonaceous material. Changes in lithology are common and gradation along and across the strike into graphite-or chlorite-rich varieties is typical.

Under the microscope, the rock seems to be composed almost entirely of micaceous material through which run thin parallel straks of finely crystalline quartz. The rock is typically plicated and shows two intersecting sets of S-surfaces, referable to different stages of rock deformation. Twisting and reorientation of mica flakes resulted in a slip cleavage that is superimposed on the originally undeformed and aligned flakes of micaceous material. Such wavy arrangement of micaceous and chloritic films is particularly characteristic of quartz-sericite-graphite schists.

Disseminated cubes of pyrite grow across the primary schistosity, and curvature of adjacent muscovite flakes indicates rotation of the porphyroblasts.

Single outcrops of Ottauquechee quartz-sericite-graphite schist are undistinguishable from similar rocks in the Bonsecours group, but, in general, the schists of the latter group contain wider quartz laminae and are generally albitic.

Thickness

The thickness of the Ottauquechee is difficult to assess, because of repetition of beds by folding and possibly faulting. Furthermore, considerable additions to the apparent thickness of the formation must be attributed to the many intrusions of ultrabasic rocks. Assuming an average dip of 75 to 80 degrees, its approximate thickness is estimated at 1000 to 1500 feet at its southern extremity; at its northern boundary and in the vicinity of Parker pond, the approximate thickness of the Ottauquechee formation is probably in the order of 200 to 500 feet.

Age and Correlation

The exact age of the Ottauquechee is unknown, since no fossils have been found in the map-area. There are, however, in Quebec and in Vermont very good indications that suggest a Middle or Upper Cambrian age for the Ottauquechee rocks.

In southern Quebec, rocks similar to the Ottauquechee are exposed in a more or less wide belt that extends from the Quebec-Vermont border to as far north as Temiscouata county and possibly beyond it.

Clark's description of the Sweetsburg slates (1937, p. 150) agrees well with that of the Ottauquechee in the map-area. The corresponding lithologies and stratigraphic positions of these respective formations are indicative of similar age relationships.

It is possible, however, that the writer's Ottauquechee includes Clark's upper Oak Hill Series, in other words, the Dunham dolomite, Oak Hill Slate, Scottsmore quartzite, Sweetsburg slate and possibly the latter's Vail slate member. It has been mentioned before that at the base of the formation lies a brown weathering, dark grey, crystalline dolomite criss-crossed by a network of quartz veins. This description is in close agreement with that of Clark' Dunham dolomite. In fact, some of the calcarous quartzites within the Ottauquechee strongly resemble Clark's Scottsmore quartzite (1936, p. 149).

A Cambrian age for the Ottauquechee formation has been generally accepted by most Vermont geologists, since it overlies the eastern equivalent of the Cheshire quartzite (corresponding to Clark's Gilman quartzite) in the Rochester-Middlebury area (Osberg, 1952, p. 65).

From the above evidence, it is concluded that the Ottauquechee formation in the map-area may be traced northward into Sweetsburg and Rosaire and southward into the Ottauquechee, as defined and described by Cady (1956), Osberg (1952), Béland (1957), and others (Map III).

Miller Pond Formation

General Statement

The Miller Pond formation has been named after Miller pond, a narrow half a mile long lake, northwest of Brompton lake and approximately 13 miles N. 25°E. of Eastman lake. The writer accepted the name proposed by Osberg since no adequate geographical term, previously unused in the literature, was available in the map-area.

In recent reports on the geology of the Eastman-Orford Lake area and immediate vicinity, Miller Pond rocks have been referred to as Mansonville group and Mansonville slates (Clark, 1930-31, 1934), 'Quartzite, some Slate' (Ambrose, 1942), Mansonville formation and Brompton Rocks (Fortier, 1945, 1946) Caldwell group (Cooke, 1950), and Caldwell facies (de Römer, 1957, 1958). Since the above terms (except the last) included the Ottauquechee formation and even the Bonsecours rocks, a new name had to be given to the predominantly greywacke-slate-schist succession, in order to separate it effectively from the underlying Bonsecours schists and the Ottauquechee quartzite-phyllite sequence.

The belt underlain by the Miller Pond formation has a constant width of about 2.5 miles. The rocks underlie a broad, rolling plateau that varies in altitude from 850 to 1250 feet and averages about 1000 feet above sea-level. The higher landforms are commonly underlain by relatively more resistant rocks of the schist division, southwest of Orford lake, while greywackes and slates crop out in the intervening low areas.

The formation is made up of four units: the greywacke-slate, the schist, the rhyolite and the greenstone divisions.

The contacts between the units are entirely gradational without clear-cut delineation. Massive, feldspathic greywackes and argillites at the base of the formation are succeeded by successively more schistose greywackes and slates; the latter sequence pass gradationally into quartz-sericite-chlorite schists, which, west of Orford lake, are overlain by an upper member of the greywacke-slate division.

West and east of Miller pond, from which the formation has its name, vast outcrops of a schistose and altered greywacke with intercalated, thin and unconspicuous interbeds of argillite and slate are exposed. Here and there, schistose greywacke beds grade across into sub-parallel zones of a highly disturbed rock that, in its lithology and complexity of folding, is similar to Miller Pond schists described below. These, somewhat irregular, 2 to 25-foot wide belts of intensely folded rocks, have a generally northeasterly trending schistosity. Numerous, contorted quartz veins parallel the schistosity or cut across it, and are characteristic of these zones. At some places, where the schistosity is distinctly plicated, a faint cleavage is developed. The attitude and mode of occurrence of the latter are strongly reminiscent of the slip cleavage (late axial plane cleavage S_2) typical of Bonsecours rocks. Slip along schistosity planes with consequent offsetting of folded segregational layers is extremely well exhibited in some outcrops.

Greywacke-slate Division

The greywacke-slate division takes up approximately four fifths of the Miller Pond formation in the map-area, and is exposed in a broad zone averaging one and a half miles in width and extending northeastward across the map-area. It overlies the Ottauquechee conformably along a heavily masked zone that follows the Missisquoi River valley for most of its length. Its eastern contact is with the igneous complex of the Serpentine Belt (including Orford and Chagnon mountains) along a sinuous line that runs from the southern boundary of the Eastman-Orford Lake area northeastward to Orford lake and thence takes a more or less rectilinear course to the north. Reconnaissance into adjacent districts indicated a northward (Miller Pond area) and southward extension of the greywackeslate sequence. It was observed, however, that south of Mansonville, greywackes and slates wedge out and gradually give way to an assemblage of schists that are in many respects similar to rocks of the schist division in the present area.

Greywacke

Megascopic Description

There is a gradation from feldspathic greywackes at the base of the formation to what appear to be typical greywackes interstratified with dark-grey slates and argillites higher up in the stratigraphic section. West of Long pond, several beds of arkosic grit, a few tens of feet thick, are interbedded with the basal feldspathic greywackes. This rock contains up to 35 per cent angular and rounded feldspar grains that range up to 1/8 of an inch in size, together with angular quartz and slate fragments that rest in an argillaceous matrix. Occasional horizons of feldspathic arenite, quartz arenite and conglomeratic beds are interstratified with the latter. The conglomerates are well-indurated gravel wackes consisting of rounded to sub-angular quartz pebbles set in an argillaceous matrix. They are probably intraformational. One small lens of dark and siliceous limestone is intercalated between beds of greywacke in the extreme corner of the St. Etienne map-sheet.

The greywackes are massive, well-indurated medium-grained sandstones that resemble an igneuos rock in weathering. They are dark to light grey when fresh and lighter in colour when weathered or leached.

Although the rock has generally a massive appearance in the field, closer inspection discloses a pronounced alignment of micaceous material that produces a rude schistosity parallel to the regional trend. At some places, the schistosity is cut by a faint fracture system that in its appearance is similar to the late axial plane cleavage encountered in the Bonsecours rocks.

Graded bedding, was occasionally observed; it is, however, not an obvious characteristic feature of the Miller Pond greywackes in the area. At most places, coarser fractions are abruptly succeeded by argillites and slate beds without apparent grain gradation. Subsequent washing away of the finer clay-sized fractions may explain this anomaly. It may be observed that relatively massive and apparently structureless greywackes southwest and west of Orford lake grade into schistose greywackes farther north. As a result, north and east of Eastman lake, Miller Pond rocks consist mainly of greywackes exhibiting a pronounced directional pattern. This is accompanied by a more advanced reconstitution and increased metamorphism in the schistose greywackes. The slates and argillites associated with the schistose greywacke similarly display greater internal reorganization and an incipient schistosity and lineation.

An analysis of a representative sample of Miller Pond greywackes is given in Table 1. The rock analysis is essentially in agreement with that of greywackes in other parts of the world; the rock is highly siliceous, has lime in excess of magnesia and contains more soda than potash.

Microscopic Features

A characteristic textural feature of the greywacke is the poor to moderate sorting and the presence of clastic grains and occasional slate fragments embedded in a finer grained matrix (Plate III B). The amount of matrix varies between 18 and 31 per cent. Another textural feature is the marked sub-rounded to subangular shape of the clastic grains. The rock fragments tend to be rounded, although in shape they depart widely from sphericity.

The clastic grains are composed mainly of quartz, feldspar and mica. Quartz usually forms 40 to 60 per cent of the rock; the grains are irregular and about 0.5 mm in size with a ratio of length to breadth of two to three.

Feldspar may form up to 24 per cent or more of the rock (up to 35 per cent in arkosic greywacke, Table 3, No. 1) and occurs in sub-rounded, irregular or rectangular crystals ranging in size from more than 1 mm to less than 0.1 mm. Two types of feldspar were distinguished: potash feldspar and sodic plagioclase; in one section only, was andesine encountered. The dominant plagioclases are: albite (An_{0-10}) and oligoclase (An_{12-20}). The oligoclase normally displays multiple twinning, whereas the albite is more often untwinned. In the oligoclase and in some albite, inclusions of sericite, epidote and chlorite are common; most of the albite, however, is clear or only faintly clouded. The potash feldspar is usually untwinned orthoclase and has been found in considerable amounts in one section only (Table 3, No. 1). (Introduce Table 3).

Muscovite occurs in large lamellae up to 1 mm in length and is usually associated with chlorite flakes. Accessory zircon, colourless or yellowish epidote, hematite, leucoxene and occasional anhedral grains of pink garnet are present in some sections. Patches of a carbonate (probably ankerite) occur in large detrital grains or as irregular aggregates within the matrix and replace grains and matrix alike.

Rock fragments constitute a small percentage of the rock and generally consist of black to grey slates or siltstones.

The matrix (in the order of 0.01 mm or less) is made up of interstitial silt and clay, which has been altered during compaction and incipient metamorphism largely to sericite and chloritic material. Replacement of larger grains by matrix minerals is evident; the grain margins are penetrated by tiny sericite and chlorite flakes resulting in hazy grain boundaries. It seems that part of the cement is due to the alteration of feldspar and part is made up of the detrital constituents; the greater part, however, has probably been derived from the recrystallization of original argillaceous material.

Slate and Argillite

Second in order of abundance to the above-mentioned sandstones are light-to dark-grey slates and argillites. Although the distribution, lithology and colour of the slates seem to be uniform throughout the area, there is a gradual change from light grey argillites and siltstones at the base to dark-grey, black, green, and purple slates at the top of the Miller Pond formation. In the vicinity of the schist belt, the slate becomes a dark-grey to greenish-grey sericitic variety. Its weaterhered surfaces are, at places, rust-stained from the weathering of contained pyrite.

The beds range from a few inches to several hundreds of feet in width and are characteristically intercalated between greywacke and greenstone horizons. Good outcrops of siltstones and argillites are exposed near the schoolhouse at 1000 feet and at 1.5 miles northeast of Eastman lake, respectively. Bedding is at places discernible and occurs in form of colour banding and faint laminations, which strike northeast and dip steeply to the southeast.

The slates invariably display a well-developed cleavage that is parallel to the schistosity and general trend of the adjacent rocks. At some places, closely-spaced fractures sharply truncate the above cleavage. The latter fracture system has been identified with folds which probably belong to the same orogenic period that was responsible for the late structures in the Bonsecours rocks. These fractures seem therefore to correspond to the slip cleavage found in the Bonsecours and Miller Pond schists.

In thin section the rock is seen to be very fine-grained (0.005 to 0.06 mm) and generally uniformly textured. Here and there, scattered quartz lenses and recrystallized mica and chlorite are aligned parallel to the prevailing schistosity. Accessory clastic grains of epidote and pyrite are occasionally present.

A few horizons of black, lustrous slates are found 3000 feet northwest of the Orford Lake bulge; these grade south and eastward into quartz-sericite-graphite-bearing varieties of the Miller Pond schists.

With the exception of two isolated beds, most of the purple and green slates occur east of the schist belt. Some outcrops are uniformly coloured; others, such as on the west shore of Orford lake, consist of sporadically distributed, irregular patches that show all gradations in colour from deep purple, through green to almost white, depending on the amount of leaching and the state of oxidation of their iron minerals.

The occurrence of green and purple slates is generally restricted to marginal areas of greenstone and tuff beds. The close association of coloured slates and greenstones suggests that the finely devided hematite in the slates was derived from the greenstones.

Under the microscope, the purple slates consist of tiny lenses and stringers of quartz embedded in a cryptocrystalline paste. Partial chemical analyses of Miller Pond slates are given in Table 1.

Greenstone

A continuous, 200 to 1000-foot wide belt of greenstone is exposed at the base of the greywacke-slate succession, west of Long pond. It is conformably overlain on the east by arkosic greywacke and conglomeratic beds, while its western contact is marked by massive greywackes and grey argillites, and serpentinized peridotite sills. Along the latter brecciated contact, replacement deposits of copper have been exploited for over the past hundred years.

The rock is uniform in appearance, both across its width and along its strike, although small alteration zones are everywhere apparent. Several tuff horizons were located within the greenschist and at its margins; they are exposed intermittently and are not useful as marker horizons. The grey-green tuffs have a pronounced schistosity and show tiny, oriented rock fragments distributed at random throughout the rock.

In the vicinity of Long pond, the rock shows well developed pillows, which strike N. 15°E. and dip at 60 to 80 degrees to the southeast. Their tops are consistently to the east. Zones of amygdules fringe the peripheries of some pillows; in the majority of cases, however, they are concentrated in the center of the pillows. The amygdules average 1/2 to 2 mm across, are commonly flattened parallel to the schistosity and are filled with quartz and feldspar.

Some greenstones of the eastern greywacke-slate beld also contain abundant amygdules consisting of circular cavities, 1/4 of an inch in diameter and filled with epidote or carbonates (Plate IV A). Acicular oligoclase, iron minerals and chlorite commonly make up the rim of the amygdules.

In thin section, the rock is seen to be composed essentially of tremolite-actinolite, chlorite, plagiocalse, quartz and calcite, with minor magnetite, epidote and talc.

The plagioclase occurs as a fine mosaic of shapeless grains; it tends to be untwinned and is probably of the albite-oligoclase variety. The amphibole is generally pale-green tremolite and takes the form of imperfectly terminated slender prisms and needles, with random orientations. Chlorite occurs as laths or irregular patches and veinlets replacing tremolite or be segregated in fine minor shear planes.

Two other small grennstone bodies of similar megascopic and microscopic appearance have been located east of the schist zone. (Introduce Table 4).

Schist Division

Distribution

Rocks of the schist belt occupy a northeasterly trending 1000 to 3000-foot wide zone in the center of the Eastman-Orford Lake area. In its southern portion, the zone is flanked on both, east and west, by greywacke and slate. Southwest and west of Orford lake the belt is overlain by rhyolite and underlain by greywacke and slate and dies out about two miles northwest of the lake. The Miller Pont schists are also exposed immediately west of Orford lake, where they underlie a thick sheet of spilitic greenstone.

Lithology

The schist belt comprises two dominant rock types: a quartz-sericite-chlorite schist and a greenstone associated with pyroclastic and coloured slate beds.

The quartz-sericite-chlorite schist consists characteristically of a segregation of quartzo-feldspathic layers, 1 mm or less in thickness, separated by laminae of micaceous material. Two thin horizons of a graphite-bearing variety have been located in the area west of Orford lake. A partial chemical analysis of a typical quartz-sericite-chlorite schist, as compared with an analysis of a Miller Pond greywacke or subgreywacke, is given in Table 1. Compositional layering is not as apparent as in the Bonsecours rocks, while the major schistosity S_1 is well-developed parallel to the bedding of the adjacent greywacke and slate beds. At places, the schistosity exhibits the characteristic minute crenulations and associated late axial plane cleavage S_2 (slip cleavage) typical of the Bonsecours rocks.

The greenish, fine-grained greenstones, are exposed in three lenses, 200 to 1000 feet across, and are interstratified with quartz-sericite-chlorite schists and green and purple slates. They are characterized by a well-developed compositional layering made up of thin light-coloured bands of quartz, feldspar and epidote alternating with darker layers of actinolite, chlorite and minor magnetite, sphene and carbonate. Other parts of the same outcrop exhibit deformed and sheared pillows and zones rich in amygdules. Nodules of epidote, up to one foot across, are common and are probably the result of original differences in composition, rather than due to metamorphic segregation. A partial chemical analysis of the greenstone is given in Table 6.

A somewhat more passive, isolated and small outcrop of greenstone is exposed south and north of the bent in the Montreal-Sherbrooke Highway, 2500 feet west of Orford lake. It is underlain by east-west striking and steeply dipping purple slates and conformably overlain by horizons of quartz-sericite-chlorite schist in what is probably the centre of a steeply southward plunging fold. It is inferred that the greenstone outcrop is part of an originally more extensive lava sheet, a remnant of which was preserved in the core of the fold. Stratigraphically, this sheet is probably about 900 feet below the main spilitic greenstone body described below.

The marginal areas of the greenstone lenses exhibit regular and continuous banding that is probably pyroclastic in origin. This is indicated by a rapid transition in mineralogical composition and in grain size. Thin sections show that the fine banding is not only due to an alignment of planar elements, but more commonly to a segregation of the darker minerals into bands, where they have formed with random orientation. This is suggestive of a relict bedding.

At places, the pyroclastic rocks grade into green and purple slates or clayey siltstones with a grain size ranging from 0.01 mm to less than 0.003 mm. The latter are similar to the coloured slates of the greywacke-slate division.

Structural Relations

The eastern margin of the schist belt is brecciated for most of its length and suggests a marked zone of dislocation. This is also indicated by the abrupt termination of east-west schistosity trends as contacts with the rhyolite- and the greywacke-slate-belts are approached. Similarly, one half mile west of Orford lake, east-west striking beds of quartz-sericite-chlorite schist and purple slates are apparently cut off by a northeasterly trending belt composed of rhyolite, cherty shales and pyroclastic beds.

It is believed that, following the deposition of shales and minor greywackes, normal sedimentation was temporarily interrupted by the extrusion of lava of rhyolitic composition and the deposition of pyroclastic beds; this was succeeded by greywacke and shales and covered by a thick sheet of greenstones west and north of Orford lake. During the first period of folding, Miller Pond rocks were thrown into folds and the predominantly shaly fraction converted into quartz-sericite-chlorite schists and subsequently brecciated.

During a renewed period of deformation, the schist zone became again the locus of considerable movement. It is inferred that stresses were relieved by faulting, whereby the upper part of the folded schist zone south of the rhyolite belt was displaced northward along a line coinciding with the above belt. The rhyolite was competent enough to resist folding and served as a glide plane for the upper schist horizons which, as a result of this displacement, came to overlie the rhyolite belt west of Orford lake.

Rhyolite Division

Distribution

Rocks of the rhyolite division occupy a 500 to 2000-foot wide belt that extends from a point 1.5 miles southwest of Orford lake northeastward to Stukely lake, 2.5 miles beyond the northern limit of the map-area. In its southern part, the belt is underlain by a zone of schists and overlain by greywacke and slate. In the vicinity of Orford lake, it is in contact with schists above and below, whereas north of the lake, the rhyolite belt is both, underlain and overlain, by greywacke and slate.

Lithology

The rocks making up the rhyolite division vary considerably in structure, texture and possibly composition. The major part of the belt consists of an evenly banded siliceous rock at the base, succeeded by a dense and massive, cherty rock at the top of the assemblage.

The layered rock is characterized by persistent colour banding. The bands are commonly light and dark grey, continuous and remarkably regular. The chert beds, in general ranging from less than one inch to several inches in thickness, usually show a fine lamination. The layers are sharply marked off from somewhat less pure cherty rocks, in which some of the fine laminae contain enough micaceous material to make the rock split into plates. At some places, the partings in the cherty rocks are as thick as the chert beds themselves and occasionally thicker.

Microscopic examination of the banded rock shows that it is composed of microcrystalline sericite, quartz, feldspar and chlorite. The platy minerals are oriented parallel to one another and give the rock a schistosity which conforms to the boundaries of the division. Small, broken quartz phenocrysts of irregular shape are present in most sections. At places, the crystal fragments are elongated and oriented parallel to the schistosity.

The upper dense and massive cherty rock, generally overlying the layered siliceous rocks varies in colour from black, one mile southwest of Orford lake, to a shiny white, west and northwest of the lake. The rock is tough, has a splintering conchoidal fracture and is at places, close-jointed. Weathering is commonly 0.5 inch deep and is accompanied by oxidation and conversion of an iron carbonate to small specks of limonite.

Under the microscope, the massive rock is a colourless, microfelsitic aggregate of feldspar, quartz and sericite in which small, corroded and broken grains of quartz are sparingly distributed. Small quartz-carbonate veinlets filling straight-walled fissures, cut across the matrix and quartz-phenocrysts. The grain of the rock is so fine that it is difficult to determine accurately the percentage of the constitutents. It is probable that the bedded material represents an intimately mixed material consisting of clay and silt on one hand and volcanic ash on the other. They may have been deposited contemporaneously or their hybrid nature may be due to mingling of pyroclastic and sedimentary material following erosion and redeposition. The presence of angular and broken crystal debris set in a fine matrix composed of comminuted mineral grains suggests that some of the beds at least are of pyroclastic origin.

Considering the highly porous nature of pyroclastic rocks and the unstable character of their fragments, it is possible that the cherty layers may represent pyroclastic beds, that were indurated by silicification.

Indications of fluidal structure suggest that the massive cherty rocks are lava flows, rather than sedimentary deposits. Lava of rhyolitic composition may turn to felsites in course of time; in that case their original nature should be betrayed by relics of sperulitic or perlitic structure; no threads or vesicles of original glass, however, were detected under the microscope.

In view of the pronounced flow structures and broken-up quartz crystals, the writer is of the opinion that the massive and cherty rocks of this division are lava flows of originally rhyolitic composition. Partial chemical analyses of two typical specimens of the banded and the massive siliceous rocks are given in Table 5. +) (Introduce Table 5).

The analyses indicate the high proportion of silica in both specimens and show the low $\frac{K_2O}{Na_2O}$ ratio in the rhyolite, in comparison to that in the banded ash beds.

Spilitic Greenstone Division

Distribution

An extensive belt of spilitic greenstones within the Miller Pond formation extends in a zone varying from 500 to 3000 feet in width from a point 1000 feet west of Orford lake, northeastward to Chain Pond, and possibly beyond it. On its northeastern margin, the spilitic belt is in contact with members of the greywacke-slate division. Although thick glacial deposits obscure its western contact for almost its entire length, scattered outcrops of greywacke northwest of Orford lake and in the northern part of the map-area, indicate that the greenstones overlie the former conformably. West of Orford lake, however, the greenstone is underlain by rocks of the schist division.

Macroscopic Description

Primary structures in the spilitic greenstone include pillows and flow breccia. Of common occurrence are yellowish-green knots and nodules resembling sheared pillows and indicating the dip of flow; these are well exhibited in the greenstone belt west of Orford lake. Schistosity and foliation are prominent secondary features and are exceptionally well displayed at the latter locality. All degrees of schistosity are present, from an incipient type that has little influence on the direction of fracture to strongly schistose types that are well-developed in the foliated and banded greenstones west of Orford lake. The bands range from

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+) By the Quebec Department of Mines Laboratories, Montreal, Quebec.

1/16 to 1/4 of an inch thick and are commonly light or dark-green-grey or yellow and simulate bedding. The banding is continuous and parallel to the contacts with the other rocks and with the schistosity in associated greywackes. Some of these regularly and continuously banded zones, marginal to the volcanic flows, grade across and along strike into schistose greywackes and probably represent sediments of pyroclastic origin.

At several places northeast of Orford lake, excellent sections show folded greywacke beds conformably overlain by volcanic flows. The folds range in amplitude from two to ten feet and are overturned to the west.

Microscopic Features

The rock commonly exhibits a fine-grained, intergranular texture of divergent feldspar laths and patches of chlorite and calcite with granules of pyroxene and epidote associated with actinolite. The coarser varieties are subophitic with feldspars penetrating relict granules of augite. Commonly, the albite occurs in clear laths up to 0.5 mm in length or stubby phenocrysts including chlorite and magnetite. Relict pyroxene is almost wholly replaced by chlorite and fibrous actinolite. Quartz is normally present in subordinate amounts and possibly results from the liberation of silica in the process of conversion of the original pyroxene to amphibole. Where it takes up a considerable percentage of the rock (Table 4), it may be contributed from the intercalated metasedimentary of pyroclastic beds. Chlorite commonly makes up 15 to 48 per cent of the rock. It occurs as irregular clusters interstitial between feldspar laths, replacing pyroxene or partly filling vesicules. In places, it is associated with a colourless variety that is spherulitic and is probably clinochlore. Epidote occurs as clusters of granules and irregular knots, paralleling the foliation of the rock or as veinlets accompanied by quartzo-feldspathic material. It is commonly associated with contacts between feldspar and amphibole. Ilmenite is generally altered to shapeless granules of leucoxene, that are brown or cloudy grey and white. Other minor accessories are rutile and magnetite.

Metamorphism

Miller Pond Quartz-sericite-chlorite Schist

When traversing from west to east across the Miller Pond greywacke-schist contact, it is apparent that there is a gradual transition from greywackes and slates into partly reconstituted quartz-sericite-chlorite schists. This transition, observed in the field within a distance of 200 to 600 feet, suggests strongly that the quartz-sericite-chlorite schists are metamorphosed greywackes and slates; this is also supported by the similarity in chemical composition (Table 1, Nos. 5 and 6).

The increased metamorphism is indicated by the gradual disappearance of the original clastic structure of the greywacke and the formation of a finely laminated schist, accompanied by abundant quartz veins. In that respect, Miller Pond schists closely resemble Bonsecours schists, although the degree of recrystallization and mechanical reconstitution is not as advanced in the former as in the latter.

Although schistosity is well-developed and incipient segregation into light and dark minerals is obvious, compositional layering due to metamorphic processes is not immediately apparent. At some places, the original bedding is still preserved by the persistence of darker layers that represent the original argillaceous beds.

Relict clastic grains of quartz and feldspar, measuring up to 1 mm across, are surrounded by a partly recrystallized matrix to which a semi-schistose texture is imparted by the oriented growth of crystalloblastic minerals, principally muscovite, their long axes being parallel or sub-parallel to S_1 and S_2, (Plate II, A and B).

In Table 1 the analysis of a typical Miller Pond quartz-sericite-chlorite schist (No. 5), as compared with the analysis of a Miller Pond greywacke (No. 6), appears to be accompanied by no significant increase in silica, nor is there any suggestion of increase of Na_2O or K_2O. There is no evidence that the content of any essential constituent has been appreciably changed by metamorphism.

Miller Pond Spilitic Greenstone

Several lines of evidence in the map-area suggest a secondary origin of albite in the Miller Pond spilitic greenstones. Owing to very minute inclusions of chlorite and sericite, most of the feldspars are cloudy, and produce a mottled appearance in what appears to be a relict ophitic texture; amygdaloidal zones with euhedral, water-clear albite crystals lining former vesicular cavities, whose centres are now filled with quartz, chlorite and calcite, suggest a hydrothermal origin of albite. However, no evidence for albitic segregation veins or relics of more calcic plagioclase could be found in the field or in thin section.

Two partial analyses of spilitic greenstone are given in Table 6. (Introduce Table 6).

Metasomatic Dolomite

General Statement

Four small bodies of dolomitic rocks have been found in the vicinity of Orford lake; they have the following characteristics in common:

1) Their size is small and their shape lensitic.

2) They are marginal to serpentinized peridotite bodies.

3) They grade into ultrabasic rocks by gradual decrease and increase of carbonate and serpentine minerals, respectively.

4) The purer fractions consist of a buff-coloured, vuggy and crystalline dolomite, mottled with greenish patches of serpentine or talc.

A particular study was made of one of these dolomitic bodies, located in the western extremity of lots 3 and 4, range XI, Bolton township, and 2000 feet southwest of Orford lake. Its mode of occurrence and mineralogy are representative of the rock and, furthermore, it is easily accessible from the Montreal-Sherbrooke Highway.

Description

The dolomitic body mentioned above is 100 to 300 feet wide and approximately 1500 feet long, and is exposed along the eastern and western margins of an irregular mass of serpentinized peridotite. Its contact to the east is a much silicified greywacke of the Miller Pond greywacke-slade division. A traverse across strike from the ultrabasic rock on the west, over the dolomite, to the silicified greywacke on the east, a distance of about 800 feet, disclosed the following facts:

The ultrabasic typically exhibits all shades of green and black and is usually mottled due to the presence of numerous blotches of mesh-structure serpentine, which is characteristic of partially replaced olivine. Stringers of iron ore granules are developed in cracks; at some places euhedral porphyroblasts of magnetite replace antigorite flakes.

As the contact with the dolomite is approached, there is a general development of talc and carbonate. In hand specimen, the rock of this transition zone (about 50 feet wide), has the appearance of a breccia made up of sub-angular to rounded patches of serpentinized material ranging from microscopic to half an inch in size, criss-crossed by numerous, narrow and irregular talc-carbonate veinlets.

Excellent examples of replacement of antigorite by carbonate and minor talc may be observed. At places, where the mesh structure is not entirely destroyed, the carbonates seem to have followed the olivine and to have spread from these.

A few feet farther to the east, the rock becomes lighter in colour due to the increasing amount of dolomite and talc. It is characterized by round to oval patches of varying size of thorn-shaped antigorite, through which run occasional, thin (1/16 of an inch wide) seams of cross fibre asbestos. The clots are embedded in a sutured mass of small, rounded carbonate grains separated by sheaves of white talc fibres. All stages of replacement may be noticed, from that of serpentine practically free of carbonate, to that in which the former is almost completely obliterated and surrounded by fine-grained, variously oriented aggregates of carbonate (Plate IV B).

Gradually, over a distance of some 40 feet, the number of antigorite and mesh serpentine patches decreases to a point, where the rock becomes a pink to buff-coloured, vuggy dolomite, peppered with isolated islands of medium to light-green serpentine and criss-crossed by irregularly distributed white quartz veins.

Siliceous greywacke beds border the dolomite to the east. In hand specimen, it is a tough, grey-blueish rock, speckled with jasper-like patches that are erratically distributed throughout the greywacke and do not seem to follow a particular horizon. At places, straight-walled, 1/16 to 1/8 of an inch wide quartz veinlets cut across the grey and red patches alike, resulting in a breccia-like appearance. Under the microscope, the rock shows abundant evidence of addition of, and consolidation by, quartz and hematite cement. Part of the greywacke paste has been replaced by silica cement, so that at places, the whole rock is made up of interlocking, hematite-stained crystals of quartz. Normal greywackes and slates are exposed a few hundred feet southeast of the silicified greywacke.

Origin

There is no evidence that the dolomite is primary. The following criteria support a metasomatic origin for the dolomite in the map-area.

1) The general mode of occurrence of the outcrops, that is, the location of the dolomite near the margins of ultrabasics, suggests a close relationship between the serpentinized peridotites and the carbonate rocks.

2) The general passage from serpentinized peridotite over antigorite, talc and dolomite to a massive dolomite rock indicates a close genetic association between ultrabasics and the carbonate rocks.

3) Islands of partly digested antigorite and talc are con-

spicuously present in the massive dolomite.

4) The irregular, swelling and pinching shape of the carbonate rocks does not seem to conform to any particular stratigraphic horizon.

5) There is definite indication in thin section that carbonatization of the silicate minerals has occurred. The transfer of material was therefore probably in the direction: Serpentinized peridotite ⟶ carbonate rock.

6) The expected liberation of silica as a result of carbonatization produced abundant quartz veins in the dolomite and resulted in extensive silicification of the adjacent greywackes.

A partial chemical analysis of the dolomite is given in Table 7.
(Introduce Table 7).

Thickness

Estimates of thicknesses have been complicated by the fact that the western and particularly eastern boundaries of the formation are entirely gradational and at places difficult to delimit accurately. Numerous instances of broad and open folding have been found in the area underlain by the greywacke-slate assemblage with no definite indication of repetition by faulting or isoclinal folding. It is suggested that the Miller Pond formation of the map-area is probably in the order of 1000 to 2000 feet thick.

Age and Correlation

The greywacke-slate unit of the Miller Pond formation dies out gradually southeast of Mansonville, where the major part of the formation is taken up by purple and green slates with occasional grit beds. The writer agrees with Cady's opinion that the rocks of the schist division in the map-area are stratigraphically equivalent and lithologically alike to, and therefore correlatable with the Stowe formation in Vermont (1960, p. 549).

Since no fossils have been found in the rocks underlying the

Castle Brook graptolites, a Cambro-Ordovician age is suggested for the Miller Pond rocks in the map-area.

Beauceville Formation

General Statement

The Beauceville formation forms a northeasterly trending belt at the eastern margin of the map-area. It comprises mainly two rock types: a metabasalt exposed on the eastern slopes of Chagnon mountain and an overlying series of interbedded slates and quartzites, which generally occupy areas of low relief.

Metabasalt

Macroscopic Description

A metabasalt, exposed on the eastern slopes of Chagnon mountain, constitutes by far the largest body of volcanics in the map-area. This belt extends from Trouserleg pond, where it is 1500 feet wide, northwards to within 1200 feet east of the summit of Chagnon mountain, where it reaches a maximum width of about one mile, then swings eastward across the Chagnon-Orford gap. to cover the eastern slope of the latter mountain. It is underlain on the west by gabbro and the acidic facies of the Orford-Chagnon-Baldface Complex and overlain by a series of interbedded slates and quartzites on the east.

The rock is typically grey-green, massive and fine-textured. The basal part of the flow contains irregular patches of a quartz-rich rock, which represents the acid differentiate of the basic magma that gave rise to the Orford-Chagnon-Baldface Intrusive Complex. In the upper part of the flow, the rock is characterized by sheared pillow structure and wrinkled or ropy forms as well as flow breccia, the latter being particularly well exhibited in a road-cut of Highway No. I, about 0.7 miles east of Orford lake. The eastern contact of the belt is also characterized by irregular zones rich in amygdules and carbonates.

Broadly viewed, the rock is of uniform texture and composition. However, about ten per cent of the flow is taken up by discontinuous and irregular patches of an extremely tough rock, distributed sporadically throughout roughly the central part of the belt. The glass-like rock is aphanitic, has a conchoidal fracture and suggests a mobile and quickly solidified flow.

A northeasterly trending 0.5-mile long breccia zone consisting of angular lava fragments cemented by quartz and feldspar occurs a few hundred feet west of O'Malley pond. Thin stringers and small concentrations of iron sulphides and oxides are associated with the breccia zones.

Microscopic Features

The Beauceville metabasalt is a highly altered rock similar in mineral composition to the underlying gabbro. The rock is essentially a completely uralitized basalt, in which almost no primary minerals have been preserved. The feldspars make up from 30 to 60 per cent of the rock and are usually clouded and saussuritized. Some of the fresher feldspars show broad albite twins suggesting that they are recrystallized products of a more calcic primary plaioclase. Uralite occurs in distinct, euhedral crystals or in aggregations of slender prisms, parallel in position to each other, indicating alteration from pyroxene. Some of the needles (probably actinolite) are 8 mm long and average about 0.03 mm. Some sections exhibit an originally poikilitic texture, in which euhedral uralite crystals are enclosed in large saussuritized feldspars. Other sections show pale green amphiboles enclosing small feldspar laths and cut across by 0.5 mm wide veinlets of grey-green chlorite. The latter occurs in well-developed crystals replacing uralite and is also, together with shreds of amphibole and altered feldspar, part of the matrix in aphanitic portions of the rock. Small grains of clinozoisite are strongly pleochroic clouded epidote crystals are present in almost every section. Sphene is present here and there, and is commonly clouded with whitish leucoxene. Quartz occurs in veinlets together with fresh feldspar and chlorite. Iron sulphides are the most common accessories. Apatite is rare.

Almost all minerals making up the metabasalt appear to be secondary, which suggests that the volcanics were subjected to strong deuteric action, or were permeated by hydrothermal solutions that emanated from the magma responsible for the Orford-Chagnon-Baldface intrusion. This resulted in uralitization of pyroxenes and the formation of cross-cutting veinlets composed of quartz, relatively fresh-looking sodic feldspar and euhedral chlorite crystals.

Slate and Minor Quartzite

Slates with interbedded minor quartzite horizons of the Beauceville formation occupy areas of low relief in the southeast corner of the Eastman-Orford Lake area.

Dark, argillaceous slates overlie the above described metabasalt conformably and constitute about 90 per cent of the slate-quartzite assemblage in the map-area. The slates are as a rule, laminated, the thin beds consisting of continuous and alternating graphite-bearing and silty horizons. At places, the beds exhibit folds which range from a fraction of an inch to several feet across. A few outcrops exposed on the west side of a north-south gravel road, 1500 feet north of Malaga pond, show angular fragments of impure quartzite and graphitic slate embedded in an ill-defined matrix composed of apparently similar ground-up material. The brecciated rock, which seems to be of local occurrence has a total width of a few hundred feet and is exposed about 1500 feet east of the metabasalt-slate contact. A partial analysis +) of a typical dark and argillaceous Beauceville slate disclosed 2.12 per cent and 4.05 per cent for Na_2O and K_2O, respectively (Table 1).

While laminated and black slate are by far the most preponderant sediments in the Beauceville of the area, jointed, massive

+) 300 feet west of the northern tip of Malaga pond. (Analyzed by the Quebec Department of Mines Laboratories, Montreal.)

quartzite beds, up to three feet wide, are quite common (Plate V A). On the south side of a gravel road, 1.5 miles east of South Bolton, sheared and indistinct fragments of quartzite and slate are enclosed in a shaly matrix that 'flows' around the lens-like fragments. It is probable that intense folding together with shearing eventually resulted in the disruption and separation of the quartzite beds, thus bringing about an offsetting of the lens-like quartzite fragments. At some places, quartzite fragments have lost their angularity and may easily be mistaken for boulders or pebbles of a true conglomerate. Other exposures of laminated slate with intercalated and disrupted quartzite lenses may be seen 2000 feet northeast of Malaga pond, just beyond the eastern boundary of the map-area.

The grey quartzites are commonly of uniform grain size and are relatively pure. Quartz constitutes 75 to 85 per cent of the rock and occurs in small (0.02 mm) subangular grains with sutured boundaries. Rare, detrital feldspar, some of them, partly altered to saussurite, have been found in one thin section. Muscovite flakes, zircon and pyrite grains are commonly minor accessory minerals.

Structural Relations

Cooke, Clark and Riordon, among others, are of the opinion that the Beauceville, considered Middle Ordovician, is separated from the underlying greywacke-slate assemblage by an angular as well as erosional unconformity, thereby suggesting an early disturbance preceding the Taconic orogeny.

There is no indication in the map-area of a basal conglomerate underlying or overlying metavolcanics of Chagnon mountain. The writer made numerous traverses across the boundary between the Miller Pond and the Beauceville formations, which, immediately south of the map-area, is almost everywhere transitional over a distance ranging from 200 to 800 feet. There is, however, an apparently local shear zone separating greywacke-slate from Beauceville rocks, 1.5 miles southeast of South Bolton. Two-foot wide quartz veins and a pronounced schistosity in the gabbro as well as in the volcanics indicate that some movement may have taken place locally along a north-south plane. The seemingly offset pattern of the lava body also suggests this.

Age and Correlation

A Middle Ordovician age for the Beauceville formation has generally been accepted on the basis of fossil findings in several localities outside of the map-area. From the studies of numerous collections of graptolites from the famous Castle Brook locality (3.3 miles southeast of Orford lake), various writers (recently, Ambrose, 1942 and Cooke, 1950, p.48) concluded that the age of the graptolite assemblage is equivalent to lower Trenton.

Recently, various authors familiar with the Beauceville rocks, have expressed the opinion that certain areas mapped as Beauceville may actually belong to the 'Caldwell' lithology. If this proves true, then deposition of Miller Pond rocks could extend well into Middle Ordovisian. However, judging from his own observations of the Castle Brook lithology, the writer is inclined to think that at this latitude the Miller Pond-Beauceville contact is west of Chagnon mountain as indicated on the map (No.I).

Beauceville rocks have been traced southward across the International boundary into Vermont, where they were named the Moretown formation by Cady (1956).

From information gathered during a field trip. supplement by supporting evidence from the literature, it is concluded that the Beauceville of the Eastman-Orford Lake area is stratigraphically equivalent to the Moretown formation in north-central Vermont as has been suggested by Cady (1960, p. 550).

Intrusive Rocks

General Statement

The intrusive rocks of the Eastman-Orford Lake area are part of a northeasterly trending belt, named the 'Serpentine Belt' by Dresser (1910, 1913, 1920), that extends from the Green Mountains in Vermont, throughout the length of the Eastern Townships of Quebec and into the Schickshock Mountains of Gaspé. In the map-area, the rocks of this belt comprise serpentinized peridotite, pyroxenite, gabbro, an 'acidic rock', quartz-diorite-and granite-breccia, and lamprophyre dikes. The bulk of the igneous rocks have the form of elongated sills or laccoliths, the emplacement of which was controlled both, by the pre-existing structures and by the competency of older rocks.

Serpentinized Peridotite

With the exception of a small lens of dunite exposed 2000 feet east of Parker pond, the majority of the olivine-bearing rocks are serpentinized peridotites, which grade from serpentinite on one hand, to pyroxene-rich fractions on the other. All gradations can be found in one outcrop between a pure serpentinite and only slightly altered peridotite.

Most of the outcrops of serpentinized peridotite are found in two narrow, well defined, sub-parallel belts conformable in strike to the regional trend. One belt is co-extensive with the Ottauquechee formation and the basal part of the Miller Pond. The other invades the Miller Pond schists and underlies the massive rocks of the Chagnon and Orford mountains. No ultrabasic bodies were found in the Bonsecours group or in the area underlain by Beauceville rocks.

With the exception of large and irregularly shaped bodies of ultramafic rocks in the vicinity of Orford lake, most of the serpentinized peridotite outcrops are sill-like sheets ranging in length from a few tens of feet to at least one mile. They are characteristically associated with, and appear to be genetically related to, pyroxenites and gabbroic rocks.

The rock is usually dark-green on a fresh surface, but weathers to a characteristic greenish-white colour of the verde antique type. Such varieties are usually traversed by numerous fractures filled with wholly serpentinized material. Less common is a uniformly serpentinized and someqhat more talcose peridotite, which, on weathering, takes a rusty brown tint. Immediately south of Orford lake the verde antique type contains several 1-foot wide shear zones, in which polished, pebble-like masses of relatively fresh peridotite are embedded.

The serpentinized peridotite varies in composition from place to place. The bulk of the rock is made up of scattered remnants of irregularly fractured olivine that is partially or completely replaced by scaly serpentine (of the antigorite variety) producing the usual mesh structure. Locally, concentrations of rounded pyroxene crystals (both enstatite and diallage), the boundaries of which are deeply corroded, are embedded in a coarse serpentine groundmass. Magnetite and rare chromite are invariably present in small disseminated grains and are commonly visible on fresh surfaces of the rock. At 300 feet northeast of Long pond, the northern end of a serpentinized peridotite body is wholly altered to a brown-weathering, talc-carbonate rock made up of talc, magnesite and small amounts of dolomite. No deposits of pure talc or steatite were found in the map-area. On the east shore of Long pond, an outcrop of altered peridotite contains several 6-inch wide, irregular veins of white to pale-green fibrous crystals of brucite, several inches in length.

Pyroxenite

Pyroxenite is almost invariably associated with serpentinized peridotites. It forms sheets and irregular pods capping the peridotite, and also occurs as dikes cutting the latter rock. South of Orford lake, where pyroxenites are best developed, the two rocks are interbanded and form a series exhibiting all variations in composition from serpentinites to rocks composed wholly of coarse-grained pyroxene.

The pyroxenite is usually coarse-grained and weathers from rusty brown to grey to almost white, depending on the grain size and the amount of olivine or serpentine it carries. The predominant mineral of the rock is uralite, which at places still retains the form of the original pyroxene. Small remnants of greenish diallage exhibiting a fine lamellar structure are still visible; in a few sections enstatite seems to be the dominant pyroxene. Chlorite is present in minor amounts and is secondary after amphibole. Patches of mesh-structure serpentine in some of the sections observed, attest the presence of original olivine in the rock. Feldspars (15 to 45 per cent) are saussuritized and contain small inclusions of epidote.

Gabbro

Gabbro appears to be the principal intrusive rock of the map-area. By far the largest mass of gabbro is exposed in the eastern part of the map-area, where it underlies the western slopes of Orford and Chagnon mountains, an area of about four square miles.

Small gabbro dikes and sills were located in the Miller Pond and Beauceville formations and several gabbro sills not exceeding one mile in length, have also been found within the Ottauquechee.

The gabbro massiv at Orford and Chagnon mountains is underlain by interlayered pyroxenite and peridotite and capped by irregular patches of an acidic rock and thick lava flows, which form the crests of the above mountains. In its megascopic appearance the average gabbro is a dark-green, medium-grained, massive and equigranular rock, in which the ferromagnesian minerals are preponderant over feldspar.

The highly altered rock is made up largely of uralite and saussuritized feldspar. Except for a few scattered remnants of augite and rare diallage, most of the pyroxenes have been altered to uralite. Most of the plagioclases are thoroughly altered to cloudy and isotropic masses of saussurite, which in some cases, completely mask the twinning of the feldspars. In a few sections, however, labradorite could be identified. Associated with the highly altered grains and surrounding the turbid saussurite material are abundant untwinned and fresh-looking feldspars that are probably recrystallized plagioclase of albitic composition. Small plates of blue-green chlorite, fairly characteristic of the rock, commonly surround uralite or cut across both, pyroxenes and amphiboles. Other accessories include small aggregations of shapeless clinozoisite grains and small well-shaped apatite crystals. Leucoxene is usually found in small amounts and is associated either with tiny grains of sphene or with amphibole. Quartz and calcite are occasionally present. Pyrite and pyrrhotite are common constituents in almost every section observed.

The typically ophitic texture is characterized by large plates of green uralite enclosing numerous thin laths of feldspar; where feldspars are of the same order as the amphiboles, the texture becomes subophitic.

On the whole, the rock appears to be homogenous; locally, however, and particularly as the top of the sheet-like intrusive is approached, the gabbro becomes lighter in colour and passes gradually into a dioritic facies, in which ferromagnesian minerals are subordinate to the amount of feldspar. Pegmatitic patches become very numerous in the upper levels, presumably due to the concentration of volatiles near the top of the intrusion (Fig. 5). In thin section, this is accompanied by a definite increase in the albite molecule.

Steeply north or south-dipping longitudinal and cross-joints are well developed. Some of the tension fractures are filled with discontinuous diabase dikes varying in width from a few inches to two or three feet. Near the northeastern margin of the area, the gabbro is haphazardly criss-crossed by vertically dipping, dark and porphyritic dikes containing euhedral plagioclase crystals embedded in a fine-grained ferromagnesian matrix.

There is no record that gabbro dikes or sills have intruded Silurian or Devonian beds (Ambrose, 1942). Truncation of a fine-grained rock of apparently basaltic composition by somewhat coarser-grained gabbroic rock has been observed at various places. However, no clear-cut gabbro-basalt contact could be located. This is to be expected, since chilled portions of a fine-grained gabbro are indistinguishable from basalt, particularly if both are petrologically alike. The contact relations are further obscured by zones or patches of an acidic rock exposed in the upper levels of Orford and Chagnon mountains.

The writer is of the opinion that minor intrusions of basic sills may have been widely separated in time; this may account for gabbro cutting Ottauquechee and Beauceville rocks. It is reasonable to suppose that the gabbro underlying Orford and Chagnon mountains is part of a large intrusion that reached its culmination in Taconic time.

'Acidic Rock'

The greater part of the roof of Orford and Chagnon mountains is taken up by a generally quartz-rich rock, here termed 'acidic rock'. It occurs in irregular belts and discontinuous patches varying in size from 1000 feet long and 500 feet wide, to elongated and embayed zones extending for miles and measuring from one half mile to several hundred feet across.

Megascopically, the rock has a wide range in composition, texture, and colour, depending on the amount of salic constituents, and on whether the acidic portions are within the areas underlain by gabbro or by lava. Where in contact with gabbro, the rock invariably exhibits a zoned structure; the center commonly consists of a light, coarse-grained granophyre-like rock characterized by an abundance of interpenetrating, relatively fresh-looking, feldspars and quartz grains, associated with minor saussuritized feldspars and amphiboles. The rock passes rapidly into a medium to coarse-grained variety, in which clusters of quartz crystals up to 6 mm.across are embedded in a groundmass of dioritic composition (Plate V B). By gradual decrease in feldspars and a proportional gain in mafic minerals, the rock passes into a normal gabbro. The width of the demarcation line between the quartz-rich fractions and the ordinary diorite or gabbro is in the order of a foot or so and can easily be made out in the field, on account of the rough weathering surface of the 'acidic rock' in comparison to the relatively smooth gabbro outcrops.

The contact between the 'acidic rock' and Beauceville lava is at places quite sharp. The quartzose rock, characterized by uniformly distributed quartz aggregations in a fine-grained mafic matrix, passes abruptly into an ordinary, evenly textured, lava-like rock with no indication of quartz. The contact is, however, not everywhere a streight line; commonly, the quartz-rich fractions are in form of narrow bands and wedges that penetrate and surround the fine-grained basic rock and show clear evidence of replacement structures.

Comparatively fresh-looking quartz and feldspar veinlets invade and cut across saussuritized feldspars of andesitic composition (Ab_6 An_4) as well as uralite grains (Plate VI A). Quartz occurs in well crystallized grains and is commonly interlocked with feldspars that show a well developed carlsbad or albite twinning. Blobs of quartz usually consist of many interpenetrating grains, some of which exhibit wavy extinction. At places, the quartz grains include shreds and fragments of amphibole and dusty inclusions of altered feldspars. The blue-green amphibole is commonly the uralite variety and generally surrounds and replaces original pyroxene grains, with which it is optically parallel. Where the 'acidic rock' has a dioritic matrix, the amphibole is dark, and is probably hornblende. Blue, well crystallized plates of chlorite commonly accompany the amphibole.

The plagioclase is invariably altered to a turbid, isotropic mass. Accessory minerals include shapeless patches of epidote, tiny sphene crystals and rare apatite grains and iron minerals. Minor muscovite is present in quartz and feldspar-rich portions.

Quartz-Diorite- and Granite-Breccia

Five small and rounded to lenticular bodies of quartz-diorite breccia are exposed in the vicinity of Trousers lake. The stocks or shett-like masses are 100 to 1000 feet in diameter and are, as a rule, associated and surrounded by serpentinized peridotite. Five other plugs of grey, brecciated granite, which are probably genetically related to the above quartz diorite, crop out on the islands 1500 feet north of the eastern arm of Trousers lake and 500 feet west of the Eastman-Bolton Centre gravel road. No contacts with the adjacent greywacke, gabbro or peridotite were observed.

The quartz-diorite breccia is relatively fresh and is characterized by occassional sub-angular inclusions of vitreous quartz, from a fraction of an inch to two inches across, embedded in a fine to medium-grained, gray, uniformly textured groundmass. Other inclusions consist of quartz-sericite schist and rare peridotite fragments. In thin section, the rock seems to be composed of 15 to 35 per cent quartz, 45 to 55 per cent sodic feldspar and 10 to 15 per cent of dark-green actinolite. Sericite and potash feldspar occur in small amounts. Common accessories include chlorite, leucoxene and minor apatite.

All five outcrops of granite breccia at Long pond are similar in field appearance and show comparable textural and compositional elements. The exposures range from small knobs several tens of feet to masses 1000 feet across, and are probably part of a single body in depth. Contact relations of the granite outcrops with the adjacent ultrabasics and greywacke are obscured by thick glacial and alluvial debris.

Megascopically, the rock consists of sub-rounded fragments of granite (over 60 per cent of the rock) and occassionally of greenstone, greywacke and altered peridotite in a fine to medium-grained groundmass of somewhat more mafic composition. Due to their superior resistance to weathering, granite fragments stand out in relief, resulting in an unusally rough and uneven surface (Plate VI B). Conspicuous milky quartz veins attaining thicknesses of more than 6 feet can be traced along the regional trend of the surrounding rocks for distances exceeding 100 feet.

Under the microscope, the fragments show an allotriomorphic texture and a mineral composition typical of granite. There is clear evidence of two feldspars: a sodic and a potash-bearing variety. The former (about 35 per cent) has sutured outlines, and is filled with sericite; it exhibits good polysynthetic twinning and has the composition of albite; some grains are offset or truncated by tiny quartz stringers. The latter variety makes up about 20 per cent of the rock and is remarkably fresh-looking in comparison to altered albite. The 2 mm grains display twinning and appear to be definitely younger than the albite and most of the feldspar. Quartz occurs in anhedral grains, 1 mm in size, and makes up about 41 per cent of the rock. Some grains have sutured boundaries and show a lamellar wavy extinction. Others include remnants of sericitized albite and are associated with twinned potash feldspar in small veinlets that cut across the matrix. Muscovite (5 to 7 per cent) occurs in well crystallized plates, and is associated with small amounts of biotite. Zircon and apatite are minor accessories.

The usually grennish matrix consists of a fine to medium-grained micro-breccia made up of dark-green chlorite, minor actinolite, and anhedral quartz and feldspar showing signs of deformation.

The relation of minor intrusions of granite and quartz diorite to serpentinized peridotite is a matter of considerable interest. Such intrusions are completely absent from the large areas underlain by sedimentary rocks, suggesting that a genetic relationship may exist between the acidic and ultrabasic rocks. This hypothesis appears particularly attractive in areas, where basic as well as ultrabasic phases are associated with acidic rocks, such as is the case north of Trousers lake.

Lamprophyre Dikes

Apart from the major plutonic bodies, several basic and deeply, weathered dikes have been located in the Eastman-Orford Lake area. They usually range from a few inches to 30 feet in width, and fill vertical, transverse fractures, which, due to the unhomogeneity of the rocks, are rarely continuous. The majority of the dikes fall into two varieties distinguished from each other by the phenocrysts they carry and the nature of their matrix.

One variety is exposed in the area underlain by Bonsecours schists and consists of a uniformly textured groundmass in which light-coloured, idiomorphic crystals of feldspar are embedded; the latter range from 1/8 to 1 inch in size and make up from 10 to 25 per cent of the rock. At places, spheroidal weathering is conspicuous. In thin section, the feldspar is seen to be a well-twinned somewhat altered andesine lying in a dense groundmass of radiating, slender laths of augite, andesine, dark-green hornblende, muscovite, some biotite, and magnetite. Elliptical cavities within the matrix are filled with calcite. A faint resemblance of poikilitic texture is shown at places between the plagioclase and the dark grains. Secondary minerals are quite abundant and consist of sphene, epidote and chlorite formed by the alteration of the pyroxene and amphibole. Microscopic examination of a lamprophyre in the South Stukely quarry reveals small phenocrysts of andesine sprinkled in a groundmass of small needles of dark-brown barkevikite and plagioclase; prismatic crystals of apatite and patches of calcite are relatively abundant.

The second variety of lamprophyre dikes crops out within the area underlain by Miller Pond rocks, and consists of phenocrysts of plaioclase (Ab_5 An_5) and dark-brown amphibole embedded in a groundmass of amphibole, chlorite, sericite and feldspar laths 0.1 mm across. A similar rock, exposed in a railway cut 50 feet east of Lake Orford Station, contains large phenocrysts of dark amphiboles, up to 1/2 inch long randomly distributed among idiomorphic oligoclase crystals. Thin sections show that the hornblende is largely replaced along cleavage directions by deep blue crystals of chlorite. At places, the rock has an amygdaloidal structure, with calcite filling the elliptical cavities. The plagioclase has the composition of Ab_7 An_3 and is usually twinned. The matrix varies in grain size from aphanitic to fine-grained and consists of feldspar, chlorite and amphibole. Granules of magnetite are abundant and are usually associated with amphibole and chlorite. In one section, remnants of serpentinized olivine have been found.

Most of the lamprophyre dikes of the map-area are camptonites. The fact that they generally fill fractures at right angles to the regional structure and are comparatively unaltered, indicates that they are relatively recent intrusions. It has been maintained that their alkalic affinities suggest a correlation with the Monterregian intrusives (Dresser, 1910, p. 213; Ambrose, 1942; Fortier, 1946; p. 213). Similar dikes are present locally throughout north-central Vermont where they have been generally assigned a Mississipian age (Cady, 1956; Albee, 1957).

The Orford-Chagnon-Baldface Complex

'Orford-Chagnon-Baldface Complex' is a name proposed by Fortier (1946, p. 178) to include the intrusive rocks exposed on the Orford, Chagnon and Baldface mountains. The writer is familiar with the intrusives underlying the first two hills and consequently excludes the rocks of Baldface from the following account.
It is a northeasterly trending belt, five miles long and one and a half miles wide, which is underlain by Miller Pond rocks on the west, and overlain by Beauceville lava on the east.

The sub-concordant nature of the complex, indicated by the general parallelism between the regional trend of the formations and the contacts of the intrusive, suggest that emplacement was guided by the existing weaknesses in the rocks provided by the Miller Pond-Beauceville contact. There is no evidence of stoping, and it is believed that the intrusive wedged its way up mainly by forcing the country rock aside. The complex is probably either a laccolith or a thick sheet that has subsequently been tilted westward. This conclusion, reached from the structure of the country rocks, is in accord with the evidence within the intrusives themselves.

The Orford-Chagnon-Baldface complex exhibits two types of banding: first, rhythmic banding near the floor of the intrusive, consiting of alternating peridotite and pyroxenite layers, and secondly, a large-scale zoning consisting of ultrabasic rocks at the bottom overlain by belts of successively more acid differentiates at the roof of the intrusive.

Rhythmic Banding

In general, the pyroxenite bands are six inches to ten feet wide and average several tens of feet in length. Northeast of Orford lake, they form great sprawling masses that can be traced for considerable distances. The bands are easily distinguished in the field from the adjacent, somewhat wider peridotite layers by their characteristic white weathering surface and their conspicuously large grain size. The banding is roughly conformable with the attitude of the bedding in the neighbouring sediments of the Miller Pond formation. The contacts between the pyroxenite and peridotite layers are usually gradational, so that with increase in pyrosene (diallage and some enstatite), the rock passes within an inch or so into a coarse-grained pyroxenite; no chilles edges were observed. Locally, the pyroxenite bands expand to irregular masses which send dike-like apophyses into the surrounding peridotite. At other places, sub-angular fragments of pyroxenite, six inches across are surrounded by serpentinized material that appears to 'flow around them'.

There are no chilles zones or sharp contacts between adjacent layers, one or both of which would be present, if the layering had been produced by successive normal injections of magma. The petrological difference between adjacent peridotite and pyroxenite bands is usually merely a difference in the relative abundance of minerals common to both bands. There seems to be no doubt that gravitative settling was a controlling factor in the production of the banding in the Orford-Chagnon-Baldface complex. It appears that, following the settling of olivine at the base of the intrusion and accumulation of the thin 'bed' of pyroxenite, the normal course of differentiation was interrupted by a factor or combination of factors, which eventually resulted in the deposition of another layer of peridotite.

Large-scale Zoning

From west to east, a basal layer of serpentinized peridotite, 100 to 1000 feet wide, is overlain by an equally wide belt of interbanded pyroxenite and peridotite, which is, in turn, succeeded by a massive layer of gabbro that varies in width from 500 feet to almost a mile. Capping the latter is a discontinuous zone of 'acidic rock', ranging in composition from quartz gabbro to granophyre. Although the passage from one rock type to another is, as a rule, gradational, sharp junctions between ultrabasic and basic phases have occasionally been observed. In such cases, the more acidic phase invariably transects the more basic one; thus gabbro dikes cut across ultrabasic fractions, but are themselves invaded by apophyses of dioritic and acidic composition.

The succession of rocks indicates that the differentiation process was essentially a simple and normal one and that, except for rhythmic banding, there is no large-scale repetition of zones.

The writer believes that, although minor and short-lived additions or pulses of magmatic material may have occurred in the early phases of emplacement, the zoned intrusives of the Orford-Chagnon-Baldface complex represent essentially a single intrusion of magma. The latter is conceived to have differentiated in place through the mechanism of crystal sorting under the influence of gravity; the principal reasons for this view are given below:

1. A regular distribution of an ultrabasic phase at the base of the intrusive, successively overlain by gabbro and an acid phase at the top is evident. This is reflected by a general decrease in rock density from the lower to upper levels. It goes hand in hand with a general decrease of ferromagnesians an a complementary rise in the amount of feldspars present.

2. The zoning is apparently related to the floor of the intrusion.

3. There is apparently a rise in the soda-content of the feldspars from the base to the upper levels of the gabbro zone.

4. The majority of ultrabasic rocks in the area are associated with gabbro in such a way that the latter is overlying the former. Actually, wherever peridotite is met in the field, it may be expected to be accompanied by gabbro.

5. Finally, the striking similarity of the Orford-Chagnon-Baldface complex with layered intrusive masses in the Thetford-Black Lake region and in other parts of the world, suggest a common mode of origin.

Origin of the 'Acidic Rock'

The occurrence of granophyre in the upper levels of the intrusive grading through quartz-impregnated diorite to a quartz-rich gabbro, carrying a higher proportion of the albite molecule, suggests immediately that the 'acidic rock' forms part of an acidic phase of a deep-seated parent magma. No remnants of foreign rock have been located within the complex, and there seems to be insufficient evidence to show that enrichment of the magma took place by incorporation and solution of quartz-rich sediments, or by introduction of quartz from granite. No contacts between basic rocks of the Orford-Chagnon-Baldface complex and granite are exposed in the map-area; their age relationships and genetic affinity are therefore obscure.

It is concluded from observations in the field and in thin section, that the 'acidic rock' of the complex represents residual liquids squeezed away when the intrusive as a whole had almost completely solidified. The acid facies of the magma crystallizing last gave rise to zones and veinlets of granophyre and quartz, which impregnated and replaced certain portions of gabbro and lava alike.

Silica may be stored up in the residual liquid through the early separation of olivine and pyroxene, and does give rise to a residuum rich in quartz and in alkaline feldspars. The formation of amphibole at some stage of the crystallization would also augment the amount of free quartz available and therefore increase the possible quantity of a quartzose differentiate. It is possible that, after its complete consolidation, the gabbro was transformed into an amphibole-bearing rock, and the reactions between plagioclase and pyroxene, which have accomplished the formation of uralite, have likewise resulted in the setting free of quartz.

Sequence of Events

The deposition of the Miller Pond rocks was succeeded by a period of volcanic activity resulting in the extrusion of a sheet of basaltic lava of great thickness, which formed the roof of the later intrusion. This was followed at some later dato by an intrusion of a homogenous magma that was probably derived from the same chamber as the volcanics and that spread in the form of a thick sill beneath an effective blanket of already consolidated lava and overlying sediments. Within the igneous body began a long-continued differentiation, largely gravitational in character, proceeding steadily and uniformly over wide distances, and leading eventually to a pronounced zoning. It is not possible to say just what the composition of the original magma was, but it must have been basic enough to allow early separation of olivine and the formation of a layer of peridotite at the base of the sill-like sheet.

Although its specific gravity decreased considerably, the magma was, however, so low in silica as to be saturated with mafic constituents, which eventually crystallized and gave rise to an overlying pyroxenite band. At this point, the normal sequence of crystallization was interrupted by melting of the already solidified ultrabasic band or by some other disturbing cause, thereby setting back the course of differentiation and initiating a new cycle in the process of crystallization. This probably took place at intervals and resulted in a succession of interbanded peridotite and pyroxenite layers. Although the factors which were responsible for the rhythmic nature of the banding are unknown, gravity separation of olivine and pyroxene constituents appears to be clearly indicated.

The increasing thickness of ultrabasics at Orford lake and north of it may tentatively be explained by convection currents or by magmatic movements, whereby crystals were banked up at some places and drained at others.

Deposition of ultrabasic bands gave rise to an overlying magma saturated with both pyroxene and plagioclase, which subsequently crystallized to form a thick belt of gabbro. The interlocking nature of pyroxene and plagioclase suggests that crystallization was essentially contemporaneous. The primary banding disappears in the gabbro. Since there is an apparently gradual change of calcic plagioclase at the base to a slightly more sodic variety farther up the section, it is assumed that the differentiation process was very slow and favourable to a differential sorting of crystallizing feldspars. That differentiation was slow is further indicated by the fact that rock types have gradational contacts, since sharp boundaries are usually interpreted as being due to rapid cooling.

Dikes of more acidic composition invaded less acidic rocks, suggesting that the time between their respective crystallizations was great enough to allow for the less acidic fraction to become rigid. An upward concentration or transfer of acidic fractions eventually produced patches and discontinuous zones made up of a granophyre-like rock at the roof of the intrusive. The 'acidic rock' is thus considered to be the end-stage derivative of a differentiating magma, which impregnated the gabbro and the overlying lava alike. Subsequent tilting of the intrusive mass and of the enclosing rocks resulted in a steeply dipping and westwardly overturned succession of rocks as seen today (Fig. 5). (Introduce Fig. 5)

Age of Intrusion

The evidence presented in the previous pages has led the writer to conclude that the various intrusives of the Orford-Chagnon-Baldface complex are essentially the result of a single magmatic injection, followed by gravitative differentiation in place.

In a differentiated and zoned mass of intrusive rocks, cross-cutting relationships do not necessarily imply a separate intrusion of the individual members. On the other hand, it is probable that the ultrabasic and basic sills, encountered in the map-area and in the adjacent regions, do not belong to a single period of intrusion, but may represent multiple injections of a basic magma that subsequently differentiated at some places into peridotite and pyroxenite on one hand, and gabbroic fractions on the other. Infolded sheets made up of a basal ultrabasic layer overlain by gabbro are well exhibited in the map-area.

It is suggested that the Orford-Chagnon-Baldface intrusive complex and probably some of the dikes and sills of the map-area, were emplaced after deposition of the Beauceville, but prior to the period of folding that resulted in westwardly overturned rock assemblages. A more exact age must be tentative.

STRUCTURAL GEOLOGY

General Statement

The Eastman-Orford Lake area is part of a complex fold belt, the dominant structural feature of which is the Sutton-Green Mountain anticlinorium. Minor anticlinal and synclinal axes, essentially parallel to each other, have been located on the flanks of this major fold in the area underlain by schists and the homoclinal greywacke-slate belts. These folds have a general trend of about N.15°E. and are inclined or overturned to the west. Their axes have a gentle north-south plunge, although steep, eastwardly plunging axes have also been recorded in the greywacke-slate zone.

Superimposed upon the larger fold structures are abundant smaller folds, the pattern of which reveals the great intensity of the orogeny. A profusion of structural elements produced in these rocks point to the fact that the area has been subjected to stresses that resulted in two different fold patterns or styles produced apparently at different times. However, they may have been produced, at least in part, more or less contemporaneously during different phases of the same orogeny. Drag folds, schistosity, slip cleavage, and various lineations are the most prominent minor structures, occurring throughout the Eastman-Orford Lake area. The majority of these structures are congruous with the major folds, and generally facilitate the delineation of the latter. In some areas of disharmonic folding, however, intensely twisted and distorted schistosity may be quite misleading, if interpreted as bearing normal relations to larger structures.

Early and Late Structures

The structural features of the map-area may be differentiated into early and late structures.

Early structures comprise schistosity S_1, minor folds, and lineation L_1. In the majority of cases, S_1 is mimetic after bedding and is therefore a bedding schistosity. It also represents the schistosity parallel to axial planes of early folds, since the latter are commonly isoclinal.

The late structures include the axial plane cleavage (slip cleavage) S_2, minor folds, and lineation L_2.

Following is a brief summary of the major differences between early and late structures.

1. The pattern of late and early structures, and particularly folds, can be differentiated by their characteristic styles (Plate X A). The early folds are tight and isoclinal, whereas later folds are open and slightly inclined to the west.
2. The direction and amount of plunge of linear elements is in most cases characteristic. Most of the early elements have a generally steep east-west plunge, while the late structures show a gentle north-south plunge.
3. The axial planes of early folds are more or less parallel to the attitude of the prevalent schistosity (S_1), whereas in later folds, S_1 and the axial plane cleavage of early folds wrap around their noses, and a new axial plane cleavage appears.

Major Structures

Folds

The main structural feature of the Appalachian Upland in this area is a broad arch, commonly referred to as the Sutton-Green Mountain anticlinorium (Fig. 6). The proof of the anticlinal nature of the Sutton Mountains lies in structural, stratigraphic and metamorphic considerations. Large-scale drag folds and minor folds on the flanks of the anticlinorium have a consistent pattern, which is typical of an anticlinal structure, and bears witness to upward movements on both flanks of the major fold.

The position of the axis of the anticlinorium is approximate and is based on the average attitudes of the rocks. The crest of the fold is rather broad and shows considerable variation in dips, due to minor drag folding and warping. (Introduce Fig. 6).

In the vicinity of St. Etienne mountain, the anticlinorium has a gentle southerly plunge; this is also the consistent attitude of minor flexures both on the limbs and along the crest of the fold. Near Libby pond, rapid reversals of plunge from S.5°W. to N.5°E. may be observed over short distances.

On the western flank, the schistosity S_1 and the late axial plane cleavage S_2 dip west at about 65 to 85 degrees. On the east side, both dip east at about 55 to 75 degrees. Along the crestal part of the major fold, however, the axial plane (late axial plane cleavage S_2) dips steeply to the east at approximately 65 to 80 degrees, so that the structure is slightly inclined to the west, in accordance with other Paleozoic folds in the region. The general dip to the east is reversed locally by several subsidiary anticlines that trend sub-parallel to the anticlinorial axis. Since both, schistosity S_1 and axial plane cleavage S_2, appear to dip away from the axial line, in other words, both converge upward, the structure may be termed an asymetrical abnormal anticlinorium. In some cases a normal anticlinorium is indicated.

Other subordinate synclines and anticlines, essentially parallel to the Sutton-Green Mountain anticlinorium, were located in the greywacke-slate and schist divisions of the Miller Pond formation. The fold axes trend northeast and plunge 10 to 25 degrees in this direction; their axial planes are slightly overturned to the west.

It is believed that the observed major folds in the map-area, including the anticlinorium, are late structures; drag folds, some of them up to 15 feet across and obviously related genetically to the major folds, are superimposed on the structural pattern of earlier folds. Their axial plane cleavage (slip cleavage, S_2) cuts both, bedding and schistosity S_1.

Evidence for major early folds is meager in the Eastman-Orford Lake area. No direct proof was found in the field to indicate conclusively that such folds exist in the map-area. At places, folds or remnants of folds were observed that lacked the characteristic attitudes of either early or late folds. For example, it becomes apparent that, when crossing the transitional Miller Pond greywacke-schist contact from west to east, the strike of the beds changes gradually from the normal northeast trend to a generally east-west and southwest direction within a distance of approximately 300 feet. This zone is about two miles long and suggests that this is a site of a major fold. The schists exhibit chevron-type minor folds, the attitude of which is very variable from place to place. Although a few fold axes plunge steeply to the east, suggesting thereby their early origin, the majority plunge 27 degrees in a N.70°E. direction. Since the space available between the east-west striking beds and the northeasterly trending breccia zone is insufficient to accomodate another limb of this fold, the writer infers that the eastern segment of the fold has either been cut off by a fault or subjected to intense brecciation with consequent obliteration of its identity.

Another peculiar fold worthy of attention, occurs west of Orford lake. Here, a thick flow of spilitic greenstone, conformably underlain by quartz-sericite schists, occupies the core of a northeasterly trending fold. Near the bend of the Montreal-Sherbrooke Highway, vertical east-west striking schistosity trends apparently at right angles to the rhyolite and the breccia zone on the west, and is apparently cut off by the latter. Here again, only one segment (the eastern) of a fold is preserved; the western limb of the fold was evidently obliterated by movement along the fault zone.

Intense shearing and deformation may explain the reason why no traces of major early folds have been preserved in the map-area. Such folds are tight and isoclinal, with long limbs sub-parallel to not only the axial plane, but also to the schistosity of the surrounding schists. Considering minor structures, there is ample evidence in the field and in thin section that crests of early folds have been sheared off along their long limbs which subsequently guided flexural slip in the later folding.

The writer assumes that similar processes of shearing and slippage along S_1 were instrumental in the formation of the elongated and apparently offset and isolated lenses of chlorite schist and greenstone of the Bonsecours group and the schist division of the Miller Pond formation.

Faults

Several instances indicative of both major and small-scale faulting have been found in the map-area. In a homogeneous mass of schists, which are doubly cleaved and complexly folded, faulting is very difficult to demonstrate. Absence of horizon markers further obscures the issue.

The writer could find no positive evidence for the existence of the Bowker-Missisquoi fault in the map-area. There is a gradual increase in metamorphism from east to west across the Miller Pond Ottauquechee-Bonsecours contacts. The underlying Ottauquechee and Bonsecours appear in field exposures to grade up inti the Miller Pond with no discernable break or evidence of thrusting. No brecciation, mylonitization or stratigraphic break is indicated, such as may be expected if this contact were the sole of a major thrust. The attitude of structural elements is similar on both sides of the contact and no truncation or drastic change in trend or plunge has been observed in the map-area.

It is felt that to consider the Bonsecours-Ottauquechee or the Ottauquechee-Miller Pond contacts a thrust plane, is to introduce structural complications for which there is no local. There are some indications that the breccia zone within the Miller Pond schists, west of Orford lake, is the site of a major structural break. No clear-cut fault plane, nor striations or slickensides were discovered; it is assumed rather that this belt is not a single fracture, but a zone consisting of a sheet of crushed and shattered rock characteristic of a fault zone. The fault zone trends northeasterly, parallel to the regional schistosity of the area, and extends in a more or less rectilinear direction from the southern margin of the Orford sheet, to a point northwest of Orford lake, a distance of approximately four miles. Examples of small-scale displacements and truncations of folded beds have been observed at several places west and northwest of Orford lake. In one outcrop, at the intersection of Highway No. 1 and a north-running gravel road, about 800 feet west of the Orford lake bulge, a fault trace within the zone showing the truncation of small folds and a displacement of several feet is indicated.

The dip of the fault zone is unknown; judging, however, from the attitude of the breccia zone and the small displacements observed in the field, a fairly steep eastward inclination is indicated.

Other small faults of similar attitude were recognized farther north and primarily near the eastern contact of the breccia zone.

Since the disturbance zone, as evidenced by truncation of folded structures, topographic lows and brecciation, is roughly parallel to the attitude of axial planes of late folds, including the Sutton-Green Mountain anticlinorium, the writer assumes that the disturbance along this zone is a relatively late phenomenon, probably genetically related to the major fold structures in the area.

There can be little doubt that small-scale faulting has taken place along the schistosity S_1 and the axial plane cleavage of early folds. Examples of disruption of minor fold segments along such slippage planes have been frequently observed in the field. (Plate VII A). There are also indications that some slip has occurred along the axial plane cleavage (S_2) of late small-scale folds.

Joints

Two relatively prominent sets of joints were recognized throughout the area.

In the region underlain by the Bonsecours schists, the major rock adjustment was accomplished by movement on the schistosity planes, and consequently, joints are poorly developed. Good examples of cross joints, filled by lamprophyre dikes can be found, however, on the south side of the gravel road, 4,500 feet northwest of St. Etienne, and on the west side of the asphalt road, about two miles north of the same village.

The cross joints usually strike northwest, have steep dips and are normal to the major fold axes. They probably formed as a result of tension or stretching parallel to these axes.

Cross and longitudinal jointing were also observed in the Ottauquechee quartzites and the relatively competent Miller Pond greywacke. Here, cross joints strike nearly east-west and dip steeply to the north or south, whereas the longitudinal joints are relatively less conspicuous and strike nearly north-south, parallel to the axes of major folds.

Tectonic Breccia

A 1,000-foot wide zone of brecciated schists is exposed in the belt that extends in a northeasterly direction across almost the whole length of the map-area. It occurs within the Miller Pond formation, at the contact between the rhyolite and the rocks of the schist division. Excellent exposures of breccia can be found about 2,000 feet northwest of the Orford Lake bulge and all along the western contact of the rhyolite body.

It consists of randomly oriented, angular fragments of folded quartz-sericite-chlorite schist and quartz-sericite-graphite schist, ranging in size from microscopic to six inches and averaging two inches across (Plate VII B). Some fragments of greenstone and tuff have also been detected. The larger fractions of the breccia are sharply delineated from the matrix and show clearly an intensely folded foliation similar in pattern to that of early folds in the map-area. At several places, a set of northeasterly trending parallel fractures, truncating the fragments and matrix alike, have been observed. It is believed that these surfaces are analogous to the late axial plane cleavage S_2 associated with the later phase of deformation.

The matrix consists of a thoroughly pulverized, heterogenous rock-powder with an approximate average grain size of 0.04 to 0.08 mm. In some thin sections, the matrix is seen to be recrystallized, with the formation of abundant patches or mosaics of secondary quartz, zeolite and calcite. Strain shadows in the quartz, and curved and rectilinear twinning in the calcite are common. At places, a linear alignment of both small fragments and microcrystalline matrix is seen between the irregular edges of the larger fragments. In general, the matrix is 'dirty' and opaque, and isotropic under the petrographic microscope.

That the rocks have suffered extensive fracturing and shearing is evident from macroscopic and petrographic examinations. Several features of the breccia support a tectonic origin. The disorderly arrangement of angular fragments regardless of size set in a generally opaque matrix of similar composition, as well as the close association of the brecciated belt with fault zone, suggests that this is a fault breccia.

Furthermore, since the majority of the schist fragments show an intensely folded (bedding?) schistosity S_1, truncated by what is believed to be a late axial plane cleavage S_2, it is concluded that faulting and related brecciation took place in conjunction with the late period of deformation. The fact that the relief of stress responsible for brecciation was by fracture rather than flow, suggests that a considerable time had elapsed between the two periods of deformation. Partial recrystallization and reorganization of the matrix further supports the view that metamorphism accompanied, overlapped and probably continued after the second period of deformation.

Minor Structural Features

Planar Features

Bedding

Bedding in the Bonsecours schists is almost impossible to determine. The best indications of bedding are lenses of chlorite schist and marble; they are not common, however, and are usually not persistent along strike. In many exposures of quartz-sericite-chlorite schist, the bedding is made conspicuous by concentrations of albite porphyroblasts along certain layers (Fig. 3). Such folded, alternating layers of relatively albite-rich and albite-deficient bands probably reflect a difference in composition of the original beds.

Bedding in the Ottauquechee and the Miller Pond rocks is relatively easy to recognize. Stratification is obvious from readily visible lithologic variations. This is particularly true of the Ottauquechee formation, which is characterized by alternating strata of contrasting competency.

In the greywacke-slate sequence, where effects of metamorphism are slight, bedding may be observed in many localities; in some places, graded bedding is well developed. In thick greywacke sequences, in which only slight compositional differences are present, the bedding is often obscured by a prominent schistosity S_1 (early) and a cleavage S_2 (late).

In the area underlain by Miller Pond schists, compositional banding and bedding schistosity reflect original bedding. In these somewhat finer grained rocks, metamorphic differentiation has been moderate, so that the lithologic characteristics of the original beds have been preserved and can still be detected.

In the Beauceville formation, bedding may easily be recognized, where quartzites are interstratified with slaty material. In places, however, where quartzite beds have been disrupted, resulting in offset pods and lenses of quartzite enclosed by slaty material, the determination of bedding is difficult. In thick sections of slates and phyllites, bedding has been partially or totally obscured. Upon close examination, it is barely discernible by virtue of slight differences of colour and changes in texture.

Schistosity S_1

Schistosity S_1 or flow cleavage, is the most conspicuous minor structure observed. It consists of a dimensional orientation of micaceous minerals, and quartz, feldspar and calcite arranged in approximately parallel layers.

It should be noted that layers with different compositions are developed in the Bonsecours schists particularly in the axial regions of the anticlinorium, while it is almost absent in the Miller Pond and Beauceville formations.

Foliation is well developed in some gabbro sills and volcanic flows. Preferred dimensional orientation of platy minerals and feldspars is well displayed in a gabbro sill 7,000 feet northeast of Libby pond. The compositional layering is parallel to the contacts and consequently parallel to schistosity S_1 of the adjacent rocks.

Schistosity and bedding, where determined, are so nearly parallel to each other that for purposes of terminology, the schistosity S_1 can be termed bedding schistosity, in other words, it is probably mimetic after bedding.

Since the early folds are isoclinal, S_1 is parallel to the axial planes of early folds, except near the axes of the folds. It is exceedingly difficult to differentiate between bedding schistosity, which is the primary schistosity and the schistosity, which is parallel to the axial plane cleavage of early folds. At some places, there is a slight divergence in attitude between the bedding schistosity and the axial plane cleavage of minor early folds. However, since both features are almost everywhere parallel, the writer has grouped them together under S_1.

There are many outcrops, which show slippage along axial planes of minor folds. Behind the barn of the Elmwood farm, on the east-west gravel road, 1.5 miles east of South Stukely, a section of a series of open, gently northeasterly plunging late folds are perfectly exhibited. They are characterized by a strong compositional layering, with bands verying from 1/8 to 1 inch in width, and parallel to a pronounced schistosity that bends around the folds. Some schistosity planes are better developed than others, so that the rock is made up of alternating thin and continuous bands, where orientation of minerals was most effective and the slippage strongest, separated from 0.5 to 1-inch wide bands showing less obvious schistosity. The latter show a series of small northwesterly plunging crests of folds (Plates VIII A and B), commonly filled with white quartz. These phenomena suggest that, following tight folding of S_1, slippage occurred along the axial planes of these early folds, resulting in the complete obliteration of some fold limbs and troughs, and the preservation of fold crests. Outcrops showing similar relationships may be found on lot 10, range I, Stukely township (Plate IX A).

Late Axial Plane Cleavage S_2

Cleavage of a later period of deformation is present or dominant in most of the area, and transects or even obliterates the earlier schistosity S_1 (Fig. 7). S_2 refers to sub-parallel planes of dislocation commonly but not necessarily marked by concentrations of micaceous minerals with parallel orientation. This cleavage represents in all cases encountered the axial plane cleavage to crinkles (microplissement), and major folds associated with the late stage of deformation. (Introduce Fig. 7).

In the map-area, S_2 resembles fracture cleavage as described by Leith (1905, p. 120) in slightly metamorphosed rocks, such as Miller Pond greywackes and Ottauquechee quartzites. In the area underlain by Bonsecours and Miller Pond schists, however, it is similar to flow cleavage in that the individual surfaces show some recrystallization of platy minerals parallel to the cleavage surfaces. The cleavage S_2, as described here, has therefore the characteristics of both, fracture and flow cleavage, depending on the composition, competency of the material, and the grade of metamorphism to which the rocks had been subjected (Plate IX B).

In the schistose and argillaceous rocks, where S_2 is extremely well developed, the cleavage ordinarily comprises sub-parallel planes of dislocation spaced 0.1 to 10 mm or more apart. Individual movements along each plane of slip are slight, amounting to less than 5 mm and generally to less than 1 mm. Displacement of older structures in the rock is generally apparent and at places measureable along the planes. S_2 is distinguished from S_1 by the fact that micas and other platy minerals between the surfaces of dislocation (S_2) still preserve, at least in part, an orientation that antedates the development of the slip planes. In such places, muscovite flakes, originally parallel to the earlier schistosity S_1, have been partially reoriented and recrystallized along the surfaces of slip resulting in concentrations of platy minerals with parallel orientation (Plate II B). The plotting of poles of S_2 on stereographic nets (Map No. II) disclosed that in the area underlain by Bonsecours schists, S_2 strikes northeast and dips northwest on the west limb, and southeast on the east limb of the anticlinorium.

Linear Features

The principal lineations measured in the Eastman-Orford Lake area have been plotted on a structural map (No. II). The writer believes that the various linear features of the map-area are genetically related to two different phases of deformation. They have, consequently, been given different symbols, and are termed early (L_1) and late (L_2) lineations. The former trends mainly at right angles to the regional fold axes and includes quartz rodding, minor fold axes, mineral streaming and boudinage. The latter invariably deforms L_1 wherever both occur together; it is consistent with the trend of the Sutton-Green Mountain anticlinorium, and consists of S_1-S_2 intersections and axes of crinkles.

Lineation L_1

The most conspicuous early linear feature in the Bonsecours schist is quartz rodding (Plate X A). This lineation is produced by east- or west-trending, column-shaped concentrations of white, milky quartz. The surface expressions of these rods are usually discontinuous and somewhat shapeless quartz pods and ridges on schistosity S_1 planes. On close examniation, they are seen to be troughs and crests of early minor folds that have been dismembered along S_1 and partly along S_2.

Mineral streaming is produced by shearing out of platy minerals in the schistosity S_1 plane. It consists of dark streaks of chlorite and mica that plunge down the dip, and are elongated parallel to the plunge direction of minor fold axes. Mineral streaking is most pronounced in the greenstone bodies west of South Stukely, on the west limb of the anticlinorium. It is also conspicuous in gabbro sills, particularly northwest of Libby pond.

Boudinage

Boudinage has been observed primarily in the Bonsecours schists and in the Beauceville formation. In the former, all stages in the development of boudinage are represented, but are usually restricted to quartz beds or veins. Elongated quartz pods of all sizes, connected by thin quartz seams trend parallel to S_1 and plunge steeply down dip. The interbedded schists bend inward to close the gaps between the swelling and thinning quartz bodies.

Excellent examples of boudinage have been observed in the Beauceville rocks. Due to fracturing and elongation of the more competent quartz beds, blocks of quartzite, varying from 3 inches to 1 foot across, have been pulled apart in a direction parallel to regional structural trends. Where deformation was more intense, individual boudins of quartzite are enclosed by platy material that was sufficiently plastic to flow into the gaps. At places, the lens-shaped fragments are oriented at random and show evidence of rotation so as to obscure entirely the original continuity of individual beds.

Lineation L_2

The majority of outcrops in the Bonsecours group exhibit small corrugations on the schistosity S_1 plane (Plate X A). It is a conspicuous lineation, which is produced by the intersection of S_1 and the late axial plane cleavage S_2, and is commonly expressed by minute lines or crinkles, the axes of which show a constent plunge in a direction parallel to that of the late folds. Most of the late lineations indicated on the structural map (No. II) refer to the attitudes of these crinkles.

Minor Early Folds

Minor early folds are best exhibited in the schistose rocks of the Bonsecours group, the Ottauquechee and Miller Pond formations. These folds range in size from a fraction of an inch to as much as 10 feet in wave length, and are commonly preserved in quartzite beds and deformed quartz veins in the schists. The tightness of the folds depends on the nature of the rock. In slaty, phyllitic or schistose rocks, folds are tightly compressed with sharp crests and troughs, and parallel or nearly parallel limbs. Folds of this type have attenuated limbs and show evidence of considerable flowage during deformation (Fig. 8). Where more competent beds are present, the folds are broader and more open with gentle rounded crests and troughs. All gradations between open and isoclinal folds may be found, and their form evidently depends more upon the lithology of the rock involved than upon any other single factor.

The long limbs of these minor folds are parallel to the axial plane and the bedding schistosity in the surrounding schists. In some places, crests of quartzite folds are sliced up by shear surfaces that are coincident with the axial planes of minor folds. These surfaces, although parallel to the schistosity in the long limbs of the folds, transect the latter in the crests, giving rise thereby to separated quartz lenticles and rods that are V-shaped in cross-section. These severed crests and troughs of minor folds produce the prominent lineation L_1 on S_1 planes. (Introduce Fig. 8).

Generally, the axial planes of the folds dip steeply to the east on the eastern limb of the anticlinorium, and dip westerly on the western limb. Accordingly, their axes have a steep easterly or westerly plunge (structural map No. II).

In a few cases , remnants of early folds with shallow easterly or westerly plunges indicate a position relatively close to the axial part of a late fold.

The present attitudes of early folds are controlled by the attitudes of later folds. Thus a change in the plunge of late folds changes the direction and amount of plunge of the earlier folds. Where folds of the earlier set have the same orientation as those of the later set, structural relations are not as clear.

In the lower center of the area, approximately 1 mile northeast of Libby pond, (areas VIII and IX of the structural map No. II) what appear to be early folds are S-shaped with steep (60 degrees to vertical), southeasterly and easterly plunging axes. Their axial planes dip steeply (70 degrees to vertical) to the east in conformity with the prevalent attitude of S_1. The shear sense may be ascertained by the folded pattern of S_1. Since the short limb has been rotated in a anti-clockwise direction, the overlying rock mass has moved to the right relative to the underlying rocks. In other words, the rocks to the east have moved north relative to those on the west. On the west limb of the anticlinorium and diagonally opposite to the afore-mentioned location, westerly plunging, Z-shaped folds of the early type are well exhibited. Their axial planes dip steeply to the west. The size of the folds varies from a few inches to a few feet from limb to limb.

A similar set of early folds has been observed on both flanks of the anticlinorium west of St. Etienne mountain, with S-shaped and Z-shaped patterns on the eastern and western limbs, respectively, of the anticlinorial axis.

Minor Late Folds

The later stage folds are the most common folds in the Eastman-Orford Lake area. They vary in size from large drag folds with amplitudes of 10 to 30 feet, to tiny crinkles and plications observed in thin section.

In the St. Etienne map-sheet, the later folds are generally broad and open, and their northerly or southerly trending, nearly horizontal axes are parallel to the Sutton-Green Mountain anticlinorial axis (Plate X B). Throughout the area, the axial planes of the drag folds have an average strike of about N.5 - 20°E. and generally dip steeply to the east at 55 to 80 degrees on the east limb of major large folds. On the west flank of the anticlinorium, the axial planes of late drag folds dip at 65 to 85 degrees west. Reverses in plunge direction are common. The majority of drag folds on St. Etienne mountain plunge 10 degrees to S.5°W.; in the vicinity of Libby pond, the plunge is nearly horizontal, whereas at the northern extremity of the map-area, the axes plunge 5 degrees to N.10°E., in harmony with the major structures (Fig. 9). (Introduce Fig. 9)

The pattern of drag folds on the flanks of major folds changes from place to place depending on the plunge direction of the major fold axes. In the vicinity of St. Etienne mountain, the pattern of late stage drag folds is S-shaped on the west flank and Z-shaped on the east side of the anticlinorium, indicating "up-west" and "up-east" movements, respectively.

In the area underlain by Miller Pond greywackes and schists, a general northerly plunge of drag folds has been observed. In the altered greywackes, approximately 1 mile east of the northern tip of Long pond, sharp-angled folds of the chevron type are of common occurrence. Crinkles that are everywhere associated with the late period of deformation are conspicuous in the Miller Pond schists.

Only few late folds have been seen in the Beauceville slates. Their attitude is consistent with the movement pattern that was responsible for late folds in other parts of the map-area.

Essential contemporaneity of the crinkles and S_2 is suggested by two lines of evidence: the S_2, a slip cleavage, is parallel to the axial planes of such minor folds, and the folds are generally more abundant and more acute, where S_2 is most intensely developed

Folds that have crinkles and axial plane slippage surfaces associated with them, are commonly interpreted as shear folds. Part of the deformation may therefore be ascribed to small increments of slip on countless tiny slip planes. The crinkles are commonly almost perfect similar folds, and appear to have formed, at least partly, by flow folding, and partly by flexuring caused by drag on larger folds. Consequently, some shortening of the rock, essentially at right angles to the slip planes (S_2) must have occurred in the development of the larger folds and crinkles associated with them.

It is suggested that, after an initial phase of flexure folding involving shortening at right angles to the slip planes, slippage occurred along these planes resulting in shear folds.

Pattern of Movement

Origin of Early Folds

The writer is of the opinion that the movement pattern of minor early folds in the map-area is best explained by a hypothesis of flowage under the influence of gravity. It is probable that load and simple lateral compression, acting in conjunction on a material weak enough to creep under the action of gravity, facilitated the gliding. Deformation was thus largely by plastic flow, which resulted in thickening of some beds and attenuation of others to more films, thereby detaching altogether cores of thickened lobes. Heterogeneity of the original beds, i.e. the presence side by side of relatively mobile and stiff material, may have controlled the plastic behaviour of the rock units. This would result in over-development of some fold lobes and retardation of others. No traces of a basal shearing plane, if it had developed at all, are evident in the map-area. It is rather inferred that movement occurred along internal gliding planes, resulting in narrow zones of small, tightly compressed isoclinal folds separated by relatively undisturbed layers.

Origin of Late Folds

The writer is reasonably sure that, conforming to the views expressed by White and Jahns (1950) and others, the major structure in the map-area is a cleavage anticlinorium. There is no evidence that the anticlinorium, or for that matter any of the late structures, originated by a large-scale translational movement. The majority of drag folds on both flanks of the fold are congruous with, and seem to be genetically related to, the formation of the anticlinorium; in other words, an upward movement is indicated on the east and west sides of the fold.

Where the foliation bands contain a larger proportion of quartz-rich laminae, the folds appear to have formed by flexure rather than slip on sub-parallel surfaces. The accompanying micaceous layers, however, which take the space between the relatively more competent layers, yield readily to flowage and are intensely sheared along closely spaced surfaces. This is to be expected, since folding of laminated rocks, consisting of layers of varying competence, usually involves considerable transfer of material from the limbs to the crests and troughs in the incompetent bands. While this transfer is largely accompanied by drag folding or by slip movement, solution and redeposition of material may also play a considerable part.

Crinkles, the axial planes of which are everywhere parallel to axial planes of late major folds, are typical similar folds, and suggest shortening of the rock, essentially at right angles to S_2.

Numerous examples have been found in the field suggesting that slippage took place parallel to the axial planes of early folds during the formation of the anticlinorium and subsidiary folds. This results in juxtaposition of crests and troughs of tight minor folds, the short limbs of which are sheared off by parallel slippage surfaces that wrap around the noses of later folds. In such cases, the late structures are made up of folded axial planes of early folds. Where early structures have not been reinforced by quartz cores, or where intense gliding and recrystallization entirely obliterated not only their limbs but also crests and troughs, no trace of early folding can be detected. At such places, the rock has the appearance of a uniformly foliated schist. Such slippage of layers may be brought about either by horizontal compression or by arching. It is conceivable that gliding along the long limbs or axial planes of early folds (which served as slip planes) took place while the anticlinorium was rising. However, this would require a relative thinning on the crest of the arch and a relative thickening of rock units on the flanks.

Plasticine Models

In order to visualize and illustrate the complex pattern of folding of early and late folds, the writer prepared several plasticine models.

A slab consisting of several differently coloured layers of plasticine was folded into recumbent folds representing east-west trending axes. The resultant folded mass was then itself bent about axes at right angles to those of the first folds. In Plate XI A a section cut at right angles to the axes of late folds shows that apparent duplication of various layers is actually due to juxtaposition of the two limbs of an early fold, thereby doubling the thickness of the strata in the limbs of late folds. It is clearly demonstrated that in folded beds, the youngest bed (brown layer) may be in the core of both, late synclines and anticlines. This goes to show that in areas where two fold systems are involved, reliance on lithology alone can be misleading. Such complexities are particularly difficult to decipher in areas underlain by schists, where all trances of bedding and possible fossils have since been obliterated by plastic deformation, such as is the case in the Bonsecours rocks. Lack of continuous horizon markers further complicates the matter.

Plate XI B suggests the visualized pattern of movement that took place during the late stage of folding. Slippage along the axial planes of early folds that acted as glide surfaces resulted in the juxtaposition of crests and the obliteration of troughs of early folds. Intensified slippage in places gives rise to a uniformly foliated schist in which clues of previous folding are beyond detection.

The plasticine models illustrate clearly that in areas, where superimposed folding is indicated or suspected, special attention has to be paid to current-and graded bedding, in addition to other structural features.

Relation Between Deformation and Regional Metamorphism

The metamorphic history of the Eastman-Orford Lake rocks is best elucidated, when considered in conjunction with the structural evolution of the area. As indicated in the preceding chapter, the structural features of the map-area suggest two stages of deformation. Both stages were accompanied by metamorphic phases, the effects of which in the majority of cases, could be made out in the field and in thin section. At some places, however, both phases could not be distinguished with certainty, possibly because the younger episode had completely erased all earlier mineralogical features, or because both episodes were similar in nature of metamorphism.

In general, evidence from the Eastman-Orford Lake area indicates that a late phase of metamorphism (porphyroblasts and S_2-cleavage) is superimposed on a earlier, pre-S_2 mineral assemblage (schistosity S_1). The time relation and main characteristics of the two phases of metamorphism are as follows:

Early Phase: It is maintained that during the early stage of deformation, platy minerals crystallized parallel to the direction of flow cleavage, thus imparting a true schistosity S_1 that, in most parts of the area, is parallel to the bedding. Paratectonic and post-tectonic crystallization (during and after the early stage of deformation), is well exemplified by the presence of albite porphyroblasts enclosing twisted lines of inclusions, the trend of which merges without break into the surrounding schistosity lines.

Late Phase: It seems that the late phase of metamorphism is clearly related to the late stage of deformation. From what is at present known, it seems likely that the formation of S_2 and the appearance of most muscovite and albite porphyroblasts were associated with the late stage of deformation.

In almost all cases observed, muscovite and albite porphyroblasts cut across the early schistosity S_1. Complex microfolding of relict S_1-surfaces in the porphyroblasts, which in every case axamined, are superimposed on the groundmass inherited from the first metamorphism, lends distinct support to the view that strong deformation had taken place prior to the development of porphyroblasts. It is also apparent that considerable recrystallization took place along S_1 during the late phase of metamorphism. This is evidenced by detrital quartz grains, crushed and drawn out into lenses or into narrow, ribbon-like layers.

Several criteria, characteristic of post-tectonic crystallization (after the late stage deformation) suggest, that the chemical processes of solution, reaction and diffusion have continued long after deformation had subsided. S_2-cleavage planes probably supplied channels of readiest migration of solutions and hence served as surfaces of greatest ease of growth for newly formed crystals. This is evidenced by the presence of well-crystallized muscovite flakes, the parallel orientation of which intensified the late axial plane cleavage and rendered it more conspicuous (Plate II A and B).

While some porphyroblasts related to the early stage of deformation, have been rotated and disrupted by the later deformation, the majority of the porphyroblasts grew independent of rock structures and are clearly post-tectonic (post-S_2).

They cut across or produce a buldge in S_2, so that the latter curve around the former (Fig. 3).

Although deformation and metamorphism were probably simultaneous processes, it seems clear from the above considerations that the processes have been intermittent, overlapping and probably of considerable duration.

It is evident that the intensity of metamorphism of the rocks in the map-area is highest in the central belt of the Sutton-Green Mountain anticlinorium, and falls away both to the east and to the west.

Concurrently with the increase in deformation, segregation and recrystallization of the schistose rocks become more pronounced in the axial belt of the anticlinorium. In addition, the zone yielding by far the largest development of albite porphyroblasts, coincides with the axial part of this major fold. It appears then that metamorphism was slightly more intense, where the stresses and temperatures were more pronounced, i.e. in the central parts of the arch.

The writer concludes that metamorphism in the Eastman-Orford Lake area is dynamothermal, the heat being due in part to burial and in part to friction. It is believed that regional metamorphism in the area was initiated by mimetic crystallization essentially along bedding planes of deeply buried sediments. Shearing movements along these planes of slip, concurrent with small-scale metasomatism and accompanying mineralogic transformations, probably operated together and resulted in the metamorphic features observed in the map-area today.

Time of Deformation

There is sufficient evidence to indicate that a fold system with north-south trending axes is superimposed on a fold system with east-west trending axes. Contrasting orientation and style of folding, truncation, as well as overprinting of early structures by later ones, suggest at least a relative difference in age between the two fold systems.

Traverses from east to west across the Missisquoi River valley in the map-area and south of Bolton Centre display a gradual passage from relatively unsheared greywacke, arkose and argillite horizons of the Miller Pond formation into massive, blue-grey quartzites and graphite schists of the Ottauquechee formation; the latter in turn pass transitionally into quartz-sericite-chlorite schists and phyllites of the Bonsecours group.

Evidence relating to a pre-Ordovician disturbance in the Thetford region has recently been cited by Cooke (1955, p. 113) and by Riordon (1957, p. 389).

South of the map-area, Miller Pond greywackes and slates grade eastward into Beauceville slates and quartzites without apparent stratigraphic or structural break. Although the pre-Taconic rock units underlying the Siluro-Devonian rocks display certain lithologic and consequently metamorphic dissimilarities, they have many structural features in common. The superposition of early and late structures, the similarity in style of folding, and parallelism of formations along strike suggest that no important pre-Taconic disturbance took place in the map-area. On the other hand, the presence of a basal conglomerate, sharp angular uncomformity, a marked difference in grade of metamorphism between the post-Taconic and Beauceville rocks, as well as a comparatively simple uniaxial folding in the post-Ordovician rocks indicate that the region was subjected to a period of diastrophism in late Devonian time. Evidence of Appalachian orogeny has not been recorded in this part of the Eastern Townships.

In spite of the various characteristics of early and late sets of structures outlined in the preceding pages, insufficient evidence has been accumulated to decide, whether the two generations of structures are products of two separate orogenies or merely pulses of a long continued deformation. It is by no means clear, whether the area owes its deformation to the Taconic disturbance, the Acadian disturbance, or to a combination of both.

HISTORICAL GEOLOGY

In early Paleozoic, Schuchert (1930, p. 703) visualized a northeasterly trending St. Lawrence geosyncline that occupied Vermont, northern New York and Maine, southern Quebec, (including Gaspé), northwest Newfoundland and northern New Brunswick, and that received coarse sediments from the nearby borderland to the east, the New Brunswick geanticline.

Near the beginning of the Cambrian period, this geosyncline was divided into a western trough, the Champlain miogeosyncline, in which carbonates and shallow-water sediments were deposited, and an eastern trough, the Magog eugeosynclinal belt, in which the sediments of the Eastman-Orford Lake area were laid down. It is inferred that a land barrier of probably Precambrian age ('Quebec Barrier') separated the two troughs (Kay, 1937, p. 290).

It is reasonable to assume that it was in the zone of interfingering miogeosynclinal and eugeosynclinal facies (in the Sutton Mountains) that structural movements were particularly concentrated.

Considering the nature of sediments deposited in geosynclinal environments, it is believed that the Eastman-Orford Lake area is situated on the western margin of the Magog trough, the eugeosynclinal facies of which interfingers with the miogeosynclinal facies of the Oak Hill Series to the west. While the chiefly carbonate and clastic sediments in the Champlain trough were principally derived from the nearby craton to the northwest, the source of the Cambrian sediments in the Magog eugeosyncline is attributed to a volcanic arc (Kay, 1951, p. 91), that erupted through the geosynclinal sediments and was raised above sea-level, or to Precambrian fold ridges that arose in the interior zones of the geosyncline. In any case, they were eroded , and the detrital material was quickly transported and deposited in the trough of eugeosyncline as conglomerate, greywacke and associated shales.

Subsidence throughout most of Cambrian time resulted in the accumulation of a vast assemblage of clastic sediments (Bonsecours rocks) in an ever widening and deepening trough. Intermittent volcanism occurred as evidenced by interstratified extrusives and pyroclastic beds within the Bonsecours group.

The succeeding Ottauquechee quartzites and graphite schists reflect stable shelf conditions of sedimentation with relatively mild subsidence during accumulation, and considerable transport and winnowing action before final accumulation. While loose arenaceous material was washed clean, the argillaceous products of erosion were carried farther out to sea. Interbeds of fine-grained silt and shale, interbedded with quartzite horizons, suggest rhytmic sedimentation in waters of the littoral zone of a slowly and continuously sinking geosyncline that was deepening eastward.

With the eastward migration of the shore line, probably accompanied by crustal oscillations and fluctuations in the level of the sea, quartzite deposition gradually gave way to the sandstone, siltstone and shale assemblage of the Miller Pond formation. A few thin conglomerate horizons and subgreywacke beds at the base reflect shallow water conditions for at least part of the depositional period, in which some winnowing action occurred to produce a slightly cleaner type of sand. Intercalated grit beds may have been due to a particularly abundant supply of sediment during floods or heavy storms, or to disturbances in the source area.

Farther east, the sandstones become muddy and impure and represent typical greywacke of orogenic belts. The wide extent of graded beds of relatively coarse, poorly sorted and rounded detrital material, lacking cross-bedding and ripple marks, indicates an environment in which erosion, transportation and deposition were too rapid to allow effective chemical weathering to take place. Alternating coarse greywacke and shale beds display sharp contacts suggesting rhythmic deposition, during which 'washed in' material was dumped over large areas and then allowed to settle according to size; such periods that may have been controlled by seasonal effects or sudden storms were succeeded by intervals of complete quiet in which fine-grained beds were deposited. Absence of cross-stratification in the greywacke beds and poor sorting indicate that the sediments were undisturbed by scouring currents and were deposited in deep waters.

Normal sedimentation was interrupted by intermittent volcanic activity, during which thick flows of pillowed and massive basalt, as well as rhyolite were extruded and pyroclastics deposited. Times of relative stability in the source area, permitting intensive decomposition of the land, may account for the presence of zones of fine-grained, argillaceous material within the Miller Pond formation (Miller Pond schists).

The Eastman-Orford Lake area does not offer direct proof of an unconformity between Miller Pond and Beauceville. Nowhere is there a break in the area or south of it that can be determined without question as the Cambrian-Ordovician boundary, and it is probable that with the exception of massive lava extrusions, sedimentation was continuous across this arbitrary boundary. However, since eugeosynclines are tectonically mobile areas, it is possible that a brief period of erosion separated Miller Pond from Beauceville.

In the Eastman-Orford Lake area, the base of the Beauceville time is marked by extensive basalt extrusions; these flows varied in viscosity and composition so that all gradations are encountered, from massive and pillowed material to explosive varieties of tuff and agglomerate; gabbroic rocks, probably consanguinous with the lava flows, were intruded into the Beauceville in the form of narrow sills.

Continuous eastward deepening of the troughs during Ordovician time resulted in the deposition of a thick series of shales and intercalated thin quartzite horizons of the Beauceville formation. That this portion of the Magog trough was flooded by marine waters in Ordovician time is supported by Trenton fossils found at Castle Brook, three miles southeast of Orford lake and outside of the map-area.

It is inferred that, following the deposition of Beauceville rocks, a pre-existing line of regional weakness provided the locus of intrusion of a large sheet-like body, the Orford-Chagnon-Baldface intrusive complex. Long-continued differentiation in place, largely gravitational in character, led eventually to pronounced zoning of peridotite at the base, through interbanded peridotite and pyroxenite to gabbro and an acidic rock at the top of the intrusive mass.

Post-metamorphic lamprophyre dikes of alkaline composition were apparently intruded along transverse tension joints, related to the main anticlinorium, and probably represent the youngest igneous rocks of the Eastman-Orford Lake area.

ECONOMIC GEOLOGY

General Statement

This part of the Eastern Townships has been the scene of an intensive search for mineral deposits for more than a century. Since 1847, several mining companies, individual geologists and prospectors have examined the mineral resources of the Eastman-Orford Lake area and have done a great deal of detailed geological mapping, drilling and geophysical work. Generally, the work has been aimed at exploration and development of copper mineralizations and asbestos showings.

Most of the mineral occurrences of the map-area investigated by the writer in the course of his field work, have been described in early official reports by Logan (1863), Harvie (1911) and Bancroft (1915).

Copper

The majority of the noteworthy copper occurrences of the Eastern Townships are distributed in three northeasterly trending belts, parallel to the structure of the region. They are from east to west: the deposits of Ascot and Weedon townships, the deposits of the 'Serpentine Belt', and the deposits occurring in the Sutton Mountains. Parts of the two last-named belts are located in the Eastman-Orford Lake area.

Many of the small individual showings in the Sutton Mountains have been opened by pits or small shafts. The mineralization is associated with greenstones or dolomitic marble bodies, and consists in most cases of chalcopyrite with or without minor amounts of other copper sulphides and pyrite.

While the 'Serpentine Belt' is best known for its deposits of asbestos north of the map-area, it also contains numerous showings of copper and iron sulphides, which are in, or directly associated with, basic volcanic rocks and serpentinized peridotite. Small shipments of ore have been made at times from several of these deposits, but the only producer of importance is the Quebec Copper mine, the mining operations of which are described in some detail below.

The Quebec Copper Mine (17)

Recent Developments

The present Quebec Copper mine, originally known as the Huntingdon mine, is located at 3.5 miles south of Eastman. It was discovered by Avary Knowlton in 1865 (Bancroft, 1915, p. 171).

After some years of prospecting, the Quebec Copper Corporation Limited acquired the former Huntingdon mine in 1951, and started an extensive exploration and development program in the area south of Eastman. In 1952, a vertical three-compartment shaft (shaft No. I) was sunk to a depth of 751 feet. It is collared at 70 feet north of the old Huntingdon shaft and 250 feet west of the peridotite-greenstone contact (Map No. I and Fig. 10). Stations were established at the 200, 400, 550 and 700-foot horizons, while at surface, the main plant buildings were erected and the required equipment was installed. Most of the surface drilling was of an exploratory nature to test the northward and southward extension of the mineralized zone. At the Huntingdon mine, this mineralized zone ('A') was then estimated to be 1000 feet long and 150 feet wide, containing 300 tons per vertical foot averaging 3 per cent copper, in addition to low values for gold and silver.

In the first half of 1953, the shaft was completed to a depth of 1160 feet and crosscuts were driven in an east-west direction on the 400, 550, 700 and 850-foot levels. From information gained by surface and underground drilling, as well as examination of old workings, an estimated 500,000 tons of 2 per cent copper of probable ore was outlined down to the 1000-foot level. In the second half of the year, stations were established on the 1000 and 1100-foot horizons.

Part of the ore above the 400-foot level had been extracted in the past. However, horizontal drilling on the 400-foot level indicated an ore zone ('B') of 100,000 tons averaging 0.8 per cent copper, a few hundred feet south of the 'A' ore zone. At the end of the year, the 'A' zone, extending from the 500 to the 1100-foot level, was proven to contain 600,000 tons of 2 per cent copper. To test the downward extension of the main orebody ('A'), several holes were drilled from the 1100-foot level to a vertical depth of 1550 feet.

The mine was brought into production in the early part of 1954, and the mill was started at 450 tons a day. By the end of 1954, the shaft had reached a depth of 1238 feet, while at surface a total of 5349 feet of diamond drilling was completed in an effort to explore the mineralization in the vicinity of the old Ives showing, 2.5 miles north of the Quebec Copper mine.

The most important development during 1955, was the indication of 2 new orebodies at depth, the 'C' and 'D' ore zones. To permit development of these, the shaft was deepened from the 1238-foot to the 1810-foot horizon. Short crosscuts were driven at the 1250 and 1400-foot horizons to permit lateral drilling, while sinking was in progress. The 'C' zone north of the shaft, indicated 392,975 tons of 1.14 per cent copper, while the 'D' ore zone south of the shaft, indicated 310,000 tons of 1.2 per cent copper. The capacity of the mill was increased to 800 tons a day, with most of the feed being supplied by the 'A' and 'B' zones.

During 1956, the major part of the work was done below the 1000-foot horizon to prepare the 'C' and 'D' zones for stoping. The 'D' zone, which extends from the 1100 to the 1400-foot horizon, was prepared and made ready to supply ore to the mill by the end of the year. Scram dirfts were established at the 1400-foot level, a crusher at the 1525-foot horizon, and a loading pocket at the 1650-foot level. The No. I shaft was deepened to 1875 feet to allow the development of the downward extension of the 'A' and 'C' zones for stoping operations: these zones represented then a proved total of 250,000 tons of 1.4 per cent copper. During the year, the mill operated continually at an average daily tonnage of 808 tons. The operations, however, received a serious set back in 1956, when the hanging wall of the 'A' zone, producing the bulk of the mill feed, sloughed off into the open stope, diluting the grade to an overall of 0.6 per cent for the full year (Table 8). Subsequently, the 'A' zone was abandoned and work was concentrated on the 'C' and 'D' zones. A new shaft, the No. 2 shaft, was started late in 1956, at about 700 feet south of the main No. 1 shaft. This shaft was being sunk to permit the recovery of the pillars surrounding the main shaft between the 1000 and 1575-foot levels; an estimated 600,000 tons of 0.9 per cent copper were tied up in these pillars. At the year's end, the new shaft had reached a depth of 194 feet below the collar. A new 6-foot hoist was installed at the No. I shaft to permit mining to a greater depth and to increase hoisting capacity. Exploration was also continued on the 1400-foot level for a distance of 1000 feet in a northerly direction to explore the downward extension of the peridotite-greenstone contact. Horizontal holes drilled at regular 50-foot intervals along this drive showed a mineralized zone averaging 400 feet in length and 1.4 per cent copper across 8 feet.

In 1957, the No. 2 shaft was deepened to 336 feet; sinking operations, which would have given access to the bulk of ore reserves, were, however, discontinued at this point, because of the falling price of copper. All efforts were transferred to an exploratory drive to the north of shaft No. 1 to explore the area in the vicinity of the former Bolton mine. At the end of the year, this drive at the 1400-foot level had reached a point approximately 3000 feet north of the main shaft; although a hole had intersected 5 feet of 12 per cent copper, the results were, in general, disappointing.

Although operating costs were reduced in 1957, the Company could not cover sufficiently the expenses of the mine due to the low grade of the ore treated and the reduced price of copper. In addition, an extensive underground diamond drilling program failed to give satisfactory results. Mining and milling operations were therefore suspended on April 11, 1958, when it was determined that the remaining ore reserves could not be hoisted without the completion of the No. 2 shaft, the cost of which was prohibitive. For the remainder of the year, the Company shared in outside exploration ventures with East Sullivan Mines Limited and Sullivan Consolidated Mines Limited, which, however, were unsuccessful. By the end of 1959, most of the machinery underground was sold.

Geological Setting

The ore zones occur on the west side of Miller Pond greenstone, at or near its contact with a sill-like body of serpentinized peridotite. Both rock bodies extend 2.5 miles north and for several miles south of the mine (Map No. IV). The width of the greenstone varies from 100 to almost 1000 feet, but at the mine it is 400 to 600 feet wide. Though the contact has local irregularities, it strikes N.15°E. and dips 65 to 75 degrees to the east. At places, along the peridotite-greenstone contact, the greenstone exhibits a pronounced schistosity; the ultrabasic rock, on the other hand, is altered and has a ramification of irregular veinlets in fractures and shears, normal in ultrabasic rocks.

Ore Zones

The ore zones are sulphide replacements of altered volcanic rocks. The sulphide minerals are mixtures of pyrite, pyrrhotite, chalcopyrite and a little sphalerite. Traces of gold, silver and magnetite are associated with the sulphides. The gangue consists of quartz, carbonate, and unreplaced rock.

There are four main ore zones at the Quebec Copper mine: the main or 'A' zone, the 'B', 'C', and 'D' zones. (Introduce Fig. 10).

The 'A' Zone

The 'A' zone extends from the 500-foot level to the 1250-foot horizon (Fig. 11). It is the downward extension of the 'Old Stopes', which were worked prior to 1924 from the surface down to 500 feet. The underground workings were close to, the footwall peridotite and extended for 150 feet along strike. At the 200-foot level, 2 parallel ore zones, immediately at the contact and 35 feet east of it, were mined profitably during the early years.

The 'A' ore zone is roughly a lens-shaped body in plan (Fig. 10). It is 300 feet long and 100 feet wide, and has an approximate north-south orientation. It has a southerly rake of 75 degrees and follows the peridotite-greenstone contact. The orebody becomes narrower at the 1250-foot horizon, where it is found in the greenstone at a distance of 90 feet east of the contact (Carrière, 1957, p. 465).

In the pre-production stage (1953), the 'A' zone was proven to contain 600,000 tons of 2 per cent copper. In 1956, the hanging wall of the 'A' zone, which, at that time, produced the bulk of the mill feed, collapsed into the open stope and diluted the overall grade of the ore.

Mineralization in the 'A' orebody generally consists of stringers and layers of sulphides replacing the altered volcanic rock. Locally, the replacement may be more or less complete to give a 5 to 20-foot wide zone of massive pyrrhotite along the footwall of the orebody. This zone, generally containing small amounts of disseminated pyrite and chalcopyrite, passes eastward into a 10 to 30-foot wide zone characterized by small stringers of chalcopyrite. Isolated stringers or specks of chalcopyrite and associated pyrite and pyrrhotite may be found as much as 100 feet from the ore zone.

The 'B' Zone

The 'B' zone is located 200 to 300 feet south of the upper part of the 'A' zone and between the 300 and 500-foot levels (Fig. 11). The lens-shaped body is about 150 feet long and 40 feet wide, and lies within the greenstone at some 45 feet east of the serpentinized peridotite. The zone consists of parallel, 0.5 to 4-inch wide stringers and streaks of pyrrhotite and chalcopyrite. In 1953, horizontal drilling on the 400-foot level indicated 100,000 tons, averaging 0.8 per cent copper.

The 'C' Zone

The 'C' zone is the downward extension of the 'A' ore zone and has been outlined between the 1250 and the 1575-foot levels. It has a southerly rake and is approximately 300 feet long and 10 to 25 feet wide. Carrière reports that "the ore minerals occur in a shear zone, almost parallel to the near-by contact, marked by a pronounced schistosity and extensive chloritization and silicification" (1957, p. 466). In 1956, a total of 392,975 tons of 1.14 per cent copper have been outlined in the 'C' ore zone. (Introduce Fig. 11).

The 'D' Zone

The 'D' zone extends from the 1,100 to the 1400-foot level and has a length of 250 feet and a maximum width of 90 feet. It follows the greenstone-peridotite contact and is immediately adjacent to the 'C' zone, south of the main shaft. Mineralization consists of 10 to 20-foot wide pyrrhotite and chalcopyrite-rich layers and stringers. Some of the more conspicuous ore intersections in the 'D' zone are shown in Fig. 10. The zone indicated 310,000 tons of 1.2 per cent copper, of which a total of 230,437 tons were extracted in 1957.

Structural Control and Wall Rock Alteration

Although a few minor displacements and shear zones generally filled with quartz-carbonate veins, are seen underground, no evidence of strong faulting has been found so far in the mine workings (Carrière, personal communication, 1960). There are, however, indications that mineralization was controlled partly by structure and partly by the lithology of the host rock.

Although the ore zones generally follow the peridotite-greenstone contact, it is apparent from Figs. 10, 11 and 12, that sulphides in noteworthy concentrations may also be found at a considerable distance away from the contact. For example, at the 1250-foot level, the 'A' ore zone leaves the contact and is emplaced well within the hanging wall greenstone, at some 90 feet east of the serpentinized peridotite. Similarly, the 'B' ore zone

(Introduce Fig. 12)

is enclosed in greenstone, some 40 feet east of the contact.

It is interesting to note that, at places, concentrations of sulphides are found at the noses of steep southerly plunging isoclinal folds; such folds (early?) are readily apparent in the 'C' and 'D' ore zones at the 1100 and 1400-foot levels. This suggests that mineralization, which is of the replacement and fracture filling type, occurred after the early (?) period of folding. Supporting evidence was found in the mineralized greenstones and tuffs south of the Quebec Copper mine. On lot 27, range VII of Potton township (No. 5 showing, Map IV) thin stringers and seams of chalcopyrite are parallel to folded (bedding?) schistosity S_1 of tuffaceous rocks; here, the sulphides appear to be concentrated at the crests of early minor folds. Similarly, on lot 24, range VII of Bolton township, the nose of a steep easterly plunging fold was evidently the favourable spot for the deposition of ore by mineral-carrying solutions (showing No. 1, Map IV). A sharp bend in the peridotite-greenstone contact, 0.6 miles north of No. 1 shaft, may also have been an important factor in the localization of mineralization.

From a detailed study of mineralization and alteration patterns, Murray showed conclusively that the ore deposits and accompanying wall rock alteration at the Quebec Copper mine were produced "by the introduction of sulphide-bearing solutions" (1954, p. 27).

Alteration, associated with the ore, extends outward from it to distances ranging from a few feet to 300 feet or more. The most common alteration products at the mine and in the vicinity are sericite, chlorite, and carbonate. Although their distribution is not always regular, a certain pattern of alteration is apparent. Sericite, usually accompanied by pyrite, is most abundant in the immediate vicinity of the ore zones. Chlorite is irregular in its distribution and may extend from the ore zone to the outer limits of alteration; it is more conspicuous in the lower levels, where it appears to increase towards the ore zones. Irregular bands of a tough and fine-grained silicified rock, associated with quartz-carbonate veinlets, are of common occurrence in the deeper zones of the mine. Quartz-carbonate veinlets increase outward from the ore zones, and generally mark the outer limits of alteration. There is minor talc alteration at the footwall peridotite.

It is significant that the most extensive alteration zone is to be found in the hanging wall. This is suggestive of a preferential upward migration of the solutions, giving a wider zone of alteration in the hanging wall than in the footwall.

Method of Mining

Since the outlines of the orebodies were fairly regular and the rock relatively firm, the open sub-level stoping mining method was used at the Quebec Copper mine. This method proved to be well chosen, since it permitted a maximum daily tonnage and a low cost of extraction (Table 8). The main, three-compartment shaft No. 1 is outside of the 'A' ore zone, as is usually the case when the sub-level stoping method is used. However, the shaft intersected the 'C' and 'D' ore zones below the 1000-foot level. A new shaft (No. 2) was therefore sunk in order to permit the recovery of the pillars, in which 600,000 tons of 0.9 per cent copper ore were estimated to be tied up. (Introduce Table 8).

The levels were generally established at 150-foot intervals. When stoping limits had been determined, fringe drifts, connected by raises, were driven every 75 feet around the orebody and crosscuts were opened to join the fringe drifts at about the mid-point of the stope. The crosscuts were then joined from level to level and slashed from wall to wall, thus providing the initial slot. Vertical, long hole ring drilling was done from the fringe drifts at 5-foot intervals, blasting the ore into the slot. The broken material was then drawn to scram drifts at the 490, 925 and 1400-foot levels, whence the ore was scraped to passes leading down to the crusher stations, installed at the 1015, 1250 and 1730-foot levels. The 3-inch material was then delivered to the loading pockets by means of a 48-inch conveyor belt, thus eliminating tramming from the stopes. In 1956, the Company installed a 6-foot hoist at the main shaft to permit mining at greater depth and to allow more extensive underground exploration.

This method of mining was obviously advantageous, since it permitted a large tonnage to be broken in advance of requirements. It is also relatively safe and has a small timber consumption.

The surface diamond drilling done by the Company is shown on the accompanying map (No. I).

Production and Ore Reserves

As stated above, the Quebec Copper mine started production in February 1954, and suspended operations on April, 1958. During these years, the mine produced a total of over 1,117,400 tons of ore averaging 1.05 per cent copper and low precious metal values totalling over 7,301,850 dollars (Table 8). The mine operated with a remarkably low cost of mining and milling, thereby enabling it to reap substantial profits (Table 9). Although in 1957, the operating costs at the mine were reduced to $2.49 per ton milled, and the mine showed an increase of 50 per cent over 1956 in actual pounds of copper produced, the revenue in 1957 was less, because the average price per pound received was 62 per cent less than in the previous year.

The mill increased its output from 450 tons a day in February 1954 to 800 tons per day by August of the same year. A recovery of 94.28 per cent was obtained with the mill operating at 98.5 per cent of the possible running time. In 1957, the mill operated continually at an average daily tonnage of 844 tons, the average grade being 0.83 per cent copper.

The ore reserves at the mine at the present time are, for the most part, tied up in the pillars surrounding the main shaft between the 1000 and 1575-foot levels; they are estimated to hold 800,000 tons averaging 0.88 per cent copper. (Introduce Table 9).

Lots 9 and 10, Range I, Stukely Township

A small showing of copper mineralization, referred to in earlier reports as the 'Grand Trunk mine', is located about 0.5 miles southwest of South Stukely, a few hundred feet outside of the map-area. The mineralization consists of disseminated specks and occasional veinlets of chalcopyrite, pyrite and bornite scattered over an area of several tens of square fest. The host rock is an assemblage of interstratified chlorite schist lenses and dolomitic marble beds, in strike with the Bonsecours greenstone-marble outcrops of South Stukely.

Around the middle of last century, the property was opened by a shaft 60 feet deep; it is reported that this shaft was deepened to 110 feet in 1929, and a crosscut run for 115 feet at the 100-foot level. In 1931, some 50 feet of drifting was done. No information could be obtained concerning the mineralization in the underground workings, which are now flooded. Bancroft examined the dump samples and adjacent outcrops, and noted that the copper values are very irregularly distributed and that "none of the fragments would run more than from 3 to 4 per cent in copper (1915, p. 120). It is probable that a few tons were shipped from this property.

18 Lot 24, Range VII, Bolton Township (No. 1)

The No. 1 showing, known as the 'Libby mine', is located at about 2000 feet northeast of South Bolton, (Map No. IV). Its mineralization consists mainly of pyrite, and minor pyrrhotite and chalcopyrite. The host rock is an altered and schistose greenstone about 250 feet long and 50 feet wide containing abundant amygdules; it is in strike with the greenstone exposed at the Quebec Copper Corporation holdings, farther north. Clean-cut and irregular fractures are abundant, where the rock is more acidic. The amygdules, about 1/8 of an inch in diameter, are sheared and drawn out, and plunge steeply to the east.

Pyrite occurs in well crystallized cubes 1/8 to 1/2 inch in diameter and seems to be localized in pinching and swelling quartz-feldspar-carbonate veinlets. The veinlets, generally a fraction of an inch wide, are discontinuous and randomly distributed, and do not seem to follow a particular pattern. A few specks of pyrrhotite and chalcopyrite are disseminated in the vein material.

(19) Lot 25, Range VII, Bolton Township (No. 2)

The No. 2 showing is about 2800 feet south of the No. 1 prospect and 300 feet east of the Missisquoi Valley Railway (Map No. IV).

A vertical pit has been dug in the greenstone. It is about 27 feet long, 6 feet wide and reportedly 15 feet deep. No mineralization was found in the bedrock. The chips around the pit, however, showed mainly chalcopyrite and pyrite with traces of pyrrhotite and bornite in small, disconnected quartz-calcite pockets irregular in shape and generally a fraction of an inch wide. There is also some disseminated pyrrhotite in the more massive portions of the greenstone.

The host rock is a schistose greenstone interbedded with tuff horizons that strike northeast and dip vertically. The rock also shows a late axial plane cleavage S_2 that strikes to the northwest and dips vertically. Most of the veinlets seem to be roughly parallel to the main schistosity S_1.

Mineralization appears to have formed by replacement of greenstone or tuff; there is no evident shear zone that may have directed or controlled the flow of ore-bearing solutions; furthermore, the showing is approximately in the middle part of the 400-foot wide greenstone body and 150 feet east of its contact with greywacke and slates.

(20) Lot 26, Range VII, Bolton Township (No. 3)

The No. 3 prospect (the former 'Holland mine') is located at about 1300 feet south of the No. 2 showing (Map No. IV). The site is marked by a square, vertical pit of about 15 by 15 feet and, according to local reports, of approximately 60 feet depth.

Mineralization occurs in a 5-foot wide rusty and schistose zone that apparently separates a wide belt of greenstone on the east from a 15-foot wide tuff horizon on the west. A few feet north of the shaft and along the main schistosity, steeply southeast plunging slickensides were observed, indicating some movement in this plane. The main or early schistosity S_1 seems to be truncated and offset by the late axial plane cleavage S_2 that strikes northeast and dips steeply to the southeast; these planes are barren, however.

Mineralization consists of pyrite, pyrrhotite, chalcopyrite and bornite in decreasing order of abundance, and is apparently concentrated in apinching and swelling belt of quartz-feldspar-carbonate vein material within the schistose zone. This favourable horizon is about 10 feet long and 1 to 3 feet wide and contains three discontinous 1/8 to 1/2-inch wide quartz-feldspar-carbonate stringers that carry pyrite, pyrrhotite, chalcopyrite and bornite. The veinlets are commonly parallel to the main schistosity of the host rock. About 10 feet north of the pit, some chalcopyrite, bornite and malachite stains may be seen in an irregular crack that strikes east-west and dips steeply south. It seems that here, mineralization has been controlled by a joint opening. A small veinlet containing pyrrhotite specks was found at about 10 feet south along the strike.

It may be concluded that the greenstone-tuff contact served as a favourable channel-way for the introduction of mineralizing solutions. Furthermore, the development of strong schistosity and slickensides is also an indication that some movement had taken place along this weakness zone, thereby facilitating the ingress of ore-bearing solutions. In most cases observed, the mineralized stringers are parallel to S_1, and follow the latter around the noses of what appear to be early folds. At places, such mineral-carrying veins are offset or cut off by the late axial plane cleavage S_2.

21 Lot 27, Range VII, Bolton Township (No. 4)

The No. 4 pit is located at about 2000 feet northeast of South Bolton and about 800 feet north of the South Bolton-Knowlton Landing gravel road and railway intersection, (Map No. IV).

Mineralization consists mainly of pyrrhotite and small amounts of chalcopyrite and bornite. As in the other showings, the sulphides seem to be concentrated in 1/16 to 1/4-inch wide quartz-carbonate stringers that are roughly parallel to the main schistosity S_1 of the greenstone, which strikes a little east of north and has the usual vertical dip. The late axial plane cleavage strikes northeast and dips 65 degrees to the southeast. Actually, the greenstone here is relatively massive in comparison with the schistose zones around other showings described above. Whereas mineralization in adjacent pits occurs in zones of varying width with ribbons of sulphides irregularly intercalated in the altered greenstone, pyrrhotite at this locality is disseminated and scattered, in addition to the usual vein mineralization.

16 Lot 6, Range VIII, Bolton Township

Some 100 years ago, two shafts, now filled with water, were sunk, one to a depth of 100 feet, the other to 50 feet, at the western margin of the greenstone, 0.6 miles north of the Quebec Copper mine. Examination by the writer of the dumps and surface exposures at this property (formerly known as the 'Bolton', 'Canfield', or 'Canadian' mine), disclosed a few scattered grains of pyrite and rare pyrrhotite and chalcopyrite embedded in a schistose greenstone.

In 1955, the Quebec Copper Corporation Limited started a drive along the 1400-foot level in a northerly direction to explore the downward extension of the peridotite-greenstone contact. At a point 1000 feet north of the main No. 1 shaft, horizontal holes, drilled at regular 50-foot intervals, showed a length of 400 feet averaging 1.4 per cent copper across 8 feet. In 1957, the drive had reached a point 3000 feet north of shaft No. 1 and was thus in the vicinity of the underground workings of the 'Bolton mine'. Diamond drilling was carried out from stations located at regular intervals along this 1400-foot drive. Although one hole had intersected 5 feet of 12 per cent copper, mineralization proved to be too irregular to be of economic value.

14 Lot 2, Range IX, Bolton Township

This prospect, known as the 'Ives mine' is situated about 0.7 miles south of Eastman. Copper mineralization was discovered in 1866 and was worked intermittently until 1915. Three shafts were sunk into a schistose greenstone, and about 600 tons of ore of 12 per cent copper are said to have been shipped from the property in the early days (Bancroft, 1915, p. 182). In 1914, Bancroft examined the surface outcrops and underground workings and noted that "copper values are very low", and that at one place "a zone of schist, 3 to 5 inches in width, is heavily impregnated with pyrite and a few small particles of chalcopyrite, while in addition some cubical crystals of pyrite are dispersed in linear arrangement parallel to the schistosity in the remaining portion of the schists," (Bancroft, 1915, p. 182). At other places, individual pinching and swelling veins and stringers of rich ore a few feet in length were encountered. It appears that most work had been conducted along a shear zone averaging 5 feet in width, "within which the chalcopyrite-bearing quartz veins and stringers are irregularly distributed" (Bancroft, 1915, p. 183).

Recently, the Quebec Copper Corporation Limited made a detailed examination of the rather rare surface exposures on the property and vicinity. Detailed geological mapping, followed by diamond drill sampling, failed, however, to give satisfactory results.

22 Lot 27, Range VII, Potton Township (No. 5)

The No. 5 showing is located at about 1300 feet almost due north of the Spring Valley Inn in Potton Springs (Map No. IV).

The sulphides present include chalcopyrite, pyrite, and bornite in decreasing order of abundance; malachite stains are associated with chalcopyrite.

The host rock is apparently a 50-foot wide and 800-foot long tuff sheet in contact with altered greenstone on the east and west. It is believed, however, that the greenstone has actually several tuffaceous horizons interbedded with it. When examined in detail, the tuff shows numerous intensely and irregularly folded laminae that have a general strike of N.5°E. and a vertical dip. The minor folds range in amplitude from 1/4 inch to 2 inches, with fold axes plunging 40 to 70 degrees in directions varying from 205 to 110 degrees.

Mineralization is of two types: in cross-cutting veins and in stringers that parallel the folded schistosity S_1.

Mineralized quartz-carbonate veins are partly parallel to the schistosity S_1, and partly fill southeast-dipping joint fractures that cut across that schistosity. At one place, a quartz-carbonate vein, containing a few specks of chalcopyrite and pyrrhotite, is 2 feet long and about 3 inches wide; there is no indication at the surface, however, that the vein material and the associated sulphides are continuous along strike.

Of greater significance are thin stringers and seams of chalcopyrite and pyrite that run parallel to the folded early bedding (?) schistosity S_1. The sulphides, along with some magnetite and carbonates, are concentrated at the crests of (early?) minor folds. There is definite indication that the limbs of most of these minor folds have been sheared out along their axial plane cleavages (Fig. 8).

It is evident that mineralization here, is the result of replacement and probably fracture filling in tuffaceous rocks. The mineralized crests of minor (early?) folds and the sheared-out limbs suggest, furthermore, that mineralization occurred contemporaneously or after the first period of deformation, but probably before the development of the late cleavage S_2. Barren, folded carbonate veinlets with limbs drawn out by slippage, also suggest later shearing movements that eventually isolated the (early?) fold units.

Other Small Copper Occurrences

1.1

A few tiny and isolated specks of chalcopyrite, filling fractures in Ottauquechee quartzite, were seen on lot 10, range VII, Bolton township. Several, small stringers of chalcopyrite were also observed in a small circular pyroxenite body on lot 3, range XI of Bolton township, and in a lens of amphibolite greenstone, immediately west of Eastman lake.

Asbestos

28 Lots 9 & 10, Range VII, Bolton Township

voir p 121

On the western side of a conspicuous ridge of serpentinized peridotite, about 2000 feet northwest of Trousers lake, are several prospect pits that show thin veinlets of cross fibre asbestos. On lot 10, Bolton township is a showing of asbestos, known as the Benoit prospect. There, an adit 15 feet high, 12 feet wide and 20 feet deep, has been dug in a dark and serpentinized peridotite. Although the underground workings are now flooded, small stringers of cross fibre asbestos, up to 1/8 inch thick, can be seen near the shaft; the latter is reported to be 30 feet deep.

29 Lot 22, Range VII, Bolton Township

Several small occurrences of cross fibre asbestos were found in the peridotite lens fringing a massive metabasalt body, 2 miles northeast of South Bolton (Map No. IV). The tiny stringers are 1/16 inch wide and not continuous.

30 Lot 6, Range VIII, Bolton Township

A few prospect pits have been dug into a much sheared and serpentinized peridotite body, about 1 mile due east of the southern part of Libby pond. There, the showing consists of discontinuous and rare 1/16 to 1/8 inch wide veinlets of cross fibre asbestos.

31 Lot 9, Range IX, Bolton Township

At the east shore of Long pond, along a line separating range VIII from range IX of Bolton township, two pits and a 150-foot long trench show small, 1/16 inch wide, tiny stringers of cross fibre asbestos.

32 Lot 2, Range XI, Bolton Township

Three prospect pits have been dug into a serpentinized peridotite body, at the west side of a hill underlain by spilitic greenstone, 1000 feet west of Orford lake. Two 1/8 inch wide and 2-foot long parallel stringers of cross fibre asbestos have been observed at the peridotite-greenstone contact.

33 Other Small Asbestos Occurrences

Other small occurrences of cross fibre asbestos have been found in lot 27, range VII; lots 2 and 4, range VIII; lot 2, range IX; lot 3, range XI; and lot 1, range XII, all located in Bolton township.

Although a large number of pits and other openings have been made in search of asbestos, nowhere has this been found of good enough grade to warrant serious mining operations. It appears that, in general, the veins are not of sufficient size to be of commercial grade. Slip fibre and brittle piccrolite are of common occurrence, but their distribution is sporadic. In the writer's opinion, the most promising prospect is on lot 9, range VII of Bolton township, but even there, the fibre is harsh, and the veinlets thin and of limited extent.

Steatite

35 In the eastern part of lot 3, range VII, Bolton township (on the farm of Mr. A. Lambert), two parallel steatite veins, each

about 8 inches wide, are interlayered with beds of pyrite-rich Bonsecours quartz-sericite-graphite schist. The latter strike N.15°E. and dip east at 55 degrees. The showing has been explored by a 14-foot square shaft, some 50 feet deep. According to local reports two crosscuts were run north for 15 feet and east for 20 feet, at a depth of 30 feet from surface. Some 15 years ago, Broughton Soapstone and Quarry Company Limited is reported to have shipped seven truck loads from this locality to Montreal for processing. However, the shaft was filled in 1955 and all work has been discontinued.

Other minor occurrences of steatite, mixed chiefly with magnesite, and everywhere associated with bodies of serpentinized peridotite, were located in lot 6, range VIII, and lot 9, range IX of Bolton township.

(2) Magnetite and Hematite

Discontinuous magnetite and hematite-rich layers and pods are of common occurrence in the area underlain by the Bonsecours schists; they generally show conformable relations with the enclosing quartz-sericite-albite-chlorite schists and probably represent originally iron-rich sedimentary beds. The beds are commonly 1 to 8 feet wide and of variable length; their distribution is, however, highly erratic and their values are unpredictable.

On lots 8 and 9, range X, Bolton township, there is a series of hematite-rich purple slates in conformable contact with greenstones to the east. The iron-rich beds are 30 feet wide and appear to be continuous for at least 500 feet. In one of the two pits, supposedly 70 feet deep, mineralization consists of fairly pure hematite of the specular variety; in other places, it is intimately mixed with quartz and chlorite. Copper stains are commonly found in fissures of the slaty rock. It is reported that in 1903, Canada Iron Corporation Limited made a trial shipment of 200 tons (Harvie, 1911, p. 291).

Chromite

24 Rare and disseminated chromite specks occur in serpentinized dunite on lot 22, range II of Stukely township. Fortier reports that on the south shore of Orford lake, dunite "shows dark brown grains of chromite with dark, almost black material at the periphery and along fractures. One such grain has a peripheral skeleton of dark material with interstitial antigorite" (1946, p. 216).

27 Some chromite is also found in serpentinized peridotite on lots 9 and 10, range VII, Bolton township, where it is seen to fill occasional tiny and clean-cut fissures in the rock. Harvie reports that one shipment of 27 tons of ore, containing 49 per cent Cr_2O_3 was made in 1896 from surface workings on lot 9, range VII (1911, p. 291).

Pyrite and Pyrrhotite

It was noted above that in the Quebec Copper mine and in most copper showings of the area, mineralization consisted in large part of pyrite and pyrrhotite. Pyrite is also of common occurrence in the Bonsecours quartz-sericite-graphite schists and the Beauceville carbonaceous slates. Where exposed to weathering, it is largely altered to iron oxides, which have been dissolved and removed, leaving cavities and outcrops covered with brown iron stains. Pyrite and pyrrhotite are common constituents of the massive Beauceville metabasalt, and also of the gabbro; at places, this results in gossan-like weathering (Map No. IV). A small pit in the eastern part of lot 3, range XII of Bolton township, shows a few scattered concentrations of massive pyrite, localized by fractures in an ill-defined breccia zone within the metabasalt.

Marble

(42) Lot 6, Range I, Stukely Township

Some 30 years ago, two quarries were opened by Canadian Rock Products Limited at the above locality. The quarries are located a few hundred feet outside the western limit of the map-area, 1500 feet and 2000 feet southwest of South Stukely, respectively.

The workings are in a belt of interbedded chlorite schists and marble that, in the map-area, have a total width of 2000 feet. Lenses of chlorite schists, greenstone and marble of this belt extend from a point east and south of Brome lake over South Stukely and Lawrenceville to Racine, some 20 miles northeast of the map-area. In the southern part, near Brome lake, the carbonate beds are highly dolomitic, whereas in South Stukely and in its northern part, the lenses consist of recrystallized calcium carbonate with few dolomitic interbeds and inclusions of chlorite schist and phyllite.

The quarries have been opened in a marble lens, which at this locality, has a width of about 200 feet. The rock is medium-grained, yellow-bluish to white in colour and crudely bedded. It strikes northeasterly and dips 60 to 70 degrees to the northwest. The rock commonly contains occasional somewhat darker streaks of dolomite and is usually veined by quartz and carbonate; at its western margin, the marble contains small euhedral drystals of pyrite and specks of copper sulphides; the latter are particularly conspicuous near the shaft of the old 'Grand Trunk mine' described above. The marble also contains lenses of chlorite schist and interbeds of phyllite, similar in appearance and probably in origin to those encountered at South Stukely.

The quarries were opened on the western slope of a hill and were operated by a crew of eleven. Because of its unsuitability for building purposes, the marble was used chiefly for local road construction and the making of terrazzo. According to local reports, the blasted rock was hoisted into a conveyor belt and fed to a crushing plant, which had a capacity of over 50 tons per hour (Goudge, 1935, p. 234).

In 1955, the quarries were taken over by Mr. Benoit, who supposedly shipped 6 carloads of white and green terrazzo to Toronto. The operations were discontinued, however, in July 1956.

(47) Lot 8, Range II, Stukely Township

Two large quarries, now partly filled with water, are located in a dolomitic marble lens, 0.7 miles north of South Stukely. They were opened in the previously described belt of Bonsecours marble, which was also quarried south of the village. The marble lens varies from 100 to 200 feet in width, strikes N.40°E. and dips steeply to the northwest. The stone has a fine-grained texture, is generally bluish-white in colour, and contains a considerable amount of impurities. These range in composition from dark-green inclusions of chlorite schist to yellow interbeds of dolomitic material. While the western portion of the marble lens appears to be a relatively uniformly coloured calcium carbonate-rich variety, the eastern section, on the other hand, is veined and is probably dolomitic in composition.

Prior to 1910, the marble was used in the making of quick-lime. Then, the Dominion Marble Company Limited acquired the property, from which until 1914, a considerable output of ornamental building stone was extracted. In the larger and more easterly located quarry, huge blocks of marble some 12 feet across, are still present on the property.

In 1956, Delbo Marble Incorporated drilled 5 shallow holes into the marble lenses in the immediate vicinity of South Stukely in order to determine the suitability of the stone as building material. The writer examined some of the core and concluded that, although the stone is attractive in appearance, the pinching and swelling nature of the marble lenses, and the large and unpredictable content of impurities renders the stone more suitable for the making of terrazzo or for agricultural purposes than as building material. There are definite indications, however, that, as the belt is traced northward, the physical properties of the marble, its purity, and the width of the lenses become more suitable for construction purposes.

(44) Lot 3 & 4, Range XI, Bolton Township

A 2000-foot long and 100 to 300-foot wide lens of red dolomitic marble, peppered with dark green islands of serpentinized peridotite and veined with quartz, crops out on the eastern extremity of a body of altered peridotite, 0.5 miles southwest of Orford lake. Its contact with the adjacent ultrabasic rock is gradational, and it is believed to be metasomatic in origin; this makes its dimensions difficult to evaluate. The colour of the marble is pleasant, and it easily accessible from Highway No. 1; however, the stone contains many vugs and is traversed by too many irregular fractures to have any strength as a building material; it may find use in the making of terrazzo.

Slate

The grey and black slates of the map-area are highly fissile; they break into small scales, and their cleavage is commonly warped. This makes them of little use as a roofing material. Some green and purple slates, however, exposed east of the Miller Pond schist belt in lots 6 and 9 of range X, Bolton township, are more massive, and break into larger slabs suitable as roofing material.

Sand and Gravel

Deposits of sand and gravel are abundant in the map-area; their sorting is generally poor, and stratification commonly irregular.

Great quantities of sand and gravel have been extracted from (47) an area north of Eastman lake on lots 20 and 21, range II of Stukely township for building purposes, road construction and the manufacture of concrete. Other sand and gravel pits have been opened on lot 25, range VI; lot 23, range VII (Map No. IV); and lot 4, range IX, all located in Bolton township.

1 bouteille total
3.78 litres

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APPENDIX

(Cutroduce ay 6.22)

TABLE 1

Partial Chemical Analyses+) of Schists, Greywackes and Slates of the Eastman-Orford Lake Area.

	SiO_2	Al_2O_3	Na_2O	K_2O	CaO	MgO
1.			2.97	4.05		2.23
2.			2.10	2.05		1.52
3.	56.74		2.43	3.42	0.10	1.37
4.	68.88	10.16	1.90	2.10	nil	nil
5.	74.20	7.98	2.20	1.90	nil	nil
6.	75.08	11.71	2.25	1.65	1.35	0.83
7.	55.15		0.92	3.42		
8.	54.88		2.25	3.56		
9.			2.12	4.05		
10.	53.86		1.10	3.12	nil	0.65
11.			1.20	5.00		
12.			0.95	3.85	nil	
13.			o.75	4.55	nil	

1. Bonsecours quartz-sericite-albite-(chlorite) schist (On St. Etienne mountain).
2. Bonsecours quartz-sericite-(albite)-chlorite schist (1.5 miles northwest of St. Etienne).
3. Bonsecours quartz-sericite(albite)-chlorite schist (1.5 miles southwest of South Stukely).
4. Bonsecours quartz-sericite-(albite)-chlorite schist (2000 feet northwest of Eastman lake).
5. Miller Pond quartz-sericite-chlorite schist (1 mile southwest of Orford lake).
6. Miller Pond greywacke or subgreywacke (2.7 miles south of Highway No. 1 and north-south gravel road intersection, 0.5 miles east of Eastman).
7. Miller Pond grey slate (at the road cut, immediately south of Orford lake).
8. Miller Pond grey slate (1.5 miles southwest of Orford lake).
9. Beauceville dark slate (300 feet west of the northern tip of Malaga pond).
10. Purple slate in the greywacke-slate division. (1 mile southwest of Orford lake).
11. Purple slate. (northern tip of Orford lake).
12. Typical purple slate (road cut, 650 feet west of the southern tip of Orford lake).
13. Typical purple slate underlying greenstone of the greywacke-slate division (1.6 miles southwest of Orford lake).

+) Hand specimens analysed by the Quebec Department of Mines Laboratories, Montreal, Quebec.

(Introduce in p. 27)

TABLE 2

Chemical Analyses, Molecular Proportions and ACF Values of ~~Bonsecours~~ Chlorite Schists, Phyllites and Greenstones +)

	1	2	3	4	5	6	7	8
SiO_2	39.77	47.16	45.86	50.17	47.85	46.53	49.42	42.73
TiO_2					2.20	1.98	2.60	2.40
Al_2O_3					18.00	15.92	20.33	20.87
Fe_2O_3					3.92	5.47	9.05	12.29
FeO					6.56	3.88	2.30	1.29
MnO					0.18	0.19	0.02	0.06
MgO					6.85	9.56	2.68	4.51
CaO					3.59	8.23	1.15	2.35
Na_2O	0.80	1.10	2.10	0.76	2.00	3.29	0.15	0.33
K_2O	nil	nil	0.38	nil	2.60	0.11	6.78	7.94
Li_2O					0.00	0.00	0.00	0.00
P_2O_5					0.42	0.32	0.79	0.52
H_2O+					4.94	4.01	3.71	4.12
H_2O-					0.05	0.04	0.03	0.05
CO_2					0.86	0.22	0.04	0.06
S					0.01	0.006	0.007	0.006
SrO					0.03	0.10	0.01	0.01
BaO					0.11	0.01	1.03	0.35
V_2O_3					0.04	0.04	0.04	0.06
Cr_2O_3					0.05	0.08	0.02	0.10
CuO					0.00	0.00	0.00	0.00
NiO					0.01	0.01	0.01	0.01
PbO					0.00	0.00	0.00	0.00
ZnO					0.00	0.00	0.00	0.00
CoO					0.00	0.00	0.00	0.00
ZrO_2					0.01	0.00	0.01	0.00
						Molecular Proportions		
Al_2O_3					176	155	200	200
Fe_2O_3					24	34	55	77
FeO					91	54	32	18
MnO					2	2	0	1
MgO					172	237	67	113
CaO					64	147	20	35
Na_2O					32	53	2	5
K_2O					28	2	72	85
A								
C								
F								
Total								

1. Chlorite schist (1.4 miles northwest of St. Etienne).
2. Actinolite greenstone (immediately west of Eastman lake).
3. Chlorite-actinolite schist (0.5 miles north of Libby pond).
4. Tibbit Hill chlorite schist of the Oak Hill series (from Pinnacle mountain, 7 miles southwest of Sutton).
5. Greenstone (in quarry, 0.5 miles southwest of South Stukely and immediately outside of the western margin of the area.
6. Greenstone interbeddes with marble beds (north side of Highway No. 1, 1000 feet west of South Stukely).
7. Phyllite (same locality as No. 5).
8. Phyllite intercalated between greenstone bands (north side of Highway no. 1, about 1000 feet west of South Stukely).

+) The first four analyses were done by the Quebec Department of Mines Laboratories in Montreal; the others, by the Quebec Department of Mines Laboratories in Quebec, Province of Quebec.

(Introduce on p. 41)

TABLE 3

Modes of Miller Pond Greywackes

	1	2	3	4	5	6	7	8	9	10	11
Quartz	55	60	51	57	56	48	56	68	46	55	52
Feldspar+)	35k	15a	16a	15o	10a	21a	20	10	22o	19	24
Chlorite Sericite	10	23	28	25	31	18	15	20	28	23	21
Carbonate		tr			2	8	tr				2
Iron Oxides	1	2	2	tr	1	2	8	tr	3	1	
Epidote			tr	tr							1
Muscovite			2			1					
Zircon			tr		tr	tr					
Rock fragments			tr		tr	tr	tr				

+) k,a,o refer to preponderance of K-feldspar, albite and oligoclase, respectively.

1. Feldspathic greywacke or arkosic greywacke (immediately west of Long pond).
2. Greywacke (6000 feet west of Orford lake).
3. Greywacke (2000 feet southwest of Orford lake).
4. Greywacke (2 miles southwest of Orford lake).
5. Greywacke (2.5 miles southwest of Orford lake).
6. Greywacke (1 mile west of Orford lake).
7. Hematite-stained greywacke (2500 feet southwest of Orford lake).
8. Feldspathic arenite (2.5 miles south of Eastman lake).
9. Schistose greywacke (9000 feet northwest of Orford lake).
10. Schistose greywacke (2000 feet northwest of Eastman lake).
11. Greywacke; average of eleven estimates. (After J. Béland in the St. Magloire and Rosaire-St. Pamphile areas, 1957, p. 16.).

(Introduce on p. 44)

TABLE 4

Modes of the Miller Pond Greenstones +)

	1	2	3	4	5	6	7	8
Quartz	5	14	5		11	5	1	2
Feldspar	36	18	43+	45	46+	25	40=	26+
Pyroxene			1	5		2		5
Sericite and Muscovite	4	10	15	5		8		tr
Chlorite	36	48	18	28	17	16	45	28
Actinolite and Tremolite	8	10	15	tr	11	15	10	8
Epidote	10		1		4	24	11	19
Calcite	1			14	7	5		5
Opaques ++)		tr	2	2	3		2	7
Leucoxene			tr		tr		tr	
Rutile	tr		tr			tr		

+) The first five modes are within the greywacke-slate, the last three within the spilitic greenstone division of the Miller Pond formation.

++) Mostly magnetite and hematite.

\+ Mostly oligoclase.

= Mostly albite.

1. Chlorite-actinolite greenschist (500 feet southeast of the new Quebec Copper shaft).
2. Chlorite-Actinolite greenschist (5000 feet north of Long pond).
3. Amygdaloidal greenstone (7000 feet east of Long pond).
4. Greenstone, (east of the schist belt).
5. Greenstone, (east of the schist belt).
6. Spilitic greenstone, (west of Orford lake).
7. Spilitic greenstone (west of Orford lake).
8. Spilitic greenstone (3000 feet northwest of Orford lake).

(Introduce on p. 49).

TABLE 5

Partial Chemical Analyses +) of Banded and Massive Rocks of the Rhyolite Division.

	1	2
SiO_2	75.09	74.46
Na_2O	5.35	2.80
K_2O	0.24	2.50

1. Black and massive rhyolite, 1.5 miles southwest of Orford lake.
2. Evenly banded siliceous rock, 0.5 miles southwest of Orford lake.

+) Analysed by the Quebec Department of Mines Laboratories, Montreal, Quebec.

(Introduce on p. 52).

TABLE 6

Partial Chemical Analyses +) of Miller Pond Spilitic Greenstones

	1	2++)		1	2
SiO_2	48.78	44.54	MgO	3.86	
Al_2O_3	17.90		CaO	11.41	
Fe_2O_3	4.13		Na_2O	3.70	1.55
FeO	7.77		K_2O	0.15	0.43

1. Spilitic greenstone of the Miller Pond formation. (1000 feet southeast of Orford Lake Station and 500 feet northwest of island in Orford lake.)
2. Greenstone within the schist zone. (2.2 miles southwest of Orford lake).

(Introduce on p. 55).

TABLE 7

Partial Chemical Analyses +) of Metasomatic Dolomite (2000 feet southwest of Orford lake; Quebec Department of Mines Laboratory, Montreal).

SiO_2	1.21
Fe_2O_3	2.20
CaO	31.92
MgO	17,25

+) Analysed by the Quebec Department of Mines Laboratories, Montreal, Quebec.

++) Analysed by the writer.

(Introduce on p. 112)

TABLE 8

Annual Production at the Quebec Copper Mine+)

Year	Total Production (in tons)	Copper (in pounds)	Gold (in ounces)	Silver (in ounces)	Average Grade of Copper (in per cent)	Total Value (in dollars)
1954	223,631	1,354,000			1,56	2,236,310
1955	290,883	6,601,315	1,335,135		1,20	2,688,289
1956	294,960	3,118,469	450,63	4,599,67	0,60	1,211,857
1957	307,909	4,666,068	724,02	7,280,63	0,83	1,165,390
++) 1865-1866	225				9-11	10,125
1866-1871	2,400-3,600				10	
1874	1,500					25,000
1875	4,012					66,300
1877	2,900				3.5-7	

+) compiled from mine records

++) referring to the old Huntingdon mine (Bancroft, 1915, pp.171-173).

(Introduce on p. 113)

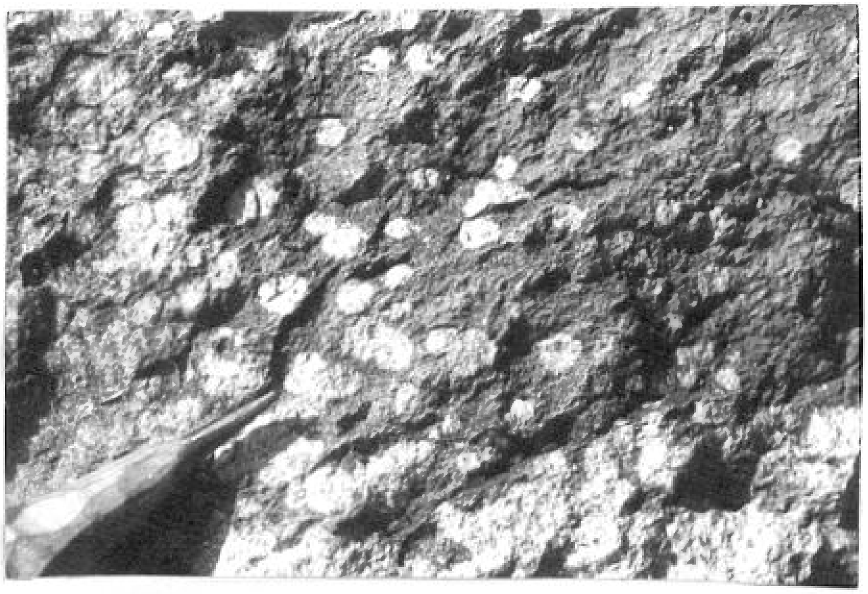
TABLE 9

Statement of Operating Costs and Profits
per Ton at the Quebec Copper Mine +)

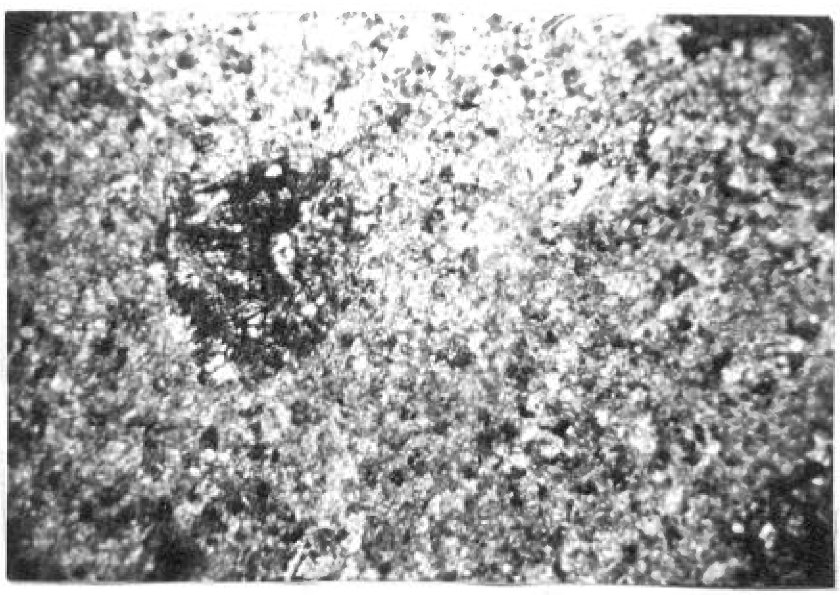
	1954	1955	1956	1957
Development	$ 0.45	$ 0.52	$ 0.83	$ 0.28
Mining	1.43	1.31	1.16	1.27
Milling	0.83	0.82	0.74	0.74
General Expense	0.22	0.26	0.24	0.19
Operating Cost at Mine	2.93	2.91	2.97	2.49
Treatment and Freight	2.74	1.83	0.92	1.28
Total Operating Cost	5.67	4.74	3.89	3.77
Value of Ore Hoisted	10.00	9.78	4.26	3.09
Operating Profit (+) or Loss	+4.33	+ 5.04	+ 0.37	- 0.68

+) compiled from mine records.

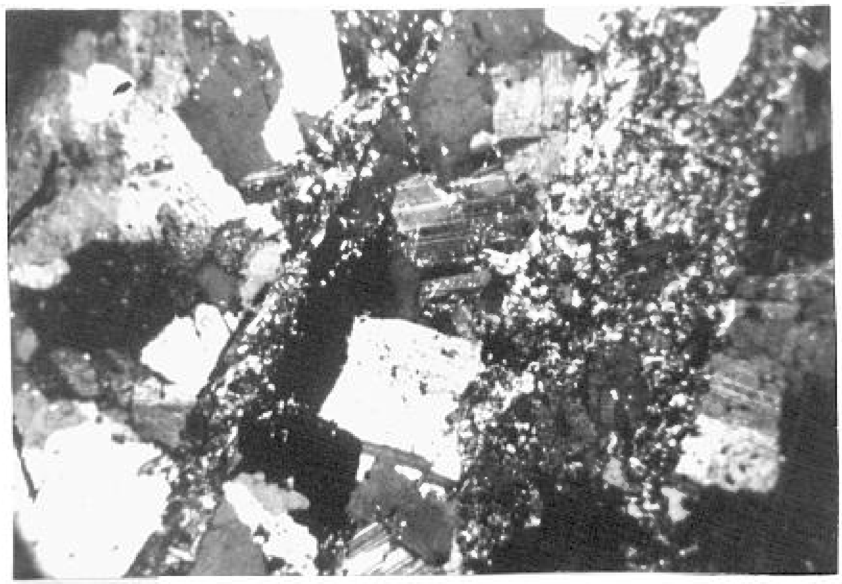
PLATE IV



A. Close-up view of quartz and feldspar-filled amygdules within the Miller Pond greenstone, 1000 feet west of Long pond. (Lot 8, range VIII, Bolton township).



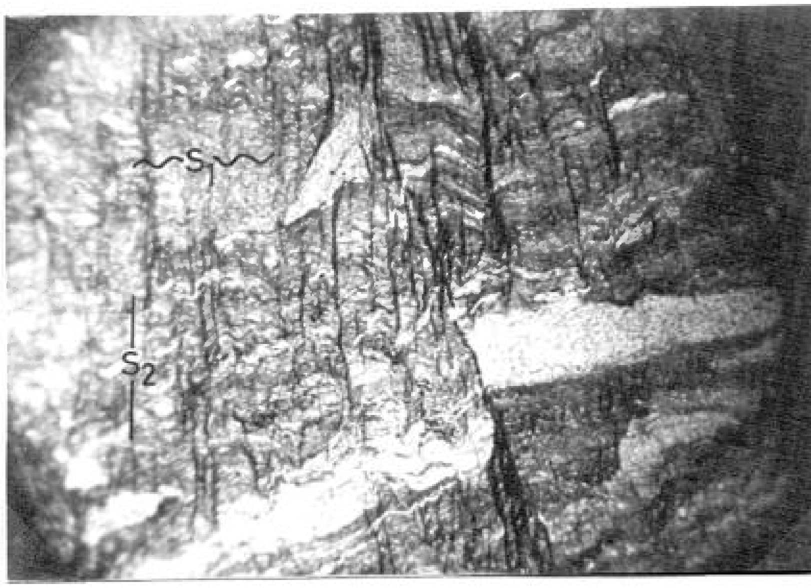
B. Photomicrograph of a partly digested island of antigotite embedded in a groundmass of dolomite. (Lot 4, range XI, Bolton township).
X nicols; x 32.



A. Photomicrograph of quartzo-feldspathic veinlets of the acidic facies cutting across labradorite crystals of the gabbro facies. (0.7 miles northwest of Trouserleg pond).
X nicols; x 32.

B. Granite breccia on the northwest tip of Long pond, showing subangular fragments of granite and greenstone (upper right) in a fine-grained matrix of somewhat more mafic composition.

PLATE VII

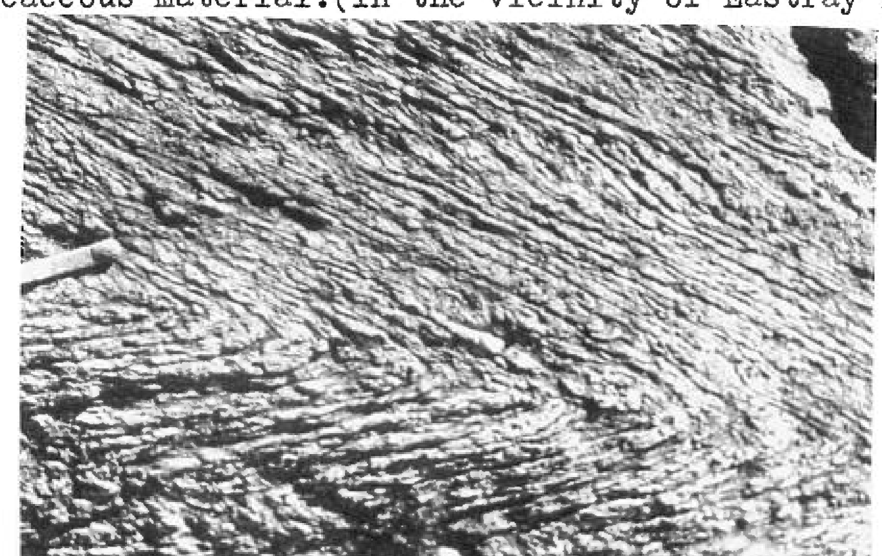


A. This photomicrograph illustrates intense micro-folding of schistosity S_1 resulting in reorientation of micaceous minerals and development of sub-parallel slip surfaces (S_2 or slip cleavage). Considerable slippage took place along most of these surfaces, as shown by truncated and offset quartz-rich layers. (Lot 7, range V, Bolton township).
Natural light; x 32.

B. Typical tectonic breccia made up of angular schist fragments embedded in a fine-grained matrix of similar composition. (Lot 8, range X, Bolton township).

PLATE X

A. Bonsecours schist sample illustrating lineations L_1 and L_2. Crinkles, associated with the later period of deformation, produce L_2, sloping gently to the left. Quartz rods (L_1), associated with the early folding, slope steeply to the right and apparently truncate L_2. This is due to differential erosion, whereby the more resistant quartz rods, unaffected by crinkling, are preserved preferentially to the micaceous material. (in the vicinity of Eastray Station).



B. Horizontal surface of a Bonsecours schist outcrop, showing a well-developed segregation into quartzitic and micaceous layers. The style of folding suggests that the folds are the product of the late stage of deformation (The match head points to the north). (Lot 7, range I, Stukely township).

PLATE XI

A. Vertical section at right angles to the axis of the major folds (late), so as to include both limbs of the northwardly (away from the observer) overturned early fold. This results in repetition of beds (represented by various colours) on the limbs of the folds, which may easily be mistaken for cyclic sedimentation in the field. The writer used six differently coloured plasticine sheets, of which the Terra Cotta is "stratigraphically" the youngest andgreen the oldest.

B. Late open fold superimposed on minor tightly squeezed early folds. In the course of flexural-slip folding, slippage was essentially guided by the long limbs and the axial plane surfaces (white paper) of early folds. This resulted in the disruption and isolation of individual crests and troughs, so commonly found in Bonsecours schists.

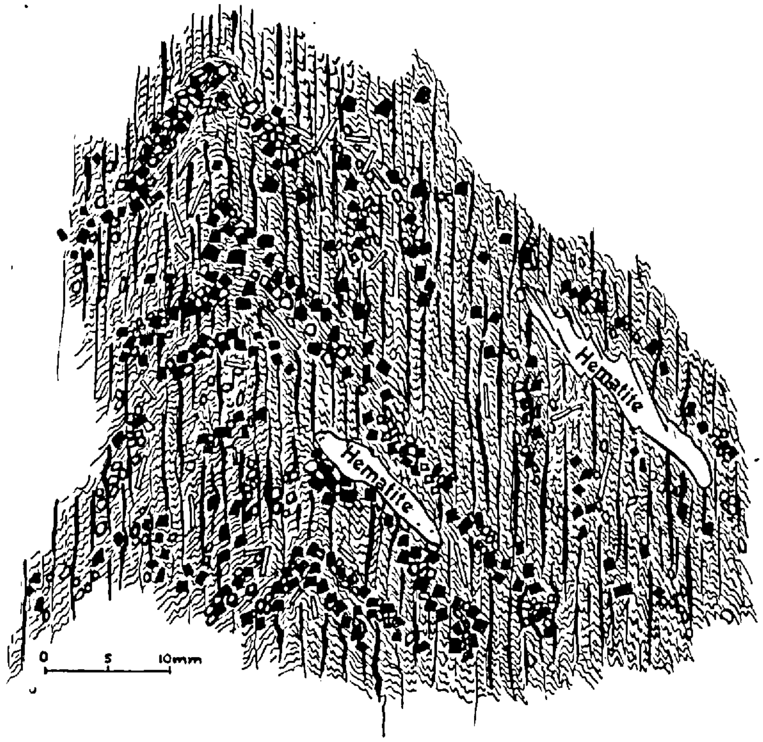


Fig. 3. East-west rock section of a Bonsecours quartz-sericite-albite-(chlorite) schist as viewed through a binocular microscope. The growth of euhedral albite porphyroblasts (black) is controlled by folded bedding (?) schistosity S_1. Also note the random orientation of muscovite flakes and the relation between the late (vertical) axial plane cleavage S_2 and the porphyroblasts. (3000 feet west of St. Etienne mountain).

(Introduce on p. 22)

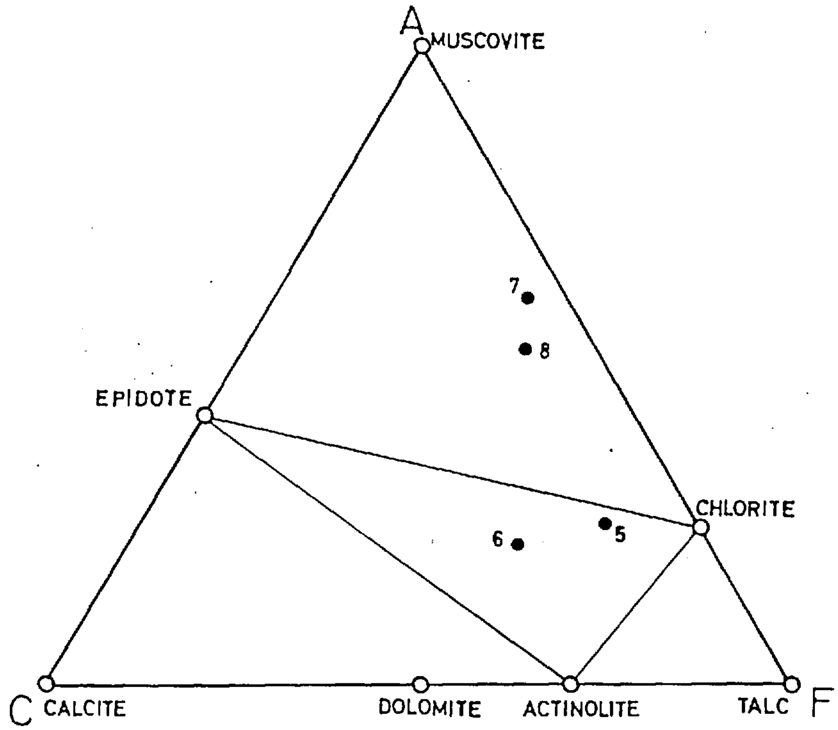
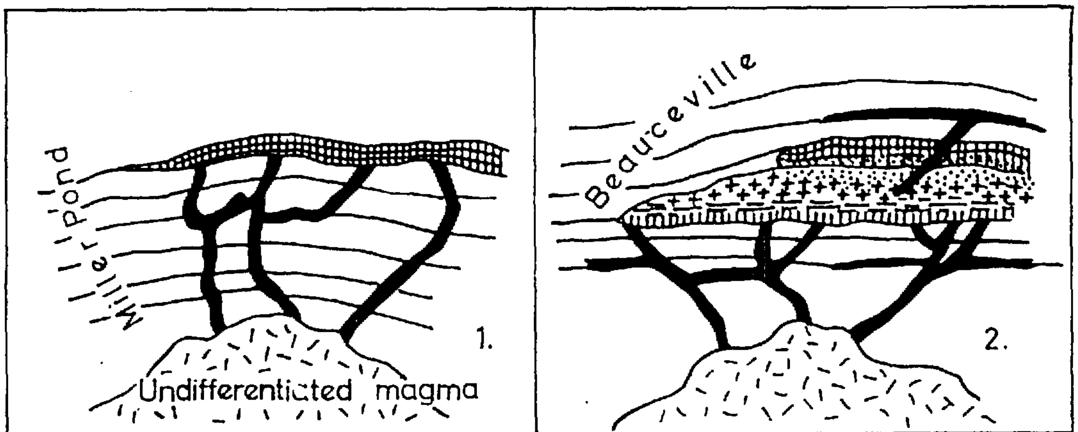
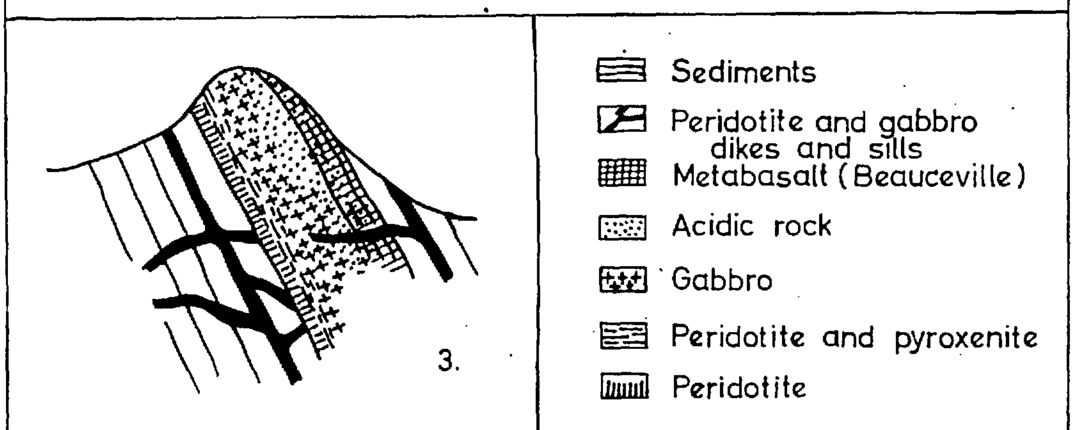


Fig. 4. Plot of Bonsecours greenstones and intercalated phyllites on an ACF diagram.
(Numbers refer to Table 2).

(Introduce on p. 30)



1. Deposition of Miller Pond rocks was succeeded by a period of volcanism, resulting in the extrusion of sheets of basaltic lava of great thickness, which formed the roof of the later intrusive.
2. A pre-existing line of regional weakness provided the locus of intrusion of a large sheet-like body, probably drawn from the same source as the extrusives. Differentiation, largely gravitational in character, led eventually to a pronounced zoning of peridotite at the base, through interbanded pyroxenite and peridotite, to gabbro and an'acidic rock' at the top of the intrusive mass.



3. Folding and erosion resulted in a homoclinal assemblage of sediments, lava and intrusives as seen today. Zoning in the latter is roughly conformable with the bedding of the enclosing sediments.

Fig. 5. Diagrammatic sketch (section across Chagnon mountain) illustrating the successive stages in the igneuos activity that led to the emplacement and differentiation of the Orford-Chagnon-Baldface complex.

(Introduce on p. 75)

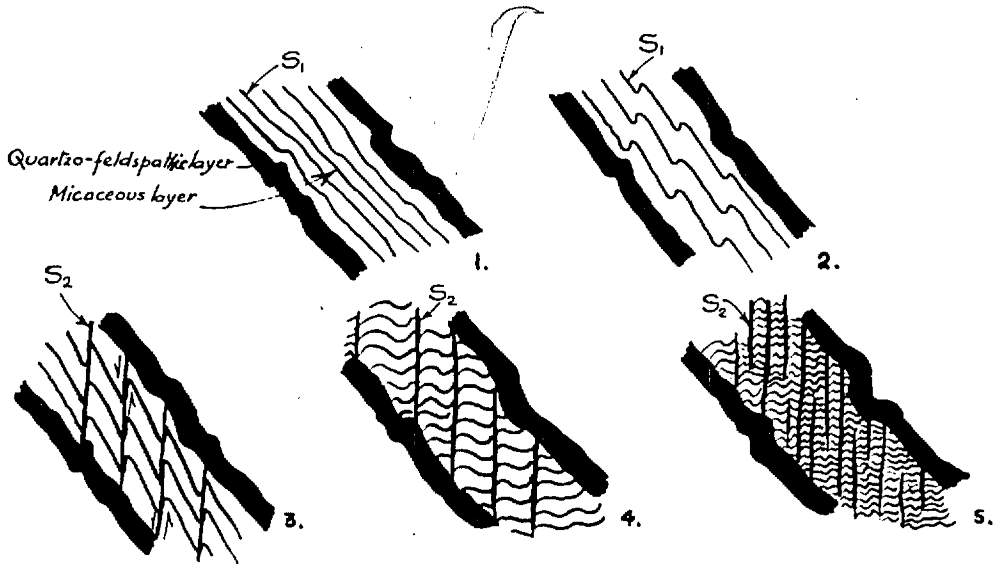


Fig. 7. Successive stages in the development of S_2 cleavage in crinkles of schists, as seen in the field and in thin section. 1) Micaceous layer bounded by quartzo-feldspathic stringers. 2) Folding, resulting in the formation of crinkles in the micaceous layer, whithout affecting the relatively more competent quartzo-feldspathic material. 3) Continued deformation develops an incipient cleavage S_2, sub-parallel to the short limb and axial plane of the crinkles. 4) Rotation and oriented growth of micaceous minerals accentuates S_2 and produces potential slippage planes along the latter. 5) Further development of S_2-surfaces with concurrent slippage and offsetting of S_1 foliae. (2 x natural scale)

(Introduce on p. 87).

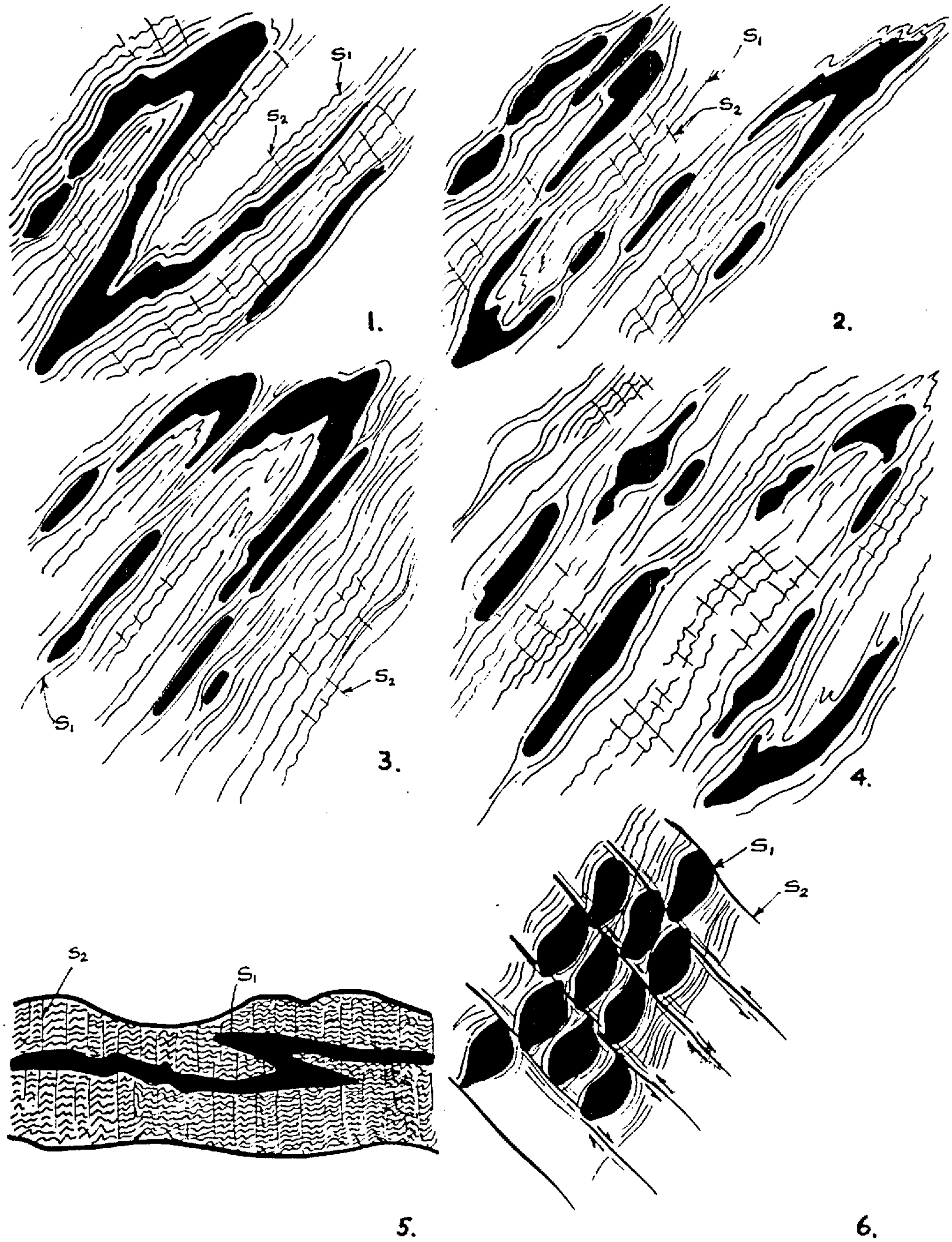


Fig. 8. Typical styles of early folds reflecting various intensities of deformation as seen in the field. Shearing and slippage along their axial plane cleavage and along schistosity S_1 resulted in the disruption of the early folds and eventually in the isolation of elongated fold segments. Note also the attitude of S_2 and associated late crenulations. The early folds are in the plane of schistosity S_1 and plunge steeply to the southeast; the crenulations, on the other hand, have a gently plunge to the northeast.(The drawings are from areas underlain by Bonsecours and Miller Pond rocks; the black stringers represent quartz or quartzo-feldspathic material; the first four outcrops are Bonsecours schists in plan; the last two are Miller Pond schists in section; scale: I" = 6").

(Introduce on p. 90).

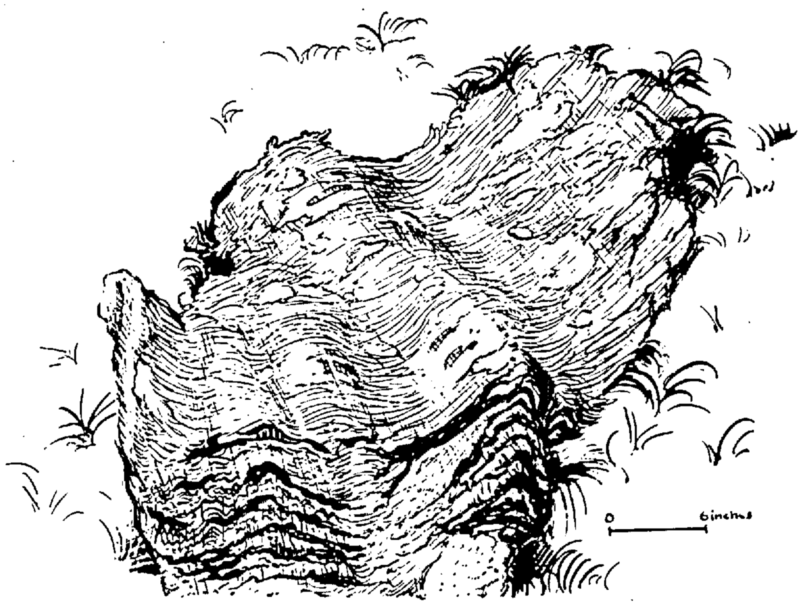
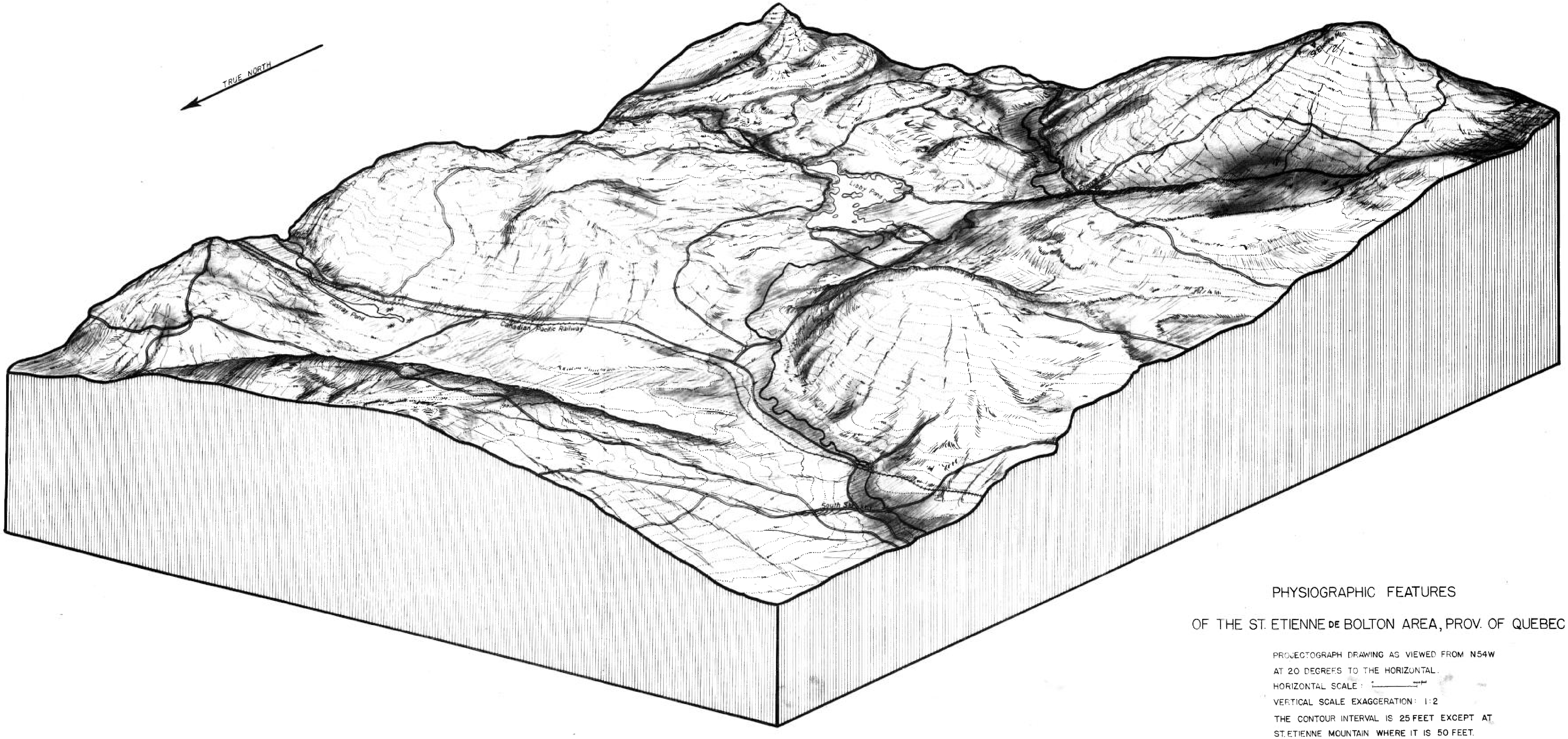


Fig. 9. Late folds of schistosity S_1 showing crenulations and late axial plane cleavage S_2 in the Bonsecours schists. Viewer is locking south.
(Drawing from photograph, St. Etienne mountain).

(Introduce on p. 92)



PHYSIOGRAPHIC FEATURES

OF THE ST. ETIENNE DE BOLTON AREA, PROV. OF QUEBEC

PROJECTOGRAPH DRAWING AS VIEWED FROM N54W
AT 20 DEGREES TO THE HORIZONTAL.
HORIZONTAL SCALE :
VERTICAL SCALE EXAGGERATION : 1:2
THE CONTOUR INTERVAL IS 25 FEET EXCEPT AT
ST. ETIENNE MOUNTAIN WHERE IT IS 50 FEET.

H. DE RÖMER

Figure 2. (Introduce on page 9).

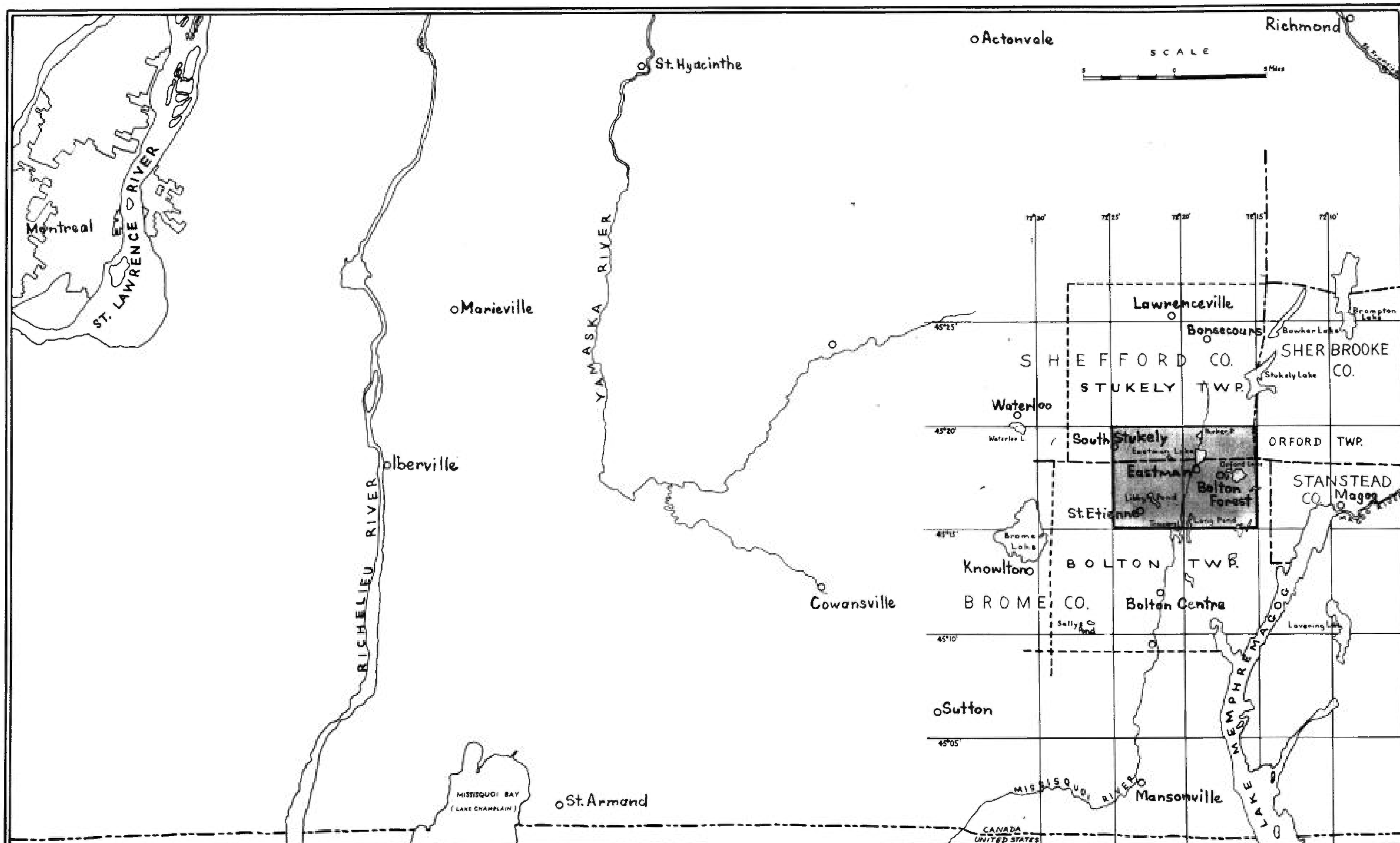


Fig. I. Location of the map-area

(Introduce on page 2)