PULBIC DOCUMENT

Gouvernement du Québec

DEPARTMENT OF NATURAL RESOURCES

Geological Exploration Service

SHEFFORD MAP-AREA

Shefford and Brome Counties

Eastern Townships of Quebec

by

H.C. Cooke, P. R. Eakins and M. Tiphane

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INTRODUCTION

General Statement

The Shefford Map-Area lies in the southwestern part of the Eastern Townships of Quebec; the centre of the map-area is approximately fifty-five miles east of the city of Montreal. It is defined by the parallels of latitude 45°15' and 45°30' north and the meridians of longitude 72°30' and 72°45' west; it is represented in the National Topographic Series (1:50,000 scale) by the Granby East-Half Sheet; it comprises approximately two hundred square miles and contains parts of Milton, Roxton, Granby, Shefford, Farnham and Brome townships of Shefford and Brome Counties. The city of Granby is located within the map-area, which is crossed by the Montreal-Sherbrooke Autoroute.

A stratigraphically important sequence of Cambrian volcanic and sedimentary formations comprising the essential elements of the Oak Hill group (Clark, 1934) extends across the southeastern third of the map-area from type-locations in the Sutton Quadrangle adjoining on the south (Eakins, 1964). This predominantly sedimentary group contains the shifting boundary between the eugeosynclinal and miogeosynclinal zones of the earliest phase of the Appalachian geosyncline (Cady, 1960). The Granby group of Cambro-Ordovician age occupies the northwestern third of the map-area; the group is made up of grits, impure green and black sandstones, and red, green and black grey slates, sedimentary rock-types of anomalous character for the generally miosynclinal nature of the zone in which they occur. These sedimentary rocks have been loosely correlated with the "Sillery" formation cropping out in the environs of Quebec City. An irregular outcrop band of younger slates of approximately Middle Ordovician age separates the Oak Hill rocks from the Granby group. These slates are variously known as the Stanbridge formation, Farnham slates, or the St. Germain Structural Complex (Clark, 1934, 1947).

The sedimentary and volcanic formations have been strongly deformed by several folding phases of Early Paleozoic mountain-building, and cleavages are prominent minor structures, but in general the rocks have been only weakly metamorphosed. The overall trend of the bedrocks is north-northeast reflecting complicated fold and fault structures. A major anticlinal structure lies to the east of the map-area. Major thrust faults may exist in the area.

The greater part of the Brome and all of the Shefford intrusive bodies of the Monteregian petrographic province (Adams, 1903) occur within the map-area, and underlie prominent "massifs" which dominate the local scenery by their rugged elevations and scenic beauty. These igneous bodies are of lower Cretaceous age (Fairbairn et al,1963).

The geology of the map-area was examined by H.C. Cooke, now deceased, and M. Tiphane during the field season of 1951; Tiphane in particular did most of the mapping of the Monteregian intrusive rocks. P.R. Eakins carried out further investigations, particularly of a structural nature, throughout the map-area in 1962, except for the part underlain by the igneous rocks. This report embodies much of earlier manuscripts by Cooke and Tiphane with emendations and additions by Eakins, who is responsible for this final version.

Culture and Access

Granby, a thriving industrial and cultural centre of a population of about 30,000 persons, lies along the banks of the North Yamaska River near the middle portion of the western boundary of the map-area. Textiles, rubber, and tobacco goods are manufactured, and other small industries are numerous; the city is famous for its fine zoo. Waterloo, the next centre in size with a population of 5,000, is close to and somewhat south of the middle point of the eastern boundary of the map-area. Waterloo is renowned for its mushrooms, which are consumed throughout eastern Canada; plywood, woodware, and other items are produced by local mills.

The villages of West Shefford, Roxton Pond, and Milton are the principal smaller communities serving the farming populace and the growing number of suburban and summer cottage developments.

Access to the area and any section of it is very easy because of an extensively-developed and well-maintained road system, much of which is paved. The cities of Granby and Waterloo are located on Route 1 from Montreal to Sherbrooke. The Eastern Townships Autoroute passes through the southern part of the map-area between Brome and Shefford Mountains with interchanges south of Granby and Waterloo.

A branch of the Canadian National Railways connects Granby and Waterloo and points to the east and west. The main line of the Canadian Pacific Railway from Montreal, via Sherbrooke, to St. John, New Brunswick, crosses the southern part of the area. A small airfield and an adjacent airport on a dammed section of the North Yamaska river serve Granby and environs for charter flights of small and medium-sized aircraft.

Paved secondary highways across the area link Granby and Waterloo with Cowansville and Knowlton in the adjoining Sutton quadrangle to the south and Roxton Falls and Drummondville to the north. A well-maintained network of gravel roads leading from the paved highways makes access almost effortless to all parts of the area including even Brome and Shefford massifs.

A number of picturesque lakes and streams attract thousands of summer visitors and residents to the region. Brome Lake, the largest body of water for some tens of miles, and lying partly within the map-area, is surrounded by scores of private cottages and many summer hotels. Large summer communities are also springing up around Brome and Roxton Ponds, and along the Yamaska River. With the advent of the Eastern Townships Autoroute dormitory suburbs of Montreal are beginning to be developed.

Good farm lands in the southern two-thirds of the map-area are underlain by glacial and fluvio-glacial material resting upon a more or less smooth and flat bedrock surfaces formed on the sedimentary formations of the Cambrian Oak Hill group and on limy and slaty Ordovician rocks. For the most part outcroppings of these rocks weather readily and break up under the plough, so that extensive cultivatible fields result. In the section of the map-area underlain by the Granby group, however, the parts underlain by sandstones are hilly with many resistant outcrops and a stoney soil, and farming is hardly possible. The slate areas of the Granby group are however farmed profitably. Fine sugar bush are numerous throughout the map-area occupying ground that usually cannot be otherwise used because of outcroppings of resistant rocks; stands of secondary deciduous and coniferous growth are common on Brome and Shefford Mountains, and along the low range of hill bounding the northwestern shores of Brome Lake underlain by the volcanic Tibbit Hill formation of the Oak Hill group.

Physical Features

Brome and Shefford "Mountains" dominate the topography of the Shefford map-area; actually each "Mountain" is composed of a number of peaks rising over a thousand feet above the surrounding countryside, and separated from one another in many instances by low saddles or deeply-incised valleys. The peaks of Shefford have not been given names, but the individual prominences of Brome "Mountain" have been named: Gale Mountain, Pine Mountain, etc., and Brome Mountain *sensu stricto*. To avoid confusion in what follows Brome and Shefford "Mountains" when referred to as entities will be called "massifs". They occupy 24 and 12 square miles of the map-area respectively.

The relief of the map-area, apart from the massifs, is gently rolling with local differences of elevations of 200 to 250 feet; the average elevation is in the neighborhood of 750 feet above sea level. Overall the countryside slopes westward towards the St. Lawrence River: low points on the western map-boundary are at 325 feet and on the eastern boundary at about 600 to 650 feet above sea level.

The northern part of the western boundary of the map-area roughly coincides with the eastern boundary of the St. Lawrence Lowland, and incidentally the cadastral boundary between the old French seigneurial divisions of the St. Lawrence Valley and the later township divisions of the Eastern Townships. The St. Lawrence Lowland is a flat to gently-rolling plain developed mainly on the southern side of the St. Lawrence River; near the river its general elevation is about 200 feet above sea level: it rises gradually away from the river to attain heights of 400 to 500 feet along its southwestern margin. In the neighbouring Sutton quadrangle to the south the Lowland is separated from the Sutton Mountains, which rise to an elevation of over 3,000 feet, by a prominent escarpment underlain by resistant formations of the upper part of the Oak Hill succession. This escarpment, which faces to the west, runs north-northeasterly from the U.S.-Canadian border through Dunham and Sweetsburg to the southwestern flank of the Brome massif. Another range of hills, of which Pinnacle Mountain is the most prominent member, intervenes between the Oak Hill escarpment and the Sutton range. These hills are underlain essentially by the Tibbit Hill volcanic formation; they continue northward across the southeastern corner of the Shefford map-area forming the northwestern border of the Brome Lake basin. Here the range consists of broad, low hills, which are for the most part forested, rising about 75 feet above the lake level and the swampy ground to the northwest, which incidentally contains a remarkably circular swamp about three-quarters of a mile in diameter. This circular feature is of undetermined origin. It can be best seen on the aerial photographs of this section.

The Tibbit Hill range of hills is breached by the Yamaska River, which drains Brome Lake to the west. North of the river the range swings northerly along the line of the eastern map-boundary and rises to an elevation of 900 feet above sea level to form an impressive backdrop for the city of Waterloo lying on the shores of Waterloo Lake, a dammed up portion of the North Yamaska River. Important gravel deposits are to be found along the eastern side of this ridge.

The St. Lawrence Lowland near its southeastern margin is an erosion surface which truncates underlying sharply-folded rocks; it appears to be a peneplain the flatness of which has been accentuated by the deposition of unconsolidated sediments of the post-glacial Champlain sea.

Between the edge of the St. Lawrence Lowland and the range of hills underlain by Tibbit Hill volcanic rocks in the Shefford map-area the prominent Oak Hill escarpment is not developed, mainly it would seem because the resistant rocks of the upper Oak Hill group are largely absent from the succession or only poorly developed. Where the Dunham dolomite of the upper Oak Hill group has been mapped, prominent hills are present, as immediately northeast of the Shefford massif and north of Martin Corner. Overall the intervening zone between the Lowland and the Tibbit Hill range, which represents most of the surface of the map-area apart from the intrusive massifs, is an irregular hilly section underlain by soft slates of the St. Germain complex, the various sedimentary rocks of the Granby group, and the Gilman formation of the Oak Hill succession. The surface of this zone rises gradually from the level of the plain of the St. Lawrence Lowland to 700 or 800 feet above sea level near the Tibbit Hill ridge; most of the rise takes place in the six miles immediately northwest of the Tibbit Hill range: a rise averaging 50 to 70 feet per mile. Such a change in slope from that of the Lowland suggests the beginning of a differential uplift of the peneplain surface. If uplift continued with increasing amplitude to the southeast it might have carried the peneplain surface over the crest of the Sutton Mountains, as certain geologists have suggested; or the movement may have culminated in important faulting.

Additional ruggedness is given to this zone in the northwestern third of the map-area by the presence of masses of quartzite and subgreywacke of the Granby group interlayered with much softer slaty rocks. Ledges of these resistant arenites form hills and ridges rising several hundreds of feet above the surrounding flatter countryside developed on the slaty rocks. A prominent ridge of this sort runs between Granby and Roxton Pond; isolated hills of quartzite and subgreywacke occur in the section to the east of this ridge, and one such hill in the extreme northeastern corner of the map-area forms the culmination of an eastern-facing escarpment 300 feet high overlooking a lowland area and providing an impressive panoramic view of the distant Sutton Mountains.

Some hills of moraine with characteristic knob and kettle topography also add to the local relief of this zone, such as those found about a mile east of Cleary station.

The Brome and Shefford massifs, which are underlain by Monteregian intrusive rocks and "collars" (aureoles) of hornfels developed in the intruded sedimentary rock by thermal metamorphism, are roughly circular groups of prominent individual peaks and semi-circular ridges surrounding central hollows which are characteristic features of many of the other Monteregian Hills. Brome Pond occupies the central hollow of the Brome massif; it lies at 425 feet above sea level not far above the average elevation of the immediate countryside, and nearly 1400 feet below the peak of Brome Mountain sensu stricto, the highest point of the massif. The massifs owe their topographic prominence as much to the resistance to weathering and erosion of the hornfels "collars" and caps of altered sedimentary rocks as to the resistance of the igneous rocks themselves, some of which weather very readily to a crumbly, easily-broken-up mass. Baked sedimentary rock of extreme hardness in outcrop occurs for example at the peak of the northeastern summit of the Shefford massif, and forms the upper elevations of Pine Mountain of the Brome mass.

A lake or pond does not occupy the central hollow of the Shefford massif, which is drained away to the southwest by a steep-walled valley. A small body of water, called Coupland Lake, occupies a semi-annular valley in the northwestern rim of the Shefford massif, and is used as a reservoir for the city of Granby. Gale Pond occupies a similar situation on the eastern rim of the Brome massif.

The map-area, except for a tiny portion in the northeastern corner, is drained westward by the Yamaska River and its tributaries, the principal of which is the North Yamaska. The central branch of the Yamaska River below the village of West Shefford occupies a drift-filled valley up to two miles wide. Apparently, therefore, this is a mature, preglacial valley filled with glacial and post-glacial deposits. Above West Shefford the stream occupies a valley relatively narrower, but still some 200 feet deep and with well-developed valley flats a few hundred feet in width. This valley is approaching maturity, and hence is probably also of pre-glacial age. It is not adjusted to the rock structure, but cuts at large angles across the trend of the underlying rocks. Between the tributary coming into this valley about a mile above Fulford and Brome Lake the valley of the Yamaska River is obviously of recent formation with a succession of small falls and steep rapids.

The North Yamaska River presents similar features. Its valley, some 200 feet deep and moderately wide, is nowhere adjusted to the structure of the underlying rock, except perhaps along the two-mile swale above Granby, where its course may be controlled by the contact between the St. Germain structural Complex and the Granby group, possibly the site of a major fault. The depth and development of the valley to a near-mature stage indicates a preglacial age for this portion of the river.

The entire lack of adjustment to bedrock structure of the two main branches of the Yamaska River suggests that these streams follow courses which they inherited from the time when, before uplift began, they flowed across the gently-sloping surface of the St. Lawrence peneplain. In other words these courses are inherited from the time when the main factor determining the stream flow was not structure but the general slope of the land. Since upwarp began time has been sufficient to incise the valleys in this section some 200 to 300 feet, but not to develop streams adjusted to the underlying rock structures. Glacial and post-glacial deposits have modified but not obliterated most of these pre-glacial courses.

The development of valleys to a state of late youth or early maturity before glaciation indicates that warping of the peneplain surface must have taken place in relatively recent geological time, possibly in the Pliocene or during the various interglacial stages of the Pleistocene. Interglacial erosion has been suggested by

Cooke (1950, 1957) to account for the narrow rock gorges of the Coaticook River somewhat farther east; hence it seems logical to date the wider, much more mature, valleys found in both the Coaticook and present map-areas as pre-glacial and Pliocene in age. Studies of the Labrador-New Quebec region undertaken some years ago by Cooke point also to the conclusion that uplift had occurred in Pliocene time, probably towards the end of that epoch. Forces great enough to elevate so large an area as Labrador-New Quebec could hardly have ceased to be effective at the St. Lawrence River, even though that river is the site of the great Champlain fault; hence it appears reasonable to correlate the late warping of the St. Lawrence peneplain with the great uplift to the north.

Previous Work

In the Geology of Canada Sir William Logan (1863) refers to the rocks now termed the Tibbit Hill schists or lavas, and describes them (p.247) as constituting "a ridge in the middle of the synclinal running from the Pinnacle Mountain in St. Armand to Brooker's Hill in Shipton". He gives rather careful petrographic descriptions of the various types that he observed, but he regarded them as altered sedimentary rocks. Toward the end of his work with the Geological Survey of Canada, Logan mapped this area and neighbouring parts of the Eastern Townships, but the results of this work were never published as these results were disputed by his successor, A.R.C. Selwyn. Specimens of the Tibbit Hill chloritic schists were submitted by Selwyn to Frank D. Adams, newly appointed to the Geological Survey as its first petrographer, and his examinations established their igneous nature. Following this, R.W. Ells remapped the whole Eastern Townships area on a scale of four miles to the inch. This reconnaissance work consumed six field seasons from 1885 to 1890 inclusive, and the results were published in four map-sheets. The Shefford map-area is included in the Southwest Quarter Sheet, and references to it are found in Annual Report VII, part J, 1894, although references to various mineral occurrences are to be found in an earlier volume (IV, part K). For some reason now unknown, Ells' results were laid down on the base map previously prepared by Logan, and Logan's formation boundaries appear on the map as very fine solid or dotted lines beneath the colours that represent the distributions of Ells' formations. For the Shefford map-area in particular, the formation boundaries established by Logan are essentially those obtained during the more recent examinations.

R. Chalmers spent three field seasons (1895-97 inclusive) on an examination of the surface geology of the Eastern Townships. In his report (1897) he refers briefly to raised beaches formed by the Champlain Sea on the side of Mount Shefford. For several seasons about the beginning of the present century, J.A. Dresser studied the petrography of the Shefford (1902) and Brome (1906) igneous rocks.

Between 1906 and 1948 no systematic geological work was done in the region around Granby. At the end of the 1948 field season

Cooke devoted three weeks to a rapid examination of the Eastman map-area adjoining the Shefford area on the east, mainly to outline the areas underlain by the schists of the Sutton Mountain anticlinorium. The results of this examination were incorporated with his report (1950) on A Southwestern Part of the Eastern Townships.

In 1931 and earlier years, T.H. Clark (1934, 1936) mapped the Sutton quadrangle lying immediately south of the present map-area for the Geological Survey of Canada, and there established the presence, succession, and interrelationships of the Oak Hill group and the St. Germain Structural Complex (Stanbridge formation in Clark's earlier nomenclature). As the result of a number of unfortunate circumstances Clark's maps were never published although the area contained the type localities of a number of stratigraphic units to be found elsewhere in Quebec, and extending for some distance into the state of Vermont. In 1961 Eakins carried our further mapping in the Sutton quadrangle, and a preliminary map was published in 1964.

The Shefford map-area was first mapped in some detail in 1951 by H.C. Cooke with the assistance of M. Tiphane as part of a regional programme of investigation along the belt of Oak Hill formations extending from latitude 45°15' north (the boundary of Clark's Sutton Map-Sheet) to the northeast as far as the St. Francis River. This programme was interrupted by the death of Dr. Cooke.

Since that time considerable additional work has been done in the region: T.H. Clark has completed the mapping of the Granby West

Half Map-Area, and P. L'Esperance completed that of the Drummondville quadrangle adjoining on the north. G. Pouliot (1962) has carried out a detailed study of the feldspars of the Monteregian Hills, including those of Brome and Shefford, and A. Larochelle (1958) has studied the paleomagnetism of Brome. M.M. Fitzpatrick has studied the gravity fields around Brome and Shefford and the adjoining regions.

At the present time a very detailed study of the Shefford massif is underway conducted by B. Frisch, a graduate student at McGill University, and plans are made for a similar study of the Brome intrusive rocks.

Field Work

The area was mapped by Cooke and Tiphane during the field season of 1951 with the able assistance of Andre Laurin and John McCallum. During this season Tiphane concentrated his efforts on the mapping of the igneous rocks of the two massifs, while Cooke mapped the rest of the area.

During the 1962 field season P.R. Eakins studied the structure of the map-area with the assistance of Nigel Grant. Eakins did not remap any of the exposures of the igneous rocks, but did examine some thin slices of them.

Cooke carried out his mapping by traversing all the roads by automobile or on foot, and by examining all areas off the roads likely to contain outcrops either from their aspect as viewed from roads, or from indications on the topographic map. Tiphane, on the other hand made numerous traverses across the massifs in a systematic way. Eakins carried out his mapping using aerial photographs, visiting all likely looking indications of outcrop revealed by the photographs. It is noteworthy that he did not find more than a few outcrops that Cooke had missed.

GENERAL GEOLOGY

General Statement

The bedrock geology of the Shefford map-area, apart from the prominent igneous massifs of Brome and Shefford, consists in essence of one volcanic and a number of sedimentary formations forming more or less parallel bands trending across the area from south-southwest to north-northeast, and ranging in age from Lower Cambrian to Middle Ordovician. These stratified rocks have been folded and otherwise intensely deformed, and now form, at least in part the northwestern limb of the northern extension of the Pinnacle Mountain anticline (known as the Enosberg Falls anticline in Vermont; Cady 1960), which is in its turn an important element of the Sutton Green Mountain anticlinorium. The principal Paleozoic map-units are, from southeast to northwest:

1) the Tibbit Hill volcanic formation, which is the oldest known unit of the Oak Hill group in Quebec, made up of chlorite schists derived through the metamorphism of intermediate to basic lavas. These lavas underlie, possibly disconformably, formations definitely dated as Lower Cambrian.

2) the Gilman formation, the middle and really most important unit of the Oak Hill group, consisting of phyllites and fine-grained schists derived from the intense deformation of inter-bedded fine sandstones and siltstones. This formation is dated paleontologically as Lower Cambrian.

3) the St. Germain Structural Complex, also known as the Stanbridge formation, and in part as the Farnham slates, made up of complexly-deformed shales and some limestone beds. This complex is dated paleontologically as Middle Ordovician.

4) the Granby group comprising a very distinctive lithological assemblage of green and black sandstones, and green, grey, black and red slates correlated on the basis of lithological similarities with formations definitely dated as Cambrian and Ordovician.

As a glance at the map will confirm, these units do not lie in an orderly succession from oldest to youngest moving from the southeastern map-corner to the northwestern across the western flank of the Pinnacle Mountain anticline: the oldest band, formed by the Cambrian Oak Hill group, is bordered on the northwest by the Middle Ordovician St. Germain Complex, which in turn is bounded on the northwest by the older Cambro-Ordovician Granby group. This arrangement of the principal units has been variously interpreted at different times as due to:

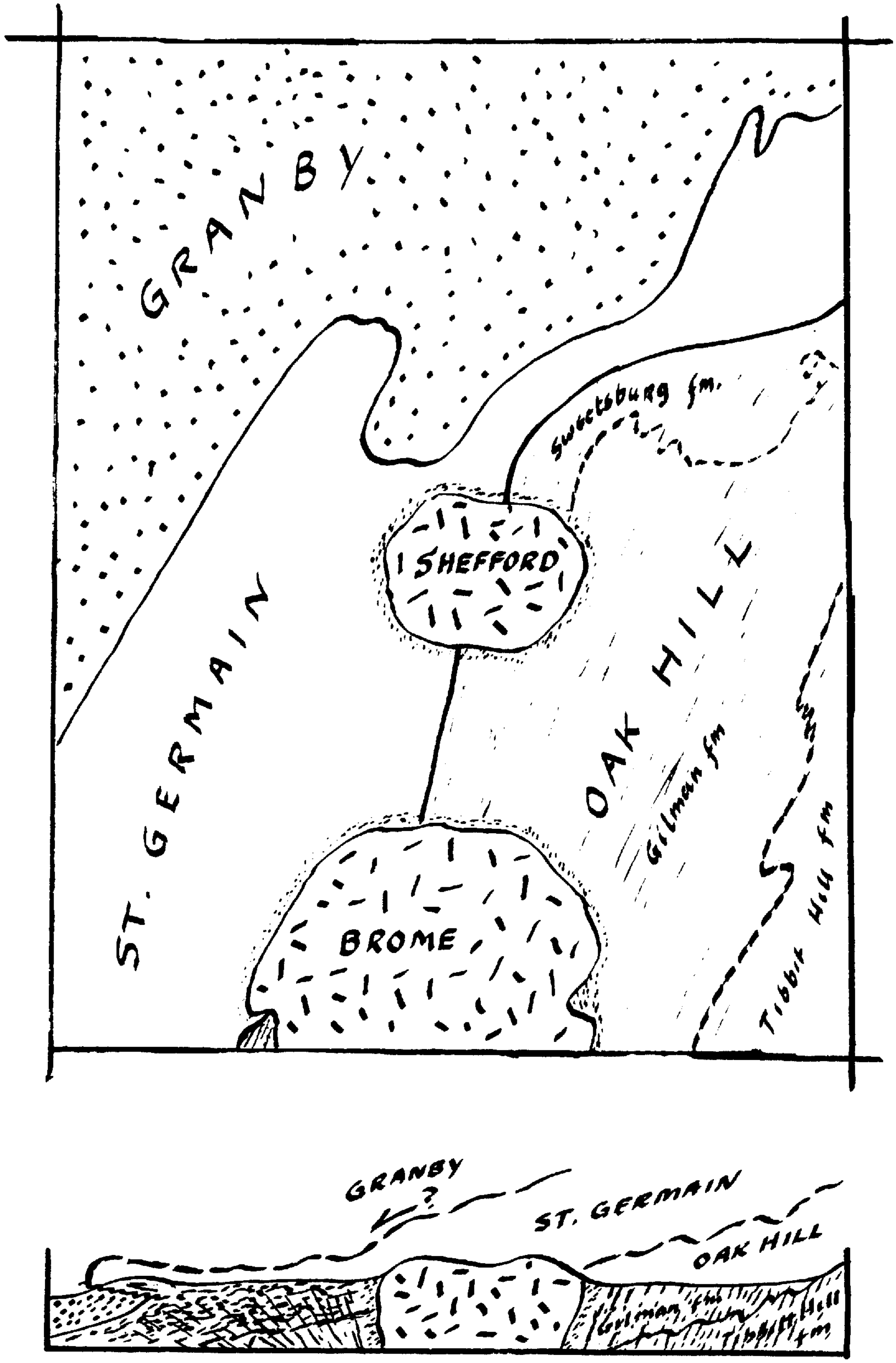

FIG. 1: Sketch Map and E-W Section through Shefford Massif.

1) the thrusting of the Oak Hill group westward over the St. Germain Structural Complex, and thrusting westward of the St. Germain over the Granby group; or

2) the thrusting-in from the east of the Granby group onto the St. Germain complex, which itself is overthrust by the Oak Hill group.

The evidence bearing upon the gross relationships of the various major units is unfortunately scant and by no means unequivocable. At the present time any decision upon major tectonic and stratigraphic relationships must be held in abeyance until further detailed mapping. The problems are ably and amply discussed by Cady (1960).

Whereas deformation is in large part intense with the destruction or transposition of bedding in many units and in many sections and resulting in well-developed cleavages, the grade of metamorphism is low and characterized by the development of the lower greenschist facies of metamorphism. Relatively narrow aureoles or "collars" of thermal contact metamorphism are developed around the igneous massifs in enclosing sedimentary rocks.

Medium to coarse-grained gabbros and syenites make up a suite of igneous rocks forming almost circular stocks or laccoliths underlying the Brome and Shefford massifs. These rocks are alkalic in composition, and belong to the Monteregian Hill petrographic province of Atlantic affinities (Pouliot, 1962). They have recently been dated as Lower Cretaceous in age by whole rock, Sr^{86}/Sr^{87} methods (Fairbairn et al, 1963). They are cut by numerous related satellite dyke rocks. A few dykes of somewhat similar rocks occur well away from the main igneous massifs; they are of undetermined age.

The area was glaciated in the Pleistocene, and lower elevations were covered by the Champlain Sea after deglaciation about 10,000 years ago.

Conditions and Problems of Mapping

Outcrops are relatively abundant, and for the most part, well-distributed throughout the map-area. They are, however, generally small and composed of one lithotype so that structural and stratigraphic relations between different lithologies are imperfectly and poorly exposed and determined and defined with difficulty, if at all. The many slaty rocks in natural exposures present rubbly surfaces with a multitude of stained joint and fracture planes pervading the rock and obscuring lithology and structure. The most prolific "outcrop-makers", the sandstone units of the Granby group, are unfortunately very well indurated and do not weather readily: their exposure surfaces are covered by an obscuring "skin" of grey licheniferous material which successfully hides the many primary and secondary variations present in almost all the outcroppings of these rocks. What cannot be seen in the usual outcrop of Granby group rocks is forcefully revealed by an examination of the perfectly clean exposures of the group uncovered by gravel pit operations in the southern outskirts of the city of Granby on the ridge west of

Highway 13. Here outcrops waterworn before the deposition of the covering gravel present colorful surfaces of light greenish-gray and purple which present in intimate detail all the variations present in these rocks, such as grain gradation, fine cross-bedding, contemporaneous disruption of bedding etc.. Nearby outcrops which were not buried by gravel in recent times on the other hand are covered with lichen, and hardly any of the features of the rock can be discerned.

The general lack of exposures along the streams and rivers of the area is remarkable for the region as a whole, where good clean waterworn outcrops along the water courses generally supply some of the better classes of exposures for detailed study, and indeed often the "key" outcrops.

Another, more serious, factor complicates the study of the tectonics of the map-area. The nature of the deformation of the stratified rocks is such that inhomogeneities are extremely common in the structural pattern of the imposed secondary structures even over small areas. The rocks have been deformed by several phases of folding and faulting, all of which appear to have taken place at no great depth in the crust; temperature and pressure conditions were not such as to result in strong recrystallizations and neocrystallizations in the rocks undergoing strong deforming stresses, and uniformly-oriented penetrative structures are poorly developed. Local inhomogeneity due to lithological variations in the stratified rocks under deformation are marked in many parts of the area. For these reasons interpretations of structural data cannot be extrapolated for any distance from the points of observation.

There is also a growing body of evidence which points to penecontemporaneous deformation in the sedimentary rocks as an important element in the overall deformation plan. Recent studies by Eakins and graduate students at McGill University in the Rioux quarry, Cowansville, to the south in the Sutton area, where limy St. Germain slates are exploited indicates the importance of such penecontemporaneous slidings and overfoldings. Such early deformations are further complicated by later folding and faulting.

Stratigraphic Column

Table I presents the stratigraphic column of the map-area. The unit names are those already in the literature, or in current use by geologists working in the region. Evidence of stratigraphic relationships is not good in the Shefford map-area, and the introduction of new terms for the few new stratigraphic elements present, or for variations in the already established stratigraphic units would be rash and premature. The "Sillery" rocks of the area which may indeed belong to the Charny and Lauzon formations of the Quebec City region, will, however, be designated the "Granby Group" to emphasize the current state of knowledge regarding the correlation of these rocks.

The stratigraphy of the southeastern two-thirds of the map-area is in all essentials the same as that worked out by T.H. Clark (1934,

1936) in his pioneer detailed study of the Sutton quadrangle adjoining on the south. Clark established the conformable succession of the Oak Hill group (series of the earlier nomenclature), and established its age as Lower Cambrian on the basis of meagre, but definite, paleontological data. The sequence defined by Clark is shown in Table II, along with the thicknesses of each formation in the Sutton quadrangle. Subsequent studies in Vermont indicate that the uppermost Sweetsburg formation of the Oak Hill is Middle Cambrian in age (Shaw 1954, Booth 1950).

The Oak Hill group is not as well-exposed in the Shefford map-area as it is in the Sutton quadrangle, and the overall lithologic character of several formations is imperfectly known, and the degree of variability in various units is uncertain. Two new minor lithological units are present in the Shefford map-area: 1) a black slate appearing below the Dunham dolomite as a thin layer almost parallel to outcrop surfaces in the prominent exposures of the upper part of the succession northeast of the Shefford massif; and 2) a highly-contorted limestone bed appearing in the position of West Sutton slates at the southern end of an old gravel pit south of Warden. Both of these new elements are exposed nowhere else within the map-area, and because of their limited extent do not merit the distinction of a new and formal designation at the present time.

The Tibbit Hill and Gilman formations of the Oak Hill group are well-developed and exposed in the Shefford map-area, and show

TABLE I

STRATIGRAPHIC COLUMN

Era	Period	Group	Formation	General Description
Cenozoic	Pleistocene and Recent	-	-	Recent stream and lake deposits; marine gravels, sand and clay; till, fluvio-glacial sands and gravels.
		Great Unconformity		
Mesozoic	Lower Cretaceous	Monteregian Petrographic Province		Gabbro (essexite), alkali syenite and related rocks; hornfels.
		Intrusive Contact		
	Middle & Upper Ordovician	St. Germain Structural Complex.		Dark grey to black slates with occasional beds of sandstone and limestone.
	Cambro-Ordovician	Granby	Not designated	Massive green and black sandstones, green, red, grey and black slates.
	Middle Cambrian	Oak Hill	Sweetsburg	Well-bedded alternations of thin white sandstone and black slates.
Paleozoic	Lower Cambrian	Oak Hill	Scottsmore) Oak Hill) Dunham)	Upper Mansville phase - the three formations are grouped together to form a map-unit: dolomite, dolomitic sandstone and slate, black slate.
			Gilman	Fawn to green siltstone phyllite and fine quartzite.
			West Sutton) White Brook) Pinnacle) Call Mill)	Lower Mansville phase - the four formations are grouped together to form a map-unit: black and blue-black slate, dolomite, dolomite schist, greywacke.
			Tibbit Hill	Green schists derived from intermediate to basic lavas.

TABLE II

The Oak Hill Succession in the Sutton Quadrangle after Clark (1934) and Eakins (1964)

Unit (Listed downwards from youngest to oldest)		Range of Thickness
Sweetsburg Formation:	fine-bedded slates with thin sandstone layers	ca. 300'
Scottsmore quartzite		thin, discontinuous
Oak Hill slates		thin, discontinuous
Dunham Dolomite		50-150'
Gilman Formation:	buff to light green phyllites with a fine quartzite developed at the top of the formation in the western part of the band	ca. 1,000'
West Sutton slate		discontinuous 40-60'
White Brook Dolomite with hematite-rich layer at top		20-75'
DISCONFORMITY		
Pinnacle Formation:	mainly greywacke with some pebble layers near base	ca. 400'
Call Mill slate		1-50'
Tibbit Hill Formation		undetermined

Overall Thickness - about 2,000 feet

no change in their character from that in the Sutton quadrangle. The other formations however appear to be somewhat different from their type-localities; in particular the Call Mill-Pinnacle-White Brook-West Sutton sequence lying between the Tibbit Hill and the Gilman formations is poorly exposed but is somewhat different from the normal Sutton sequence. Whether this change is only apparent and due to poor exposure, is due to intense squeezing and folding, or to changes in sedimentation and/or non-deposition is not clear from the outcrop evidence. East of the main Tibbit Hill band in the Sutton map-area Clark discovered a somewhat similar but very well-exposed sequence of much thinned Oak Hill rocks which he designated as the Mansville phase, and separated from the overall bulk of Sutton schists which are of unknown age and derivation. In this report the Call Mill-Pinnacle-White Brook-West Sutton sequence will be referred to as the Lower Mansville phase to set off their different character from the normal sequence, and their similarities to Clark's Mansville phase in the Sutton schists to the east of the Tibbit Hill formation. This usuage is justified on practical grounds because the individual units exposed in the map-area scarcily constitute mappable units by themselves.

The Oak Hill sequence lying above the Gilman formation, i.e. the Dunham, Oak Hill, Scottsmore and Sweetsburg formations, are entirely lacking in outcrop between the Brome and Shefford massifs in an area of scant exposures, and poorly exposed for the most part to the northeast of the Shefford massif. Whether they are present and not exposed between the two massifs has not been determined.

Their absence may be explained in several ways: by either faulting-out or by an unconformity between the Oak Hill and the adjoining St. Germain structural complex. For reasons similar to those expressed above, the Dunham-Oak Hill-Scottsmore sequence is here designated the Upper Mansville phase.

The relationships between the St. Germain Complex, which is made up of various limy and slaty rocks of Middle Ordovician age, and the Cambrian rocks to the east have not been defined with certainty in the Sutton map-area. Clark (1934) believed that the Oak Hill succession had been faulted westward along the Oak Hill thrust to overlie the St. Germain rocks (Stanbridge formation). More recent work by M.J. Richard (personal communication) and Eakins indicates that a major thrust fault is not present, and that the Oak Hill does not lie in a major thrust slice; the St. Germain suite of stratified rocks appears to overlie the uppermost Oak Hill unit, the Sweetsburg formation, with slight angular unconformity. There is no evidence for or against such a relationship in the Shefford map-area.

The Granby group underlying the northwestern third of the map-area consists of an assemblage of distinctive rock-types: green and black sandstones with grit and pebble conglomerate layers, and green, grey, black and brick-red to purple slates and siltstones. Because of deformation and the lack of large exposures in key sections, it has not yet been possible to work out a stratigraphic succession for these distinctive lithotypes. There are indications

TABLE III

The Mansville Phase of the Oak Hill Succession
Modified after Clark (1934)

Eastern Mansville Phase		Western Normal Succession
Phyllite and slate	60'	Oak Hill, Scottsmore, Sweetsburg
Upper dolomitic marble	10'	Dunham dolomite
Upper sericitic schist	35-100'	Gilman Formation
Upper slate	0-1'	West Sutton slate
Lower Dolomitic marble	10-70'	White Brook Dolomite
Lower sericite schist	6-30'	Pinnacle Formation
Lower slate	1'	Call Mill slate
Chlorite schist	-	Tibbit Hill Formation

Total thickness - about 200'

that the various units are intertongued and may be repeated at several stratigraphic levels. The relationships between the Granby group and the St. Germain complex are poorly defined in outcrop. Lithotypes typical of each are occasionally found in adjoining exposures and apparently interlayered, but whether such interlayering is due to sedimentation or to tectonic action has not been determined.

In the succession of igneous events, the sequence from older more basic intrusive rocks, the gabbros, to younger more alkalic varieties, the syenites, is exposed in several localities in both massifs, but in detail the evolution of the rocks of the two massifs is complex and gradational rock-types are common.

STRATIGRAPHY

General Statement

The principal stratigraphic units from oldest to youngest in the Shefford map-area are: 1) the Oak Hill group of Lower and Middle Cambrian age; 2) the Granby group of Cambro-Ordovician (?) age; and 3) the St. Germain Structural Complex made up of rocks of Middle Ordovician age. As mentioned previously the relationships between these units are not clearly set forth in the map-area, nor is there any conclusive data on their absolute or relative ages within the area.

According to Cady (1960) the migratory, intertonguing boundary of the eugeosynclinal and the miogeosynclinal phases of the early Appalachian orthogeosyncline is contained within the Oak Hill group; the Tibbit Hill greenstones, the Pinnacle greywacke, West Sutton and Call Mill slates represent eugeosynclinal shale-greywacke facies along with the Sweetsburg and Oak Hill formations. The White Brook and Dunham dolomites and the Gilman formation on the other hand represent miogeosynclinal carbonate-quartzite facies. The Gilman formation itself contains a facies change, well displayed in the Sutton quadrangle, from a clean fine-grained quartzite in the west to a fine-grained semi-pelite in the east.

The Cambro-Ordovician Granby group occurs in a belt underlain by limy rocks of Cambrian and Early Ordovician age which are generally considered to be related to the miogeosynclinal phase. The sedimentary character of the Granby rocks contrasts remarkably. This contrast has yet to be satisfactorily explained.

The Middle Ordovician St. Germain complex is in part made up of rock types typically developed to the west of Logan's Line, the bounding fault between the folded and faulted Appalachian terrain and the generally little-disturbed formations of the St. Lawrence Lowland. Thus where exposures are good, and mapping is carried out in detail, units of Trenton, Utica, Lorraine, etc., age of Lowland type can usually be delineated. It is for this reason that Clark (1947) has coined the designation St. Germain Structural Complex and discarded the early designations, Stanbridge formation and Farnham slates in favour of a term emphasizing the heterogeneous nature of this belt of rocks. Correlatives of some of the St. Germain rocks are known as the Morses Line formation in Vermont.

The Cambrian Oak Hill Group

The succession and age of the Oak Hill group were established by T.H. Clark (1934, 1936) from his studies of the Sutton quadrangle, which adjoins the Shefford map-area immediately to the south. The group, as a whole and in part, has been extensively studied along its strike extension to the south into Vermont (see Booth, 1950, Cady, 1960). The group as a whole also trends north-northeasterly into the Shefford quadrangle and beyond it to the northeast, but in the Shefford area only the Tibbit Hill and Gilman formations are well exposed; outcrops of the numerous other stratigraphic units are few and far between, so that if it were not for the fact that these units in general maintain the petrographic character of their type localities in the Sutton area to the south, their identification would be very much in doubt. The Oak Hill group as a whole is only reasonably well exposed in the sector north of the Shefford massif and to the east of Fulford. The group however is once more better exposed in parts of the Mount Orford map-area to the east, and in the Richmond area to the northeast, so that the continuity of the various formations is not in doubt.

The key formations of the Oak Hill group are the basal Tibbit Hill greenstones and the Gilman quartzite and semi-pelitic phyllites.

Both formations are well exposed in the map-area over widths of a mile or more, whereas the other formations outcrop in narrow bands, some of which in actual exposure are only a few feet to a few scores of feet wide, and would, if they had not already been established as of formational rank, not justify inclusion in the stratigraphic column even as members.

Clark (1936) established the age of the Oak Hill sequence upon the following paleontological evidence:

1) poorly preserved remains of a brachiopod closely resembling the Lower Cambrian genus Kutorgina in the Gilman formation near Scottsmore;

2) abundant fragmentary remains of an unidentified species of the Lower Cambrian trilobite family Mesonacidae, together with other characteristic Lower Cambrian fossils such as Hyolithus in fossiliferous limestone lenses in the Dunham dolomite formation near St. Armand Centre in the southern part of the Sutton quadrangle.

Booth (1950) has subsequently shown the Skeets Corner slate in Vermont on paleontological evidence to be Middle Cambrian in age; he correlates the Skeets Corner with the Sweetsburg formation, the uppermost unit of the Oak Hill succession.

There is no evidence of fossil remains of an identifiable nature in most of the Oak Hill succession, which is not surprising considering its deformed state with well-developed cleavages in most lithotypes.

Tibbit Hill Formation

The Tibbit Hill formation crops out in the southeastern corner of the map-area forming a band a mile and a half or less wide along the northwestern shore of Brome Lake. This band swings northward from the northern end of the lake, and extends along the eastern map-boundary to a point about one mile north of the city of Waterloo, where it passes northeastward out of the map-area. This relatively narrow strip of Tibbit Hill formation represents a portion of the western side of one of the most important marker formations in the region, which extends northward from south of the U.S.-Canada border in the state of Vermont to the St. Francis River and beyond in the Province of Quebec. In Quebec the formation is the basal unit of the Oak Hill succession, and is overlain by the thin Call Mill slate unit and then the Pinnacle greywacke formation, but in Vermont it is found to be underlain as well by the Pinnacle formation, and is thus there only considered a member in the Pinnacle formation as a whole (Doll, 1962). The type locality of the formation lies a few miles south of the Shefford map-area to the southwest of Brome Lake at Tibbit Hill.

The Tibbit Hill formation consists almost entirely of intermediate to basic lavas which have been regionally metamorphosed to the greenschist facies. These altered lavas crop out in prominent, rounded knobs and ridges which form the backbone of the low but locally rugged hills which reflect the present formation overlooking Brome Lake. Outcrops are generally abundant in the

Tibbit Hill band and for the most part preclude farming so that the ground is left as woodlots or sugar bush.

The typical exposure consists of massive-appearing, light to dark green, fine-grained rock usually containing varying numbers of scattered white amygdales. This rock does not weather readily, so that a ubiquitous tough grey film of lichen obscures the structures and textures in the rock to a very large extent. Only in the occasional natural exposure and in road cuts can the true overall nature of the textures and structures be discerned. On clean weathered surfaces, which range in colour from delicate apple-greens to darker hues of green, the rock is seen to be variably schistose, and in many instances complexly deformed. Apart from amygdales, which are often stretched or smeared out into ellipsoids, and occasional fine layering, recognizable primary volcanic features, such as pillow structures, are extremely rare. White quartz in thin straight veinlets of varying orientation and attitude and zones of discontinuous contorted lenses and stringers, is an almost constant feature in most outcrops of the formation. A schistosity ranging from very weakly to moderately strong development has been imprinted on the lavas by deformation; some very highly schistose layers within the volcanic rocks may represent sheared tuffaceous layers rather than highly schistose lava. The schistosity generally strikes north-northeastward with the trend of the formation and dips steeply to moderately to the west. A strongly-developed later slip cleavage is present in a number of exposures, but is not common or widespread. It generally strikes somewhat obliquely to that of the earlier schistosity and dips steeply eastward. A fine mineral lineation formed of chlorite streaks is present plunging down dip on the early schistosity planes.

There is little evidence of the overall attitude of the rocks of the formation, but it does appear from relationships in the Sutton quadrangle to the south (Eakins, 1964) that whereas locally the layering does dip steeply and is often highly contorted, overall the structure is that of more gentle dips to the west. The general uniformity of the formation in its exposures may thus in part reflect this structure in that only one general layer is exposed to view over most of the outcrop band.

The lavas retain little if any of their original minerals. Commonly oligoclase or albite, clinozoisite, epidote, and chlorite in a fine schistose aggregate constitute the bulk of the rock, with minor to unusual (up to 20%) amounts of magnetite, titanite and leucoxene. The iron oxides occur, as a rule, in small grains. Their presence accounts for the marked magnetic anomaly produced by the formation to be seen on the Aeromagnetic Sheet Granby (31 H/7).

The amygdales are generally composed of quartz or calcite, and less frequently of albite or epidote. Epidote "knots" up to several inches across are common features in the moderately to weakly sheared lavas.

Slaty rocks and some tuffaceous beds are interlayered with the altered lavas; some of these occurrences may be interpreted with considerable justification as downfolded remnants of the overlying Call Mill slate, when they closely resemble the lithology of that formation, but others appear to be definitely interbedded with the lavas. One of the best examples is described below at some length, even though it occurs just beyond the eastern map-boundary.

Close to the road along the Range IV-V line of Shefford township, in lot 24, some 300 to 400 feet east of the boundary between the Shefford map-area and the west half of the Orford quadrangle, an extraordinary rock can be seen on both sides of the road. The bulk of the rock is a slate with a peculiar bluish cast on the weathered surface which is reminiscent of that developed on weathered exposures of the Call Mill slate. Parts of this slate body are fragmental, however, a feature rarely seen in the Call Mill formation. The fragments are all of slates of different kinds, ranging in size from minute bits to large pieces. The largest piece seen was eight inches long by five inches wide, and of oval shape; quite a number have dimensions between two and four inches, but the great majority are less than an inch in length. In shape most of the fragments are irregular with at least one sharp angle; a few have three or four sharp corners. One fragment, an inch long, ends in three tooth-shaped prongs, one of which is thin and sharp. Clearly such a fragment could hardly have been subjected to any wear whatsoever before coming to its present position.

The composition of the fragments is variable. About ten percent of them weather to black or dark grey tints, and are dark grey on fresh surfaces; scratched with a knife, they give a bright red hematite streak. Another one or two percent are conspicuous because they weather to bright pale brown tints; the fresh surfaces are brownish-grey. The remainder of the fragments, comprising more than 85 percent of the total, include three or four different varieties, but all weather to tones of lighter or darker grey.

Both the fragmental slate and the slate with no fragments occur as low scattered outcrops in a grassy pasture. In only one of them were any relationships displayed; a band of slate about a foot wide is non-fragmental along one side, and contains very small fragments along the other. It is sandwiched between two bands of coarsely fragmental slate. The layering strikes N30°E and dips 56°NW. The layering looks like bedding, but as it is exposed only over a length of about three feet, no information could be obtained as to its behaviour on strike.

On the south side of the road lavas can be seen to the east and the west of the slate band, although actual contacts are hidden. East of the slate the lava is grey, fine-grained, and rather fresh-looking, and has a slightly reddish cast. It contains numerous phenocrysts composing perhaps ten percent of the rock; most of them are fairly fresh albite-oligoclase, and a few are of quartz. The very fine-grained groundmass appears to be mainly fresh plagioclase with a little chlorite and perhaps twenty percent of ilmenite and leucoxene.

The lava west of the slate band is of very different composition. It is a fine-grained, chlorite-green rock with numerous small metacrysts of secondary carbonate filled with inclusions of the minerals the carbonate has partly replaced. About sixty percent of the rock apart from the metacrysts is leafy chlorite in which may be seen rather numerous remnants of unaltered augite. Most of the remainder is fresh oligoclase, presumably secondary, with a few grains of magnetite, ilmenite, and their alteration products. This flow would seem therefore to have been a much more basic lava than that to the east of the slate band.

This difference in composition precludes the possibility that the two lavas are parts of the same flow, and therefore that the structure of the intervening slate is synclinal. Hence it seems necessary to conclude that the slate lies between two west-dipping flows, and that it may be a tuff of some sort. No suggestion can be offered, however, as to how a rock of this extraordinary character can have originated.

Lower Mansville Phase

In the Sutton map-area the Tibbit Hill lavas are succeeded by a sequence of distinctive, thin but generally continuous, formations which are almost everywhere present and mappable between the International Boundary and the Sutton-Shefford map-boundary, along the western side of the main Tibbit Hill band. This sequence, which consists of the Call Mill, Pinnacle, White Brook, and West Sutton formations, is succeeded by the areally very important Gilman formation. East of the main belt of Tibbit Hill lavas, which is essentially anticlinal, lie the Sutton schists; along the Tibbit Hill-Sutton schist contact and extending eastward for an undetermined distance is a zone of rocks recognizable as the sequence lying above the lavas on the western side of the Tibbit Hill belt, but with formational units considerably thinner, sometimes in the order of a tenth of the normal western thickness, and much more strongly deformed and metamorphosed along the much more strongly folded Richford-Sutton syncline (Eakins,1964). This sequence Clark termed the Mansville phase of the Oak Hill group to distinguish it from the normal succession. The rocks of the Mansville phase are very highly deformed and somewhat more metamorphosed than the units to the west, but how much of their change in thickness is due to tectonic thinning, and how much of it is due to sedimentary variation has not been satisfactorily determined. Much evidence does point to tectonic thinning, but on the other hand in Vermont several of the formations do thin to the east or are discontinuous due to lacunae in sedimentation (Booth, 1950).

The lower part of the Mansville phase can be inspected with ease in its entirety in the pasture behind the Auberge de Sutton on the highway to Cowansville north of the town of Sutton. Here the whole sequence from the Tibbit Hill to the Gilman can be seen in an area about one hundred yards square. In detail the various units are tightly folded and strongly cleaved, but overall the structure is that of a rather open shallow anticline and syncline, the smaller folds not reflecting the style of the larger ones. This locality contains rock types similar to those to be found in the Shefford area, and is therefore important in this respect for the present report.

In the Shefford map-area the Gilman formation is one of the prominent map-units. It lies in its proper stratigraphic position almost immediately to the northwest of the Tibbit Hill band. In the very narrow zone separating the two formations are scattered outcrops of varying lithologies, most of which are recognizable as Lower Oak Hill types of the intervening formations, particularly as the types which occur east of the Tibbit Hill band, as, for example, at the Auberge de Sutton locality just mentioned. These outcroppings are, however, too widely separated and too few in number to permit the drawing of the individual contacts for the Call Mill, Pinnacle, White Brook, and West Sutton with any certainty. All have, therefore, been amalgamated under one heading and unit designated the Lower Mansville Phase, and thus creating a mappable unit. Strictly speaking, Clark's designation of Mansville Phase applies to the Oak Hill rocks appearing to the east of the Tibbit Hill band and adjoining the Sutton schists, of which they form a part, and the rocks considered here lie to the west of the Tibbit Hill band and on strike with the normal formations. To introduce a new name for this mappable unit, such as Waterloo Phase of the Oak Hill, seems, however, to be unwarranted at the present time. There is some evidence in the Sutton map-area both to the north and to the south of the normal well-developed sequence that similar variations have taken place, as, for example, between the Tibbit Hill and the Gilman formation along the road crossing the north flank of Pinnacle Mountain.

Along the outcrop band of the Lower Mansville Phase on the map-sheet, exposures are not at all abundant, generally are small, and widely spaced. The best exposures are to be found on either side of Route 1 immediately east of the city of Waterloo, and between the railway and the Yamaska River a mile and a quarter east of Fulford. The descriptions of these exposures will be dealt with under subheadings for the individual formations. Material on the nature and continuity of these formations to the northeast in the Orford area accumulated by H.C. Cooke during his regional studies will be added in order to indicate the complete nature of the sequence in the Shefford map-area, and how it differs from other localities.

Call Mill Slate. In the Sutton map-area the Call Mill slate may be seen to lie directly on the upper surface of the Tibbit Hill schist in many localities. No conglomerate or coarse clastic material of any kind is found at or near this contact although some vaguely-outlined small patches of the slate have a different colour and are suggestive of fragmental inclusions within the main slaty rock. The underlying Tibbit Hill schist never appears weathered, rotted, or eroded at its contact with the Call Mill formation, although conversely it must be admitted that it also does not show any features reminiscent of flow-tops in lavas.

The slate is a dense argillite usually with no visible bedding except on extremely clean weathered surfaces where the slate is seen to be truly poorly-bedded. Whenever seen the bedding is highly deformed and contorted. The rock has a poorly to moderately well-developed slaty cleavage. It is very dark in colour, and glacially-polished surfaces have a peculiar dark hue cast exhibited by no other slate in the region, even the West Sutton, which at times is bluish on fresh surfaces. Microscopically the rock is a mat of fibrous minerals too fine-grained for identification.

As to the origin of the slate, Clark (1934) suggests that the slaty materials were formed by a long continued weathering of the Tibbit Hill lavas forming a regolith of deeply-decomposed chloritic material. After the sea invaded the area this was merely shifted about to some extent to form an unlayered blanket of mud on the sea floor mantling the eroded lavas. Such an hypothesis seems most unlikely to depict the true situation. No matter how deep or how thorough the weathering, surely at the contact of the weathered material and the unweathered bedrock (base of the C soil zone) there must be fragments of incompletely weathered rock which would form a basal conglomerate when the sea invades the area. As an alternative to Clark's view, attention is called to the rock in Shefford Township, ranges IV - V, lot 24, which has already been described in the section on the Tibbit Hill formation: a slate there is identical over much of its exposure to the Call Mill slate, but as it is found between two flows it would appear to be tuffaceous in origin.

At any rate, it may be reasonably concluded that it and the Call Mill had a similar origin, and in Shefford Township there is obviously no great difference in age between the lavas and the slate.

The presence of the Pinnacle greywacke beneath the Tibbit Hill lavas in Vermont also is against the regolithic origin for the Call Mill. It can be noted at this point that thin lenses and layers of quartz pebble conglomerates and of grits occur within the overlying Pinnacle formation immediately above its contact with the Call Mill slate. Furthermore, several phases of the Pinnacle formation are highly chloritic sediments, which when sheared are quite similar in appearance to the Tibbit Hill schists and sometimes distinguished from the latter on outcrop with difficulty; it appears that basic lavas did make up part of the provenance of sedimentation for the Pinnacle formation, and were being weathered and eroded more or less in Call Mill times. However, all the evidence does point to the Call Mill itself being a tuff.

In the Shefford map-area an isolated outcrop of slate is to be found about a mile and a quarter due east of Fulford in Brome Township, Range IX, lot 27. There the slate lies between lava 100 feet to the east and White Brook dolomite about the same distance to the west, and it is thus identified stratigraphically as probably Call Mill formation. A ten-mile gap intervenes between this outcrop and the next certain Call Mill exposure along the strike at the extreme west end of Range X, Stukely Township in the Orford quadrangle. Here the slate differs from that to the south both in composition and thickness; it is pale grey in colour and probably not more than two or three feet thick. It carries some pyrite in places which causes it to weather to rusty tints. This grey slate outcrops in quite a number of places in the northern part of the area. Peculiarly enough, however, the slate directly overlying the lava about a quarter mile south of West Ely is again the dark bluish variety typical of the Call Mill of the type locality. Although the Call Mill formation outcrops over a considerable area of this part of the region, its thickness varies from only a few inches to several feet for, although greatly crumpled, the general dip is nearly flat and often parallel to the slope of outcrop surfaces.

Pinnacle Formation. Clark describes this formation as a thick feldspathic sandstone containing locally much magnetite and ilmenite. "In composition it varies from apparently pure quartz-feldspar (chiefly orthoclase) combination through all gradations to a rock in which magnetite-ilmenite grains predominate (1936, p.142)." According to Clark, quartz may be present making up to 50 percent of the rock, feldspar up to 30 percent, and magnetite and ilmenite up to 50 percent. "Besides these minerals, which are present in every section, are variable amounts of leucoxene, zircon, tourmaline, chlorite, kaolinite, sericite, and paragonite... Secondary epidote is common (1936, p.142)". Clark has estimated the formation to be some 400 feet thick in the neighbourhood of North and West Sutton, but thinning to less than 200 feet at West Brome. Clark states that the formation is never conglomeratic, but more recent work by Eakins has uncovered small pebble conglomerate lenses and layers of grit near the base of the formation. Chloritic phases, as noted above, are also present in the formation.

In Vermont, according to Booth (1950), the thickness of the Pinnacle formation is some 350 feet about a mile south of the International Boundary, and may be thicker farther south although he states that repetition by folding makes any estimation unreliable. Between fifteen and thirty miles south of the border he finds numerous conglomeratic beds of boulder conglomerate carrying well-rounded cobbles up to fifteen inches in diameter. The latter are found in the northeastern corner of the Milton quadrangle about twenty-four miles from the border along the strike of the formation. The boulders are mostly fine-to coarse-grained syenites, quartz syenite, sodic granites, and microcline granites.

The presence of conglomerates well south of the International Boundary, and their paucity north of it, indicates that the source of the Pinnacle sedimentation was near the Vermont area. The nature of the pebbles and the boulders further indicates, as Clark concluded earlier, that the greywacke was the product of the erosion of acid igneous rocks.

Only three exposures are assigned to the Pinnacle formation in the Shefford map-area: one is a half-mile north and another a half-mile south of the east end of Waterloo Lake. The latter exposes a width of about fifteen feet of somewhat sheared impure sandstone. The position of these two outcrops relative to the western contact of the Tibbit Hill lavas indicates their correlation with the Pinnacle formation. At the east end of the hill of White Brook dolomite one and a quarter miles east of Fulford, some massive fragments of a coarse feldspathic sandstone are incorporated in the dolomite; these probably are remnants of the Pinnacle formation broken up by intense deformation and incorporated in the more plastic dolomitic marble.

It seems evident that the Pinnacle formation must thin rapidly northward from its thickness of two hundred feet near West Brome in the Sutton map-area, for it is generally a resistant formation wherever it occurs, and were it present in greater thickness than a few tens of feet in the Shefford map-area, it would surely be exposed.

As with the Call Mill formation, no further outcrops of the Pinnacle formation are found through a gap along the trend of the formations of ten miles. Then it appears on both sides of the Tibbit Hill schists, and in places overlying them in the Orford quadrangle. In this northern section both the petrography and the thickness of the Pinnacle formation are greatly changed. Here it is a distinctive, coarse, white quartzite which is very resistant to erosion. Its thickness is difficult to estimate because of the folding, but it is commonly not more than twenty feet though in one or two places it may be as much as fifty feet.

Some of the layers a few inches thick are dark-coloured due to the presence of magnetite in very fine grains. The microscope reveals that the rock consists of quartz grains 1 mm. or larger in diameter. No feldspar grains are present; the very fine-grained matrix is made up largely of smaller grains of quartz with a little partly chloritized actinolite, small magnetite grains, and in places a little carbonate. Where not too greatly deformed this striking quartzite displays crossbedding and rillmarking.

The northern white quartzite lithotype may extend under the drift as far south as Waterloo. H.C. Cooke was informed by Mr. Lawrence Purdy of that city that a drainage ditch on the street running east along the north side of the College grounds uncovered it. A piece of the distinctive rock broken out during the blasting of the ditch cut still forms part of a low wall on the street.

White Brook Dolomite. This formation is made up typically of white crystalline dolomite mottled with patches of pink, purple, buff, and other tints, and phases of carbonate-rich schist. The while colour of the common dolomite on fresh surfaces serves to differentiate it readily from the younger Dunham dolomite, which is dark grey to blue-grey on most fresh surfaces. The White Brook dolomite weathers to bright brown and buff shades, usually with prominent ribs of thin quartz in the form of veinlet networks. In places a considerable amount of calcium carbonate is present in the dolomite, so that specimens effervesce strongly with cold dilute hydrochloric acid. Locally sand grains may be numerous enough to justify classifying the rock as a dolomitic sandstone.

Booth (1950) has traced the formation some 27 miles south into Vermont along strike, and towards the southern end he finds it mixed with a good deal of clastic material: much sand with small pebbles of quartz, slate and igneous rock; locally there are thin wavy interbeds of slaty or siliceous material. As with the Pinnacle formation, therefore, the formation exhibits a near-shore facies in Vermont.

In the Sutton map-area Clark (1934) found the thickness of the formation to be about 75 feet in the southern part of the area, and decreasing to 20 feet or more to the northeast. In Vermont Booth (1950) found the thickness in many places to be less than 20 feet, and in others the formation is entirely lacking. Its absence may be due to non-deposition or to squeezing out by tight folding; in Booth's opinion the former is the more probable explanation (p.1157).

In the southeastern part of the Shefford map-area definitely recognizable outcrops of the White Brook dolomite occur at only one locality one and a quarter mile east of Fulford on the hill between the north-south road and the wide curve of the railway tracks. A road cut south of the stream at the base of a low sweeping slope west from the main part of the hill exposes strongly cleaved West Sutton slates, which are also exposed as poor small outcrops a few tens of feet to the east in the lower pasture. Upslope to the east numerous outcrops of dolomite are present along the upper break in the slope but not on the top of the hill. Along the slope to north more dolomite is exposed with slate along the lower steeper slopes of the hill here. The extent of the outcrops suggest that the dolomite is folded and the present topograph surface parallels in part the configuration of the folded layer.

A possible White Brook locality occurs on the steep hillside forming the western outskirts of Waterloo where a sandy rock highly impregnated with carbonate appears.

No more outcrops are found on strike for several miles until the locality in the west end of Range X, Stukely Township, outside the present map-area, is reached. As with the Call Mill and Pinnacle formations, the White Brook has undergone important changes. Typical White Brook dolomite is usually present over outcrop widths of ten to twenty five feet, but it is accompanied by much greater widths of a soft silty rock, which is rather dark grey in colour with a hint of brown in spots. Parts of this rock contain much calcium carbonate, and will effervesce vigorously with cold dilute hydrochloric acid; other parts carry little or none. Thin sections show a grain size of 0.05 to 0.2mm. The main constituents, other than calcite, are fine-grained chlorite and mica with four tc five percent quartz, about two percent reddish limonite, and a few fragments of hornblende and of feldspar, Carbonate present ranges from fifty percent to nil. Somewhat similar rocks are found around Waterloo and associated with the White Brook dolomite in the Mansville phase of the Sutton map-area.

There seems to have been no regular sequence of deposition in this northern phase of the formation. About the middle of Range X, Stukely Township, the rocks directly overlying the Pinnacle quartzite are composed of the silty material with little or no carbonate. Less than a thousand feet north-northeast a band of dolomite ten feet wide is in contact with the quartzite, and silty material with an outcrop width of two hundred feet overlies the dolomite and appears to be overlain in turn by a second layer of dolomite with an outcrop width of twenty to twenty-five feet. In other places dolomite is flanked by silty material on both sides; in one place, about a quarter-mile southeast of the school at the west end of Range X, the silty material contains numerous rounded concretion-like spots of dolomite about a foot in diameter. At this locality the outcrops of siltstone are large and smoothly polished by ice action and it can be readily seen that the formation is intensely cross-bedded. Similar cross-bedding can usually be found elsewhere in the formation if clean, polished outcrop surfaces are present. Where not crossbedded, the siltstones are usually thinly laminated.

Like the underlying Pinnacle quartzite the siltstones can be seen at a number of localities on both sides of the main Tibbit Hill band in the Orford map-area. An excellently-exposed band of them was traced for nearly two miles south of Rochelle and a few scattered outcrops were found in the succeeding two miles. As might well be expected, however, the siltstones are generally much less well exposed than the Pinnacle quartzite.

West Sutton Formation

Clark (1934) has described the West Sutton slate as an impalpably fine mud rock varying in colour from shades of medium and dark grey to dark blue-black. Stratification is rarely apparent. He found much hematite in the rock either disseminated in minute particles so that the rock has a dark brown or reddish streak, or more commonly concentrated at the base of the formation. The presence of hematite is quite characteristic and is notable even in the Mansville phase. Clark estimated the thickness of the West Sutton in the normal (non-Mansville) sequence to be about 250 feet near West Sutton, but thinning away from the type locality to an average thickness of about forty feet.

South of the International boundary Booth (1950) has found the formation both thicker and much more variable in composition. South of the Missisquoi River it outcrops over widths of four miles or more; such widths apparently are due to the fact that although the beds are intensely crumpled the formation as a whole maintains a nearly horizontal dip. Most commonly he finds the rock a sandy slate or phyllite which locally includes a few to numerous interbeds of coarse-grained greywacke identical with the greywacke of the Pinnacle formation. East of St. Albans, some seventeen miles from the border along strike, the formation includes thick lenses of boulder conglomerate very like those in the underlying Pinnacle formation. In general the formation would be undistinguishable from the Pinnacle formation if the White Brook dolomite did not intervene as a horizon marker.

Considerable areas are underlain by West Sutton slate near the west ends of Ranges X and XI, Stukely Township, and in the southern four lots of Range X, Ely Township, in the Orford quadrangle. It also outcrops in several places in Shefford Township. Almost throughout, the formation is a non-bedded or obscurely-bedded dark grey slate which is rather strongly cleaved. It lacks the reddish streak, but otherwise is similar in description to that given by Clark.

In the Shefford map-area it crops out on the north-south road a mile east of Fulford between the two streams. It is in contact with the White Brook dolomite and shows the concentration of hematite at its base. A variation, perhaps merely local, is found at the south end of the gravel pit, a mile and a quarter south of Warden to the east of the North Yamaska River. There, directly underlying the Gilman formation. is a band twenty-five feet wide of intensely contorted, interbedded limestone, limy slate and slate in two or three-inch layers. Possibly this should be classed as a new member of the Oak Hill succession, but as there are no other outcrops of this lithology in the map-area, it seems best to treat it as a local variation of the West Sutton formation, a product of deposition in somewhat clearer waters.

Clark has postulated that the hematite at the base of the West Sutton slate represents a soil developed upon the White Brook dolomite. This White-Brook-West Sutton contact may, therefore represent a disconformity of perhaps some magnitude.

Gilman Formation

Areally the Gilman formation occupies a prominent position on the map-sheet, extending as it does diagonally across the eastern central part of the area as a swath two and a half to five miles wide which separates the lowermost units of the Oak Hill succession from the upper ones. Lithologically and structurally the Gilman formation is somewhat monotonous in aspect: variations exist, but they are usually subtle and difficult to map and interpret.

The formation is made up of buff-weathering phyllites and fine-grained schists composed of quartz with sericite and chlorite in varying amounts, and containing in numerous exposures small lenses of fine quartzite oriented parallel to the marked secondary foliation in the rock. A very fine-grained, hard quartzite occurs at the top of the formation immediately underlying the Dunham formation. This quartzite outcrops on the north flank of Brome massif half a mile southeast of West Shefford, but the overlying Dunham is not present here.

The Gilman formation is described by Clark (1934) as a coarse grit at the base, usually light-coloured because of the presence of abundant quartz grains, but with a dark green matrix containing much chlorite. Above this, and constituting the bulk of the formation, the rock is usually an impure quartz sandstone of such fine grain that it could be called a shale. Interbedded with the very fine-grained material are thin interbeds of fine-grained quartzite. Near the top of the formation everywhere in the Sutton map-area is a hard very fine-grained white quartzite. In part this quartzite is strongly deformed and broken up into small lenses surrounded by schistosity planes, and this phase may easily be mistaken for a schistose conglomerate, in particular, in poor exposures. In a similar fashion the thin quartzitic interbeds mentioned above are disrupted by the shearing of the rock, and most commonly pulled apart so that the original stratification cannot be discerned at all, the rock consisting of a rather uniform mass of small quartzitic lenses rather closely packed in a finer-grained phyllitic matrix. All gradations, however, from completely disrupted rock to only slightly disrupted quartzitic interbeds can be found.

Booth (1950) traced the Gilman formation southward into the state of Vermont for a distance of about forty-two miles. He distinguishes four main rock types: 1) a coarse to very coarse-grained sandstone or quartzite at the base; 2) a fine-grained argillaceous siltstone; 3) a mottled argillaceous quartzite; and 4) a white relatively pure massive quartzite at the top. He emphasizes, however, that "never can all four be recognized in one traverse across the strike; none is continuous throughout the area from north to south" (Booth, 1950, p.1148). Most of the formation both north and for some distance south of the border he classifies as an argillaceous siltstone which he describes as dull, medium to dark grey rock that rarely shows bedding. The mottled argillaceous quartzite, well-exposed on Bridgeman and Minster Hills immediately south of the boundary is composed of grey to reddish sandy spots separated by darker "finer sand or grit" with some shaly material carrying a network of fine graphitic filaments. The "mottlings" appear to be few and small in the lower part of this facies, becoming larger and more numerous towards the upper part.

Most of the Gilman exposures in the Shefford map-area are similar to those to the south in the Sutton quadrangle, and consists of rather soft, fine-grained argillaceous schistose siltstone, ranging in colour from white to various shades of grey and greenish grey. Broken across the cleavage, which is everywhere well developed, the purer varieties have a shiny appearance due in aggregate to the presence of minute colourless flakes. In types of uniform lithological aspect the cleavage is quite planar, but in types with quartz lenses the cleavage is no longer planar but wavy, anastomosing around the "streamlined" outlines of the harder quartzitic material.

Bedding, as noted above, is never common, but occasionally can be observed, particularly in the section east of Shefford Mountain. Here the beds are one to two feet thick as a rule, and are separated by ribbon-like bands a quarter to a half inch wide of slightly different composition, and usually quartzitic. These are the layers which are broken down to lenticular and sometimes rod-like bodies by the cleavage and transported into new positions by the deformation. All variations of position from scarcely moved rows of rod-like small masses with lenticular cross-sections marking accurately the original bedding to a line of nodules disrupted and distributed across the rock but still traceable as parts of the original stratification to completely random distribution occur. Most commonly fragments of this kind appear to be irregularly distributed throughout the body of the rock, and this aspect, coupled with the fact that many fragments appear to contain minute vesicles, at least on clean weathered surfaces, led Cooke to regard the Gilman formation as in part composed of trachytic tuff.

A number of thin section of Gilman rocks do contain very little quartz and many grains of fresh plagioclase feldspar constituting 60 to 65 percent of the rock. The plagioclase has a composition of about An_{25}. Most of the remainder of such rocks is matte of thin needles of chlorite, white mica, and actinolite in varying proportions. In most sections large metacrysts of iron carbonate appear to have replaced other constituents in part, but are now gone over to an aggregate of hematite or limonite with some magnetite. Quartz grains are present up to 2 to 3 percent in some sections.

A coarser type of clastic rock of similar type was found in an exposure immediately east of the road corner one mile northeast of the east end of the village of West Shefford. The rock looks like a moderately-coarse quartzite: it is very hard, excessively tough, and light grey to pinkish in colour; it has been crushed into fragments averaging an inch or somewhat less in diameter. Under the microscope it was found to contain no quartz whatever; all the fragments are composed of fresh feldspar, most of which are orthoclase and microcline, although albite grains are also present with an occasional grain of hornblende or biotite. The fragments are embedded in a fine-grained sericitic matrix. The joints between the larger fragments are filled with finely granulated orthoclase and albite. In outcrop aspect this rock looks not unlike other exposures of Gilman formation in the thermal metamorphic aureoles of the Shefford and Brome massifs.

The thickness of the Gilman formation is difficult to estimate, but one fact is certain: the outcrop width does not reflect the thickness of the formation as a whole. In the Sutton map-area, where exposures with bedding are more common, the layers of the formation whenever seen are thrown into markedly asymmetrical folds with long flat to gently-dipping eastern flanks and short steeply-dipping to overturned western flanks, so that the folds <u>regard</u> to the westnorthwest. It can be readily seen from such a folding style that the formation overall dips more or less gently to the west. The formation in all likelihood is a thousand or so feet thick.

The Gilman formation is the lowermost unit of the Oak Hill succession in which fossils have been found: "At a locality about half a mile southwest of the cemetery at Scottsmore this quartzite contains a few poor fossils. The most important type is a brachiopod, which, though poorly preserved, without doubt belongs to the genus <u>Kutorgina</u>. This genus is restricted to the Lower Cambrian. The other fossils are small and delicately branching forms, probably algae, and apparently of little stratigraphic significance" (Clark, 1934).

The Upper Mansville Phase

In a manner analogous to the grouping of the lower units of the Oak Hill succession into the Lower Mansville Phase, and for similar reasons, the Dunham, Scottsmore, and Oak Hill formations are here grouped into the Upper Mansville Phase for mapping purposes. Indeed the only formation at all well exposed is the Dunham dolomite; the others are not. A slate unit appearing beneath the Dunham is shown on the map. Although lumped together under one map heading, the various formations will be described separately below.

Dunham Dolomite. The Dunham dolomite is commonly a blue-grey rock that, like the White Brook dolomite, weathers to a chocolate-brown surface cut by quartz veins. Booth (1950) found reddish-purple, pink, yellowish and cream tints occasionally present, but north of the International Boundary these generally seem to be rare or absent. In the Sutton map-area Clark found the Dunham to be forty to one hundred and fifty feet thick; in Vermont (Booth, 1950) the maximum thickness is probably greater, but accurate estimates are impossible because of the intense crumpling.

In the Shefford map-area Dunham dolomite is only found in the northern half of the Oak Hill trend, outcrops being entirely absent between the Brome and Shefford massifs, although in one section the uppermost quartzitic part of the Gilman formation is present. Whether the Dunham and other Oak Hill units are absent here because of non-deposition or alternately due to faulting-out cannot be determined from the present outcrop relationships. Where the Dunham is found scattered exposures indicate a thickness of ten feet or so, or perhaps more in the most easterly section where it appears to be more or less flatlying over a considerable area north of Martin Corner and underlying prominent knolls.

At the southernmost locality a quarter of a mile north of the east end of the Shefford massif, ten feet of dolomite lie between Gilman beds and the Oak Hill slate. Three-quarters of a mile to the north the position of the outcrop band is probably revealed by a line of dolomite boulders, and a mile to the east of the boulders the dolomite outcrops in a shallow small syncline. The next and largest outcrops are those north of Martin Corner. Here the dolomite directly underlies the Sweetsburg slate, and the relatively large outcrop area at this locality, as noted above, appears to be due to close crumpling of a section with a flat or nearly flat dip. In the northwesternmost of the exposures north of Martin Corner, at the summit of the high knoll west of the north-south highway, and west of the farm buildings, the dolomite occurs as subrounded blocks or "boulders", 2 inches to 2 feet long, in a blue-grey slate. This rock shows all the signs of intense deformation, and is probably a tectonic rather than a sedimentary conglomerate.

Further to the northeast in the Orford quadrangle the Dunham dolomite is found in only three places and is reduced in thickness to a foot or less. In the field south of the short stretch of road along Range line X-XI of Shefford Township a single outcrop was found;

the dolomite band here is seven inches wide. The band was also found on the knob north of the road near its eastern end. In Range XI, lot 2 of Ely Township it again appears between the Gilman and the Sweetsburg as a band of a foot or two in width. Its character is not typical at this locality, however, for it is a coarse quartzite with grains cemented by carbonate.

The usual lithological type of the Dunham formation is a fine-grained, brown to reddish brown weathering blue-grey marble composed essentially of interlocking carbonate grains and small amounts of quartz in fine grains. This rock almost never shows any bedding although it is occasionally finely and faintly foliated. Associated with outcrops of this lithotype are nearby exposures of dolomitic sandstone consisting of scattered subangular to rounded quartz grains in a interlocking mosaic of carbonate grains of similar or smaller grain size. Occasionally small chips of mudstone are present. The quartz grains, which rarely touch one another, range in size from 0.5 to 3mm. and make up 30-40 percent of the rock. The quartz grains are usually composed of parts of single quartz crystals, but are occasionally composed of mosaics of tiny quartz grains. Such sandy phases are found in positively-identified Dunham formation in the Sutton map-area as well as in the Scottsmore formation. Indeed, even in the Sutton area it is often difficult to separate the two formations on lithological grounds, and the distinction is usually made on stratigraphic position.

A thin layer of black slates, in lithology not unlike the Sweetsburg slate, occurs beneath the Dunham dolomite in the outcrop area northeast of the Shefford massif; it is shown as a separate map-unit although areally it is of very minor importance. It is shown thus, however, to emphasize the variations that do occur in the Oak Hill succession from place to place along and across its trend.

The age of the Dunham formation has been established by Clark (1936,p.147) as Lower Cambrian on the evidence of fragmentary remains of trilobites belonging to the Mesonacidae family. In 1950 Clark found some fossil remains in the dolomite outcropping northeast of the Shefford massif, but they proved to be too greatly broken up for identification. The presence of such fragments suggests that further search in the locality might be fruitful.

Oak Hill Slate. This slate directly overlies the Dunham in the Sutton map-area, and is described by Clark (1934) as a tough, dark brownish-grey or black rock more properly designated a siltstone than a mudstone. Its distribution in the Sutton area is patchy and discontinuous. Bedding is revealed by limonitic layers, or, in places, by more or less discontinuous flecks of limonite. South of the International Boundary (Booth, 1950) the formation, which is correlated with the Parker slate of Vermont, is more variable in composition and may contain interbeds of sandstone up to three inches thick, or of quartzite, in part dolomitic, several feet thick.

In the Shefford map-area the Oak Hill slate was only recognized at one locality about one-half mile north of the northeastern corner of the Shefford massif. There it is directly in contact with the

Dunham dolomite, and shows the characteristics typical of this rock in the Sutton map-area.

Scottsmore Quartzite. In the Sutton map-area (Clark, 1936) the Scottsmore quartzite is usually eight to twelve feet thick, but ranges from almost nil to twenty-five feet. The common rock type is brown to chocolate weathering, grey, medium to fine-grained bedded quartzite with a dolomitic to siliceous cement. In Vermont, according to Booth (1950) the formation contains more numerous and prominent conglomeratic phases than in the Sutton area where occasional limestone and dolomite cobble and pebble beds are present. The Oak Hill is a correlative of the Rugg Brook formation of Vermont.

The Scottsmore, as noted above under the Dunham dolomite heading, was not identified with certainty in the Shefford map-area. On the crest of the knoll a mile northeast of Martin Corner above the farm buildings a block of coarse white quartzite was found with exposures of Dunham dolomite and possibly Oak Hill slate nearby. The Scottsmore appears to be much reduced in thickness in this section of the Oak Hill.

Sweetsburg Formation

This formation, which is the uppermost unit of the Oak Hill succession, is also one of the most important from a stratigraphic point of view because the Sweetsburg has been traced across the Green Mountain anticlinorium (Sutton axis) into the Ottauquechee formation, a marker formation running down the east side of the Green

Mountain axis in a manner comparable to that of the Sweetsburg on the west side. In Vermont the Sweetsburg is correlated with Skeels Corners slate (Booth,1950), which contains Bovicornellum vermontense, a Middle Cambrian guide fossil.

Clark (1936) describes the Sweetsburg as a bluish-grey to black slate characterized by the presence of numerous beds,from a quarter to a half inch thick, of fine-grained white sandstone. It is generally much crumpled and well-cleaved, rendering its thickness almost impossible to determine, but as it outcrops over widths of half a mile to a mile, Clark considers that it must be at least two to three hundred feet thick.

The band of slate that runs north from Sweetsburg crosses the south boundary of the Shefford map area and ends against the south-west flank of the Brome massif. Its relationships to the adjoining St. Germain rocks here are not at all clear and, because of thermal metamorphism, varieties of the two lithologies are distinguished with difficulty. The formation does not appear between the Brome and Shefford massifs, although several exposures in the hornfels collar on the northern side of the Brome massif are suggestive of the lithology, and the slate does not appear until north of the Shefford massif where it forms a rather poorly-exposed band extending to the eastern map-boundary. In general the formation appears to be of about the same thickness as it is in the Sutton map-area. The white sandy layers are much more prominent than to the south, and in places constitute the bulk of the formation, but otherwise the lithology is similar to that of the type locality.

Interpretation of the Stratigraphic Record

The preceding descriptions bring out the fact that many of the sedimentary formations of the Oak Hill succession, with the possible notable exception of the Gilman, have thinned rapidly northeastward from their type localities in the Sutton area. Clark (1934, 1936) has also pointed out that they thin rapidly eastward; the beds he found on the east side of the main Tibbit Hill band along the Pinnacle Mountain anticline, which he termed the Mansville phase, have thicknesses which in places at least are nearly one-tenth those of the normal sequence on the west side of the anticline. Booth (1950) has shown that some 20 to 25 miles south of the International Boundary in Vermont many of the Oak Hill formations display coarse and even conglomeratic phases, and that the grain of the sediments becomes finer towards the east. All these facts point to the conclusion that the source of the sediments was a land area not far to the west or northwest of that part of Vermont where the coarse Oak Hill clastic phases occur.

Fairly shallow waters appear to have covered the whole area of Oak Hill deposition. Clark describes the Pinnacle as much cross-bedded in some sections; the similar structures in other formations, and the coarser clastic varieties, would favour a shallow water environment.

For a fuller treatment of this subject, however, reference should be made to the studies of Cady (1960) and Booth (1950).

The evidence to be gleaned from the Shefford exposures hardly warranted a broader or more comprehensive discussion here.

The Cambro-Ordovician Granby Group

The second grand division of the Paleozoic sedimentary rocks of the Shefford map-area is represented by the Granby group (a new name proposed here), which occupies the northwestern third of the map-area, but extends out of the area to the north and west. The Granby group is composed of an assemblage of colourful and striking sedimentary rocks of considerable diversity, which contrast strongly with the drab grey slates and limy rocks of the St. Germain Structural Complex which bounds the Granby group on the southeast. Apart perhaps from the igneous rocks of Brome and Shefford, the rocks of the Granby group are by far the most interesting of the map-area.

The prominent rock types of the Granby group are green sandstones and red and green slates which have long been loosely correlated with the "Sillery" lithology in the environs of Quebec City. Rasetti (1946) showed through fossil evidence that the "Sillery" near Quebec includes beds both of Lower Cambrian age and of lowermost Ordovician times, and he proposes the designations Charny and Lauzon formations for these two age groups respectively. As no fossils have as yet been found in similar rocks around Granby, it is not possible to assign them to either formation, although they may be considered to be a group of rocks of probably similar overall age, environment and origin. It is for this reason that they are here given the noncommittal designation of Granby group, which will serve for the time being to set off the present state of knowledge as regards correlations. Rocks similar to the Granby group and thus the common basket "Sillery" lithology have been observed in the overall region of the Eastern Townships in numerous localities and varied stratigraphic positions, as for instance above and below rocks correlated with the Sweetsburg formation of the Oak Hill succession. The many and varied possibilities of correlation of the Granby group with the "Caldwell", Armagh group, etc., are far beyond the scope of this report, and the interested reader is referred to Cady (1960). The stratigraphic position of the Granby group will probably not be determined by studies in the Shefford map-area, but must await the results of careful studies made elsewhere in the region where rock relationships between the main lithologies are less deformed and better exposed.

The principal units of the Granby group as observed in the Shefford area are, in decreasing order of areal importance, the following:

1) greenish-grey to pale green, thick-bedded, massive sandstones (subgreywackes) with occasionally beds of grit and pebble conglomerate and clean white quartzite, and interlayerings of varying importance of green and red slates;

2) thick-bedded, purple weathering, brick-red slates with occasional thin but quite characteristic white layers which mark the bedding, rare thin dolomitic limestone beds, and interbeddings of green slates in varying amounts;

3) grey weathering, dove-grey slates and siltstones, characteristically containing tiny, thin, streaky lenses of black carbonaceous material;

4) hard, massive, thick-bedded grey-black and black sandstones similar in aspect to the green sandstone except for their distinctive colour; they are occasionally interbedded with the dove-grey slates;

5) thin-bedded dark grey and black slates and argillites, usually with highly crumpled bedding.

The overall stratigraphic sequence of these lithological units within the map-area is not evident from the present mapping, and indeed the above groupings are in themselves perhaps rather artificial because in many instances the lithological types are intermixed so that the assignment of an outcrop to a particular lithology is arbitrary and subjective. The structures observed and this lithological variability make it clear, however, that to attempt to construct a stratigraphic column on the basis of present knowledge would be entirely misleading. The relationships observed in many outcrop areas can be readily interpreted by assuming certain structural features to be present or by inferring certain stratigraphic relationships, but when such assumptions are extended beyond a local section an edifice of conjecture is erected of completely nebulous nature which can be destroyed as easily as a house of cards by one further observation or reasonable inference. For this reason, it must be stressed that the contacts between various units must be taken as being either what they are, simple juxtapositions of different rocks, or lines drawn to delineate a boundary between lithologies which grade into each other. Such contacts may in reality be faults of various sorts, conformable or disconformable sedimentary contacts, or arbitrary division lines between gradational units, but until further and very detailed work is done, it will not be possible to specify the nature of most of the contacts covered by drift. The overall lithology of the group contains many marked physical contrasts between rocks which are clearly in normal sedimentary contact, such as massive sandstone lying upon a thick accumulation of shale. Obviously during deformation such an horizon between rocks of such contrasting "competence" will be a boundary of contrasting reaction to deforming stress, the slates crumpling while the sandstones thicken under compression, and probably thus also a plane of faulting. To prove a plane of faulting does not, therefore, prove that the contact is not overall a plane of sedimentation unless the movement has been great compared to the magnitude of the units involved.

Neither the top nor the bottom of the Granby group has been identified in the map-area, but the oldest unit does appear to be made up of green sandstone which forms the prominent belt of outcrops which run through the eastern part of the city of Granby and extend north-northeasterly through Roxton Pond, the result of an overall anticlinal configuration. At least one other horizon of sandstone deposition appears to the northeast and east of South Roxton along the northern map-boundary; here an undulating plate of sandstone forms the upper parts of the hills of this section and lies on top of other lithological units in sedimentary conformity.

Red slates would appear to lie stratigraphically above the oldest green sandstone to the west of the Granby-Roxton Pond belt, succeeded upwards by dove-grey slates, interbedded grey slates and black sandstones, and then black sandstones along the Mawcook River. Such a sequence cannot definitely be confirmed elsewhere in the map-area, however, and the westernmost belt of red slates in the north-western corner of the map-area may be a new red slate unit, or the same red slate as that forming the unit appearing to the east, a synclinal axis running more or less along the course of the Mawcook River. The apparent lack of dove-grey slates on the west side of the presumed axis would not support the latter conjecture.

Outcrops are abundant in the area of the Granby group, and particularly so for the sandstone units. Unfortunately two factors intervene to make the study and interpretation of the data gathered difficult and liable to serious error when extrapolations are made over any great distance. Firstly, all the good observations made on large and well-exposed outcrops indicate that the structural style of the deformation is complex and complicated: the present overall structure of the group is the result of at least two phases of deformation, including both folding and faulting; the first phase produced markedly asymmetrical folds facing to the west with short, steep to overturned western flanks and long, gently-dipping east flanks, and related low-angle faulting, whereas the second phase produced more or less upright open folds in the already-deformed beds, and was accompanied, at least locally, by high-angle faulting. The amplitudes of movement for both folding and faulting can be readily discerned for both phases on the scale of the average outcrop, but is not evident for larger scales, and the magnitudes of larger amplitude, if they exist, have not been determined.

Secondly, many structural features are obscured by lichen, or not exposed because the individual exposure of an outcrop group is too small to reveal them in their entirety, such as the thicker bedding units and the medium sized folds, and the extrapolation of isolated structural determinations for these reasons from a tiny part of an individual large outcrop to the outcrop as a whole, or from one small exposure to an outcrop area as a whole is fraught with error.

The Granby group is everywhere in the map-area bounded on the southeast by outcrops of rocks typical of the St. Germain Structural Complex: grey and brownish-grey slates with occasional beds of dark grey to black limestone and rarer interbeds of sandstone. The St. Germain rocks separate the Granby group completely from the Oak Hill succession over distances as little as three-quarters of a mile, and as great as four miles. If the Granby group contains stratigraphic equivalents of the Oak Hill succession, the facies changes would have to have taken place over perhaps improbable short distances, if the rocks of the two groups are still more or less in their same relative positions as they were when they were deposited. As mentioned earlier, rock types similar to those in the Granby group have been observed lying above or below certain elements of the Oak Hill succession (Cady, 1960), and if the Granby group, or a part thereof is a facies variant of the Lower or Middle Cambrian, it would seem necessary to invoke major faulting to explain the present near juxtaposition of lithologically dissimilar rocks.

On the other hand, some of the minor lithotypes of the Granby group are found in the St. Germain complex, and vice versa, which is suggestive of an intertonguing of the two groups, although again the argument put forward against an interrelationship between the Granby and Oak Hill may be brought forward for this case. This lithological similarity may be of greater importance, and certainly significantly H.C. Cooke first believed that the black slates exposed within the outcrop area of the Granby group represented St. Germain slate which had been thrust westward onto the Granby sandstones and green and red slates. More recent work by Eakins has definitely shown that most, if not all, of the black slates within the Granby outcrop sensu lato is interbedded with the Granby lithotypes, and Cooke's interpretation can no longer be sustained.

The contact between the St. Germain and the Granby is unfortunately nowhere unequivocably exposed for study, although rock units characteristic of each group are occasionally found in exposures only a few feet to a few tens of feet apart. A notable example of such a close relationship is to be found northwest of Saxby Corner at the northwestern foot of the Shefford massif where rocks of the two groups are in close and intimate outcrop relationship without revealing the true nature of the contact between them because of the overall strong deformation both lithologies have sustained.

A further example is that provided by the exposures along the western slope of the prominent ridge along which Highway 13 runs northward to the city of Granby. Here the St. Germain clearly lies above the Granby rocks which occupy the lower slopes of the ridge. At least minor thrust faulting in the Granby is evident with upper masses moving westward relative to lower ones. Such a situation would suggest that the St. Germain Complex has been thrust westward onto the Granby group. However, the overall situation may be different, with the Granby thrust in from the east (as suggested by Henderson 1958) on top of the St. Germain and then subsequent overfolding and possible thrusting producing the relationships seen. Again the relationship might be explained by supposing that the St. Germain intertongues the Granby and that subsequent deformation has been localized along this zone of intertonguing with the formation of overfolding and possibly overthrusting along the zone of physical contrast represented by the "interlocking" zone.

Green Sandstone

Green to greyish-green sandstone, often with a yellowish or buff cast on clean weathered surfaces, and with thin to thick interbeds of green and occasionally red slates and rare red sandstones and white clean quartzites occupy nearly a third of the area of outcrop of the Granby group, and because they are so resistant to erosion, form prominent outcrop areas and the summits of most of the hills and ridges in the northwestern third of the map-area.

They are the dominant rock type of the group both qualitatively and quantitatively.

In grain the sandstones range from moderately fine to extremely coarse varieties, and in places quartz-pebble conglomerates with well-rounded quartz fragments up to a quarter of an inch or more in diameter are present. Slabs of green or red slate identical in aspect to neighbouring interbeds of slate are almost ubiquitous in the sandstone, usually as tiny fragments, but occasionally as large blocks up to a foot long or more. Most of the larger grains in the normal sandstone are quartz, which may constitute over ninety percent of the rock, but a few large grains of feldspar and varying numbers of smaller grains in the matrix around the larger grains are almost always present. The feldspar grains are usually fresh to slightly altered and composed of both orthoclase and plagioclase.

The quartz grains range from completely angular and shardlike to well-rounded; the vast majority are subangular. The presence of numerous shardlike fragments, or tiny slabs or splinters with angular corners are a remarkable feature of the sandstones, and an indication of very little grinding of many of the quartz grains during transportation. Minute dusty inclusions are common in the individual quartz grains, sometimes arranged in strings. Under the high power some of these tiny inclusions seem to have angular outlines, but others are rounded as if they were minute bubbles within the solid quartz.

The quartz grains are set in a generally finer grained matrix which ranges in grain size from nearly that of the common larger clastic particles down to extremely fine dust. The amount of matrix is quite variable and ranges from as much as fifty percent of the rock down to eight or ten percent. It is definitely "pasty" in aspect. It is composed of quartz, feldspar, and varying amounts of fine chlorite, mica, carbonate and heavy minerals.

The composition of the average sandstone is that of a feldspathic sandstone or subgreywacke. According to some systems of nomenclature it might be designated as a metamorphic quartzite because the rock breaks across the individual larger component quartz grains and not around them.

Most of the sandstone beds, which range in thickness from six inches to at least ten or twelve feet, are usually fairly uniform, but also usually show a slight coarsening of grain towards their base. A few exhibit marked grain gradation from coarse at their base to fine at their top. The scattered slabs of slate, which are usually at least somewhat coarser than the larger ambiance grains of the rock, show no particular predilection for any part of the beds, and occur haphazardly. When small they produce a pleasing green or red contrasting flecked appearance in the rock.

When coarse-grained at their base the sandstones usually have rillmarked contacts with the underlying rocks. Load costs, on the other hand, are not observed. Cross-bedding is rare, but in places a bed cuts across completely a lower bed at a low angle.

The sandstones have all the characteristics of "poured-in" sediments which have been little or not disturbed since they came to rest in an environment where slates are usually deposited, i.e.

medium depths. Osborne (1956a) suggests on the basis of various lines of reasoning which he does not discuss that this depth of water was about 600 feet.

Over considerable areas little or no slate seems, from the outcrop evidence, to be interbedded with the sandstones, but in other places, as noted above, minor to considerable amounts of very fine-grained sedimentary material, now slaty, is intercalated. Such is generally the case near the contacts shown for the green sandstone on the map, but it also occurs within the main bands indicated on the map. Slates may make up as much as 50 or 60 per-cent of the local succession.

One of the most informative outcrops of green sandstone with interbeds of green and red slates is to be found in an old shallow gravel pit east of highway 13 in the southern outskirts of Granby. The exposure is reached by a suburban road turning off highway 13 immediately south of the gas station at the intersecting of the highway with the main south-west-northeast thoroughfare of the city south of the North Yamaska River. This suburban road swings south as it climbs a low hill and soon degenerates into a farm road which passes several houses and then some pasture before arriving at the pit, which is now being used to burn garbage; fortunately most of the better exposures are at the far end of the road on somewhat higher ground. Here perfectly clean out-crops waterworn before the deposition of fluvio-glacial gravel, which has been subsequently removed, provide a magnificent tech-nicolour opportunity to examine and study the Granby sandstone and slate lithology in detail. The beds in these exposures dip gently west for the most part, but abruptly swing into vertical positions in zones a few feet wide, usually with attendant evidence of faulting. The remarkable point to note in these exposures is the short distance over which the beds change position. In the shaly rocks a good cleavage is developed dipping to the east, and from cleavage-bedding intersections indicating anticlines to the west and downwards. A small cross-fault with 1-4 inches of breccia can be observed at one point.

The lithology of this spectacular outcrop is varied and shows well a number of primary sedimentary structures. Apart from normal sandstones and red and green slates, there are a number of variants which shed considerable light on the origins and environment of the Granby sedimentation. One red, fine sandy layer, for example, exposed near the west side of the higher outcrops, is finely crossbedded, and the crossbedding has been distorted by slumping and then partially eroded away in a broad channel now occupied by slightly coarser material which forms a bed about eighteen inches thick containing blocks of red slate, one of which is nearly three feet long. Obviously the fine sand was formed by bottom currents, slumping of the deposited mass, then took place followed by erosion by newer currents, and finally the later sandy material which arrived in the form of a thick slurry which was able to raft along large blocks of shale torn away from higher levels in the basin, i.e. a turbidity current.

To the east of this exposure across beds mainly composed of sandstone there is a clearly sedimentary breccia composed of angular fragments of slate of various sizes from tiny to over a foot long in a silty matrix. This breccia is interbedded with the sandstones.

These various features would indicate that from time to time coarse clastic material with varying amounts of fines were swept by turbidity currents into a quiet environment of silty and muddy deposition. The turbidity currents were probably associated with the slumping of masses of already deposited siltstones and mudstones, partially indurated, which were torn up and incorporated in the stream of coarser clastic material sweeping downslope.

Red Slates

The second most important spatial unit of the Granby group, and a very colourful one indeed, is formed by purple-weathering, brick-red mudstones and siltstones in which the development of an excellent cleavage is characteristic, and the rocks are now slates. Bedding in these rocks is usually not obvious in most exposures, but a careful search usually reveals some indication of the bedding attitude: thin white beds, an eighth to a half-inch thick, thin limy beds, and more rarely sandy interlayers. For the most part the individual beds of the red slates are thick, ranging from a foot to over ten feet in some cases, and uniform in character throughout. Green slates are here and there interlayered with the red, but not in any systematic way that could be determined. The green slates sometimes have sandy thin interbeds and frequently show very thin basal layers (1/16th inch) made up of tiny chips and grains of quartz and other detrital material.

The relationships between the red and green slates are not always those of interbedding, for occasionally a slate bed is seen clearly to change abruptly from one colour to another along a contact which cuts across the bedding planes of the rock. The change in colour is not accompanied by any other change in the slate, and appears to be simply an alteration of the oxidation state of the iron oxide in the rock without any other reaction. The red and green colours of the slates were obviously formed at the time of deposition of the sediments, or very shortly thereafter, for fragments caught up in penecontemporaneous brecciation are of both colours. Presumably changes of the rarer red colour to the more normal grey state of iron oxide probably took place in the environment of deposition more or less penecontemporaneously. The colours are premetamorphic and precede any imposed deformation such as the formation of cleavage. Their clear aspect is due to the absence of carbonaceous matter in the rocks.

The red slates and their attendant green slate interbeds and/or equivalents crop out in three continuous belts:

1) a belt running through the western half of the city of Granby and extending north past the hamlet of Roxton Pond to the north map-boundary. The bedding in this belt shows numerous attitudes which reflect the presence of numerous small-scale folds;

2) a belt in the northwestern corner of the map-area bounded on the southeast by a band of black sandstone outcrops. One of the best exposures of the slate lithology is to be found in a rocky

pasture a quarter of a mile northwest of St. Cecile-de-Milton, where cleavage-bedding relations are classically displayed. Thin limestone beds up to six inches thick occur on a low clean outcrop immediately east of the church of St. Cecile-de-Milton.
3) an irregular band of highly-contorted shape in the north-central part of the map-area.

The slates are very fine-grained, and microscopic examination reveals little about their make-up. Characteristically they contain many fine chips of quartz and feldspar set in an even finer grained sericitic matrix. Iron minerals are not identifiable, and it is obvious that they occur as thin coatings pervading the rock to produce the characteristic colours.

Dove-Grey Slate

This lithotype, like the remainder to be described, is not as spatially well-developed or defined as the foregoing types, nor is it in any way as abundant. The most prominent band of dove-grey slates occurs along the western side of the red slate belt of Granby-Roxton Pond and appears to overlie it. The grey slate is interbedded with thin beds of black sandstone on the western side of this slate belt.

The slate of this unit is perhaps the most peculiar of all the units in its general lithological character: it is a grey-weathering, dove-grey to olive-greenish white mudstone with in almost all instances where it is found tiny black lenses of carbonaceous material with somewhat frayed terminations. The origin of these tiny lenses, which appear to be parallel to bedding, is not known. Cleavage is weakly to moderately developed in this rock, but is usually not as prominent as in the other slates. A rock of similar nature, it is interesting to note, is occasionally found in the St. Germain Structural Complex, particularly in the western half of the Sutton quadrangle interbedded with other rock types north of St. Ignace de Stanbridge.

Black slates are occasionally interbedded with the grey.

Black Sandstone

Apart from its extraordinary colour this sandstone is similar to the normal green variety in all important aspects. It is extremely hard and often tenacious in outcrop and rarely displays any bedding excepting where it lies close to grey slates and then it is interbedded with such rocks. It is a dark grey weathering, dark grey to black aggregate of somewhat scattered large quartz grains (1-3mm.) set in a very fine-grained pasty black matrix. The black colour is probably due to the presence of fine carbonaceous matter. Fresh feldspar grains occur in the same proportion as they do in the normal sandstone, and the rock may be classed as a subgreywacke.

The black sandstones occur in a number of more or less isolated occurrences across the northern part of the map-area from an important belt running along the Mawcook River to east of South Roxton.

The black sandstones along the Mawcook River are clearly interbedded with the dove-grey slates. This relationship is well-exposed close to the east-west road running a quarter of a mile south of the Milton-Granby Township line. The relationships of the black sandstone and the red slates to the west is, however, not revealed in outcrop. The dove-grey slates which separate the black sandstones from the red slates to the east, do not appear to the west, suggesting that the black sandstone belt is not synclinal, and that the western red slates are a new horizon for such rocks.

Small patches of black sandstone appear in various places to the east of the main Mawcook River belt. The largest patch west and southwest of South Roxton appears to be underlain by a crumpled but overall flat plate of these sandstones. A small patch forms the top of a prominent knoll one and a half miles west of St. Joachim-de-Shefford. Here the black sandstone is accompanied by a poorly exposed layer of sedimentary breccia, and is underlain by black slates, and in turn grey slates.

Black Slates

Black slates in most respects similar to black and greyish-black slates ofthe St. Germain Structural Complex crop out in various parts of the Granby outcrop in the north-central and northwestern part of the map-area. Characteristically these slates are found in poor low isolated exposures which reveal, however, that the rock is intensely deformed or "mashed up". Cooke believed that these slate outcrops indeed represented tiny klippen of St. Germain that had been thrust westward onto an erosion surface developed on the Granby lithology. A very careful search has revealed, however, that black slate is clearly interbedded with, and part of, the Granby lithology. Such a relationship can be seen in a rocky wooded pasture north about one hundred yards from the Roxton-Shefford Township road a little less than half a mile east of the road crossing of the Cleary Station-South Roxton branch line of the Canadian Pacific Railways.

The black slates have undergone considerably more deformation than the other rock types of the Granby group undoutedly because of their greatersoftness and plasticity.

Breccia

A peculiar breccia occurs in the environs of South Roxton extending as a more or less continuous narrow belt from the northern edge of the map-area southward along the line of Route 13. It is clearly seen to be interlayered with other rock types, most notably near the northern map-boundary.

The breccia consists of streaky lenses of sandstone-quartzite set in a phyllitic "dirty" green matrix which is foliated parallel to the white lenses. The breccia appears to be the result of the intense smashing up of an alternating sequence of sandstone and siltstone beds, as is postulated to represent the sole plane of a thick sedimentary slide during the depositional period in the geosyncline. This slide zone appears to have been folded along with the other layers by the subsequent deformations. The area of this breccia is one of many tiny scattered outcrops and until mapping is carried out on a scale of 1"-100' or so the exact nature of this breccia belt will not be known.

Interpretation of the Stratigraphic Record

As Osborne (1956a) has pointed out for the Charny part of the "Sillery" of Quebec City, and which equally applies for the Granby group, the lithology represents a remarkable contrast in sedimentary types: coarse sandstones in an environment of quiet deep waters where siltstones and mudstones normally accumulate. The sandstones have obviously arrived in this environment through the agency of turbidity currents triggered by submarine slides and slumps which disrupted the red and green slates and provided fragments for accumulation along with the settling sands.

The red colouration of siltstone and mudstones reflects the conditions of weathering in the provenance area of the sedimentation, rapid transportation to the site of deposition, and quick burial before bottom reducing conditions could bring about an alteration of the iron oxide to a more normal green state.

Middle-Upper Ordovician St. Germain Structural Complex

In the Sutton-map-area to the south, a wide belt of slates separates the Sweetsburg slate, the uppermost formation of the Oak Hill group, from the Upper Cambrian-Lower Ordovician formations of the Philipsburg area to the west on the shores of Lake Champlain. These slates were named the Stanbridge formation by Clark (1934, 1936). Fossils are fairly rare in this belt because of well-developed cleavages, but sufficient paleontological evidence has been obtained from various localities to show that the Stanbridge rocks are Middle to Upper Ordovician in age, ranging for the most part from earliest Trenton into the Lorraine times. Stanbridge rocks have also been called Farnham slates, a rather general term for shales and slates of Middle and Upper Ordovician age in the Appalachian region of Quebec.

In recent years during his careful mapping in the St. Lawrence Lowland, and even more recently during his investigations of the Granby West Half quadrangle adjoining the Shefford map-area on the west, Clark has begun to separate out from sections previously designated as Stanbridge formation or Farnham slates, various lithologies which he could positively identify as Trenton, Utica Lorraine, etc., and present in nearby, undeformed or slightly deformed, sections of the Lowland. Because some of these newly-identified sections were too small to show upon an areal map, or because work had not been detailed enough to separate out all the various units, or because of sections of poor exposures in the general zone, Clark has used the term St. Germain Structural Complex to designate this grouping of Lowland rock types, and has dropped his earlier term Stanbridge formation and the older designation of Farnham slates. Recent studies in the Sutton map-area by Eakins (1964) show that it will be possible and desirable to subdivide Clark's former Stanbridge formation in that area by careful remapping carried out in the light of new knowledge provided by Clark himself in the intervening years since he made his first studies of the Sutton rocks in the late twenties. The designation St. Germain Structural Complex, which appears on the Sutton map-legend, is to be recommended because it clearly emphasizes the problems to be solved by future workers in this part of the Appalachians, and does not create a sense of security and finality that a formational designation would engender.

In the Shefford map-area the St. Germain Structural Complex forms a belt of slaty rocks of varying width extending across the map-area, and completely separating the Oak Hill succession from the Granby group. This belt narrows more or less progressively from a width of about three and a half miles in the southern part of the map-area to three-quarters of a mile in the central part of the area north of the Shefford massif, and then broadens progressively towards the northeast. The St. Germain-Oak Hill contact is reasonably straight throughout its extent in the map-area; it is interrupted by the presence of the Brome and Shefford plutons. The St. Germain-Granby Group contact in marked contrast takes several violent swings, which account for the variability in the width of the St. Germain belt.

The true nature of these two contacts is still in doubt. In the Sutton area recent work by Rickard and Eakins has shown that a thrust fault, the Oak Hill, as envisioned by Clark, probably does not exist, although some local thrust faulting is present along and near the contact in various localities; the contact is considered now to be essentially sedimentary - a slight unconformity between the younger St. Germain and the older Oak Hill. On the other hand, the absence in the section between Brome and Shefford of the Oak Hill succession above the Gilman formation, i.e., the Dunham, Oak Hill, Scottsmore, and the Sweetsburg formations, is a feature never encountered in the Sutton map-area, and one which might well be put forward in favour of a thrust fault along the St. Germain-Oak Hill contact. Alternate hypotheses to explain the absence of these formations would involve non-deposition (unlikely), a remarkably thinning of all the units (conceivable for the Dunham, Oak Hill and Scottsmore, but unlikely for the Sweetsburg), or overlap of the St. Germain hiding the missing formations.

The presumed lowermost beds of the St. Germain are found on the southwest flank of Gale Mountain on the west side of the Brome massif. There the strata are for the most part much metamorphosed by the heat of the Brome intrusions. The lowest beds, and also the least metamorphosed, lie immediately north of the farmhouses in the middle of lot 4, Range III of Farnham East Township. They are rather hard, grey argillites with a moderately well-developed cleavage. The beds range in thickness from about two inches to a foot or more, and contain numerous white oval spots. The spots are somewhat irregular in shape, and range in size from a fortieth to a quarter of an inch in diameter. Peculiarly, they are concentrated in the lower halves of the slate beds. The beds here form the crest of a rather broad anticline plunging northeasterly at ten degrees. They are broken by an anastomosing system of tension cracks with a general strike N35°E, and a general dip of about 50°W. The west sides of these irregular cracks appear to have moved downward for distances ranging up to three inches.

Going north along the crest of the fold, and therefore higher in the succession, harder and harder beds are crossed until finally the hardness becomes about 5 in the Moh's scale, the rock is recrystallized and weathers a dark red-brown. These rocks effervesce somewhat with hot concentrated hydrochloritic acid; the microscope shows them to consist largely of skarn minerals, including diopside, biotite, quartz, and some chlorite. The metamorphic compositions suggest that they were originally impure magnesian limestones.

The crest of this anticline is about five hundred feet across. On the east its flank is drift covered for several hundred feet beyond which similar rocks are seen again. On the west the dips increase rapidly to about forty-five degrees. Thin limestone beds were noted in this section, and some parts of it were said by Dr. Wallace Cady in a personal communication to resemble strongly the Beldens formation to the south in Vermont. As this formation in Vermont underlies rocks correlated with those in the St. Germain Structural Complex, the resemblance here seen tends to confirm the inference drawn from the structure, that these rocks are somewhat older than the slates lying to the west.

The slates of the St. Germain Structural Complex are generally dark grey to black, and weather to pale grey, dark grey, and brownish tints. Bedding an inch to several inches thick is normally seen in most exposures. This bedding is for the most part mechanically unimportant and does not affect the development of the cleavages. Other variants of the slates, however, do have thin interbeds, either sandy or limy, which are mechanically significant, and do affect the development of the cleavage. The thicker beds of black limestone (as would be expected) are generally not cleaved.

Limestone beds are not uncommon in the St. Germain Structural Complex. They are generally only a few feet thick, but one eight feet wide was noted half a mile northeast of Granboro Corner. Occasional dolomitic beds up to four feet thick are also interbedded with the slates.

The slates are composed mainly of tiny feldspar grains (about An_{30} in composition) embedded in a matrix of mica and chlorite fibres. Many of them have a larger or smaller component of calcite or dolomite and will effervesce with cold dilute hydrochloric acid.

Limestone conglomerate, although it is of fairly common occurrence farther to the south, was found interbedded with the slates in only one place. A road cut bordering the south side of the road on the Waterloo-Granby highway (Route I) just west of Saxby Corner shows three thin beds ranging in thickness up to four inches. The pebbles, mostly less than an inch in diameter, are mainly limestone with a few of black chert or fine-grained quartzite. The matrix is grey limestone. These beds are vertical and are thoroughly weathered to a soil to a depth of six feet, so that they would never be noted except in unusually deep road cuts.

Some of the best exposures of the St. Germain are to be found about one and a quarter miles north of West Shefford on both sides of the east-west road. At the east end of this road large exposures display the St. Germain slates tilted into gentle folds with anticlinal axes only 200 to 300 feet apart. Dips on the flanks of the folds range up to fifteen or twenty degrees for the most part, although in places steeper dips may prevail for a few feet. A perfect cleavage has developed striking N20°E and ranging in dip from vertical to forty-five degrees east.

West of this locality the same gentle folding is maintained for about a mile and a half. This zone of comparatively slightly folded although strongly cleaved rocks runs almost north-south for a distance of more than five miles, or from West Shefford to about the North Yamaska River. On the hill north of the road in lot 3, Range III of Granby Township the gentle folding described above gives way to more intense crumpling. At the summit of the hill beds of very fine-grained, grey rock, a half- to one-inch thick, are interbedded with the slates. These interbeds are very light grey weathering and have a hardness of six. Superficially they resemble quartzite; in thin section the grains are seen to be mainly fresh feldspar (about An_{25}), with some fibres of white mica, actinolite, and chlorite, some carbonate and a little quartz. The interbedded zone is separated from the surrounding slates by a bed of blue limestone about two feet thick. The whole assemblage lies in a syncline plunging north at twenty degrees.

In the next half mile to the northwest outcrops are scattered but the slate beds become more and more intensely folded. With the increase in folding the disruption of the bedding by the cleavage increases until the bedding is completely pulled apart and broken up. Much of the slate in a band running along the west contact of the St. Germain with the Granby group is in such a state along the southern half of this contact. This intense smashing-up of the slates has been interpreted as being due to the thrusting of the St. Germain westward onto the Granby. There is indeed considerable weight of evidence behind this conclusion for this section of the contact, but the amplitude of such a movement is not known. The breaking-up of the St. Germain bedding, in places to form a veritable tectonic conglomerate has been considered as strong evidence of this faulting but such disruption is not restricted to this zone in the St. Germain but is to be observed in a number of places, and in particular in the Rioux quarry near Cowansville where detailed studies are presently underway. In the quarry six to eight inch beds of limestone in slate are recumbently folded and broken-up in places by the deformation into boulders and cobbles of subrounded limestone lying in a matrix of slate. The essential movements in the deformation are of upper material moving westward over lower material to produce the overfolding and disruption. This folding style contrasts markedly with the upright open folds with associated upright slaty cleavage of a clearly later phase of deformation. The earlier phase, at least in part, appears to have been penecontemporaneous with sedimentation, and similar in nature to the penecontemporaneous deformations in the Granby group. Thus the tectonic conglomerates may reflect, rather, crustal unrest in the zone of deposition in the geosyncline, a prelude of the main deformation yet to come, rather than evidence of major thrust faulting.

Pleistocene and Recent

Most of the bedrock of the area is overlain by rather stony ground moraine left by the retreating ice sheet of continental glaciation. In areas never brought under cultivation the surface of the moraine is covered by numerous erratics of all sizes dropped during the final melting of the ice sheet; in cultivated areas these have been collected and dumped along fence lines or in large heaps, usually upon outcrop, if any were available. Large terminal moraines were noted only at one locality a mile or more east of Cleary Station, where the drift, seen in a creek section, is more than 100 feet thick and has a characteristic knob and kettle topography.

The area for about two miles northwest of Brome Lake is flat, swampy, and underlain by clays. It was probably the bottom of a post-glacial expansion of the present lake. The remarkably circular swamp noted under heading Physical Features near the beginning of this report is located in this flat area of clays.

The northwestern corner of the map-area, underlain by slates of the Granby group, is part of a fairly flat plain composed mainly of clays and silts. Extensions of this plain enter the wide preglacial valleys of the Yamaska and North Yamaska Rivers. These clays and silts are Champlain Sea deposits. Large deposits of sand in the North Yamaska River valley below Savage Mills are probably a shore facies of the sediments of this ephemeral post-glacial sea.

Glacial striae are not common in the Shefford map-area, as most of the rocks are soft and easily weathered and eroded. The few found have directions S20°E, and indicate movement from the northwest to the southeast. Chips, pebbles and cobbles of the distinctive red slates of the Granby group are found in the soils and gravels of the southern part of the map-area, and farther to the south in the Sutton region, confirming the evidence of ice movement gained from the glacial striae.

In the eastern part of the map-area and to the east in the Orford quadrangle, a more complicated situation exists. Cooke's attention was first called to it by Mr. Lawrence Purdy of Waterloo who had found boulders of serpentine in that neighbourhood, eight or nine miles west of the nearest exposed likely source of such a distinctive rock. Later a number of glacial striae and grooves were found trending S75°W; roches moutonnées associated with them indicate that the glacial movement was from east to west. Furthermore, these grooves are crossed by striae of the S20°E set indicating that the ice movement from the east was earlier than that from the northwest, instead of being later as has been commonly supposed. The localities where the S75°W striae were found are:

Stukely township:	Range I, about 250' WNW of the railway station;
" " :	Range line VIII-IX, 1 mile east of boundary of Shefford township in roadside outcrop;
Ely township :	Range line X-XI, about 100' east of road, and 50' south of Ely Stukely boundary. Excellent large grooves.
Ely township :	Range X, east side, lot 5, about 300' west of range line IX-X. Excellent large grooves.
Ely township :	1/4 mile south along road from West Ely, then about 300' east.
Ely township :	about 1/2 mile south of Boscobel on outcrops east of road.

At the third locality above, a bulldozer cleared all dirt from a large roadside outcrop which was subsequently washed clean by rain. On this outcrop four sets of striae were observed: the oldest trend S85°W and presumably are part of the S75°W set, as variation from S70° to 80°W were observed in other localities. This set appears to be overridden by a set trending S45°W. The direction of movement along this set was not determined. A still later set trends S10°E, the usual late set, and finally a set trending S50°W cuts all the others.

IGNEOUS GEOLOGY

General Statement

The igneous rocks of the Shefford map-area consist of the metamorphosed lavas of the Tibbit Hill formation, the plutonic masses of the Brome and Shefford massifs, and their associated dyke rocks, and other dyke rocks of unknown age. This last category is represented by a few scattered, generally northeasterly trending, altered dykes in the Paleozoic terrane. The first have been dealt with along with the other formations of the Oak Hill succession. The remainder will be discussed here.

The crystalline rocks of the Brome and Shefford massifs have long since been recognized as intrusions into the surrounding Paleozoic stratified rocks (Adams, 1903; Dresser, 1903, 1906); recently they have been positively dated as Lower Cretaceous in age (Fairbairn et al., 1963). The special alkaline character of these igneous bodies clearly allies them to other bodies to the west which also form prominent topographic eminences, and together comprise the Monteregian Hills petrographic province. The rocks of this province have strong "Atlantic" affinities, and have attracted much attention from petrographers because of their unusual chemical and mineralogical composition, particularly shortly after the turn of the century, but intermittently ever since. The most recent intense research was carried out by Pouliot who studies the nature, structure and thermal history of the feldspars of all the "Hills", and his thesis (1962) contains a bibliography to which the interested reader should refer.

The igneous rocks of Brome and Shefford, varieties of gabbro and syenite, were first studied intensively in the hey-day of what can be called the "species concept" of petrological nomenclature when it was believed that there were a large, but finite number of individual igneous rock types which could be designated by names based on their type locality (e.g. yamaskite), which rock types could be distinguished elsewhere by their mineralogical and particularly their chemical composition. The comparison of chemical compositions was assisted by the conversion of the particular rock composition into a normative mineralogy or "norm". The norm is the chemical composition of the rock expressed in the proportions of simplified standard mineral formulas, i.e. it consists of the artificial assemblage of actual mineral varieties selected because their fixed and generally simple chemical compositions. The norm is derived from the whole rock chemical components by following a standardized set of rules and calculations of considerable complexity. In many cases the norm of a rock is similar or identical to its "mode" or actual mineralogical make-up, but in many more cases it is not for a variety of good reasons; indeed a single norm can arise from a number of distinctive modes depending upon the crystallization history, mineral formation, and late-stage alteration which affect the particular rocks.

The normative system of nomenclature rapidly led to a proliferation of igneous rock names, and the more unusual rock types, such as those making up the Monteregian Hill petrographic province came in for more than their fair share of the new names (e.g. okaite, montrealite,etc.). The system, however, had several serious drawbacks, not the least of which was the fact that it could not be applied in the field as it was based on precise chemical analyses. Furthermore, as analytical techniques improved many earlier analyses were found to be faulty, resulting in some instances the rock of a type locality turning out to be representative of another category named for yet another locality, etc. But the worse fault perhaps was the ever-increasing wave of new names, often based on very insignificant differences in composition. In more recent years a saner and simpler nomenclature based on "familial" lines has prevailed, but parts of the old still linger on, particularly for the more unucual rocks, and thus the names essexite for the gabbros, and pulaskite and nordmarkite for the syenites, have survived in Monteregian nomenclature.

The original essexite from Essex County, Massechusetts is an Alkali-rich gabbro containing modal nepheline. Now nepheline is rare in the modes of the various gabbroic masses of the Monteregian Hills, and does not, for instance, occur in the gabbros of Brome or Shefford. These rocks, however, do contain alkali-rich amphiboles in their normal mineralogical make-up, and this unusual alkali content in the amphiboles is of course reflected in the chemical compositions of the rocks, but under the rules of normative calculation is not reflected in the mineral make-up of the norm, because there is no provision for such complex alkali-rich minerals, and, therefore, the alkali appears as normative nepheline, and justifies the appelation of essexite. To underline this difference from true essexites, Pouliot (1962) recommends that the designation Monteregian-essexite be used for the gabbros.

The varieties of alkali syenites have in the past been given a number of designations: nordmarkite for alkali syenite with some quartz; pulaskite for porphyritic nepheline syenite; laurdalite for a variety of nepheline syenite with rhombic anorthoclase and minor amounts of pyroxene, amphibole or biotite; tinguaite for the dyke-rock equivalent of an aergirine-bearing alkali-syenitic lava, etc., etc.

The nordmarkite and pulaskite varieties of the alkali syenites of Brome and Shefford are the important end members of a sequence of differentiations from an originally-alkali gabbro through a variety of "dioritic" rocks of considerable mineralogical variation.

Mapping of the Brome and Shefford Massifs

Prior to the present study which was largely carried out by Tiphane, the Brome and Shefford massifs had only been studied systematically by Dresser (1903, 1906), who spent several summers mapping the intrusive bodies and studying them chemically and microscopically. A comparison of his maps with the present one of the massifs will show that the mappings are essentially the same with one important difference: whereas Dresser recognized only two principal intrusive lithotypes, the alkaline gabbro or essexite and the alkali syenite or nordmarkite, in the present mapping a third variety termed mica diorite -- hornblende-biotite syenite is also recognized in an attempt to take into account the many outcrops of igneous rock which do not correspond to the generalized descriptions of the main types. The mica diorite -- hornblende-biotite syenite forms a number of bodies of fair size, most of which were mapped by Dresser with the gabbro. In his report he makes no mention of a distinguishable variant, and it follows that if thin sections of the mica diorite-- hornblende-biotite syenite were grouped with those of the gabbro, differences in the descriptions of the latter would be introduced.

In view of the detail in which Dresser's petrographic work was done, little attention was given to the possibility of finding any differences, and, accordingly, only a modest number of specimens for thin section study were collected, and those were from the few localities where fresh material could be readily obtained. It was a matter of some surprise then to find some of the present specimens differing considerably from those described by Dresser. As will be shown below, these differences represent local, but important variations. In the following paragraphs, Dresser's descriptions are fully indicated, and differences found are noted. The Geological Survey of Canada kindly loaned Dresser's thin sections of the Brome rocks, and so provided an opportunity for comparative study.

Since the major part of the field work was completed by Tiphane and Cooke, Pouliot (1962) has carried out a very detailed and thorough study of the feldspars based upon X-ray analyses and petrographic examinations. In the course of his studies Pouliot mapped the massifs of Brome and Shefford in a semi-reconnaissance fashion, and collected numerous specimens for close examination. Unfortunately time did not permit him to make a systematic outcrop examination of the massifs. His petrographic studies, and in particular, some of his map boundaries do not agree with those of the present study, sometimes only in detail, but in others on major points. The present study was more systematic as regards field work, although by no means all the outcrops have yet been mapped, but much less thorough as regards petrographic examinations and interpretations.

It is now obvious from both these recent studies that the gabbros and the syenites are the end members of a continuous and complex series of variants in composition between the two poles, and that many differences in mapping and petrography will arise until a final study is made that is absolutely thorough and complete in all respects. Therefore the present map and descriptions must be considered as preliminary, revealing the broad overall features and discussing some of the variants encountered in the study of these rocks. In the text which follows additions and emendations have been made in the light of the findings of Pouliot (1962) and a few investigations made by Eakins, but no major changes in the original mapping has been attempted, although there are some important differences between the present map and that prepared by Pouliot. These differences will have to be resolved by more detailed work, and until then, it seems inopportune to disturb the unity of the present map: many of the contacts are the result of subjective decisions on the assignment of a particular outcrop lithology to a particular pigeonhole of a varying series, and to attempt to modify these decisions in the light of another's less complete work would be to attempt to meld two subjectivities, an impossible task.

Physical Features

The Brome and Shefford massifs rise in the southern and central parts of the map-area from the eastern edge of the St. Lawrence plain. They are underlain by the easternmost plutons of the Monteregian Hills proper, although the Monteregian type of intrusion is recognized some seventy miles farther to the east in the nordmarkite rim of Mount Megantic. The two massifs are six and a half miles apart from centre to centre, and two and a quarter miles at their closest points. The line joining the centres trends N20°E, or about parallel to the local structural trend of the surrounding Paleozoic rocks.

The Brome massif, the largest by far of the Monteregian Hills, comprises a group of "mountains" which together have a crudely circular outline with a diameter of six miles. These "mountains" are divided into two main ranges by a broad valley trending approximately east-west, deeply dissecting the massif, and occupied by Brome Pond (Elev. 450' above S.L.) and creeks flowing to pond. This valley is about half a mile wide; its elevation drops from 675 feet above sea level at the eastern side of the massif to 350 feet at the western edge where the valley debouches on the Lowland, a distance of five miles. Other narrower, but almost as deep valleys dissect the mountains in various directions. One runs almost due north from Brome Pond nearly to West Shefford with a height of land at 625 feet elevation immediately north of the Pond. In this manner the massif has been dissected into a number of isolated hills or "mountains", some of them not more than a mile in diameter, the heights of the individual hills being more or less proportional to their diameters and areas. The largest mass lies north of Brome Pond and is crudely circular in ground plan and about two and a half miles in diameter; it includes the highest point of the massif, Brome Mountain, which rises more than 1,725 feet above sea level; Spruce Mountain at 1,625 feet, and two unnamed peaks at about 1,500 feet. No other area of the massif rises above 1,300 feet.

The Shefford massif is smaller, crudely rectangular in outline, and three and a half miles from east to west, and two and a half miles from north to south. It has not been dissected to the same extent as the Brome massif, probably because of its smaller size. The eastern end over an area of about half a square mile has been reduced to a level between 950 and 1,000 feet above sea level, and a narrow valley connects this level with a caldera-like hollow about a half mile in diameter in the very centre of the massif. This hollow lies between 950 and 1,100 feet above sea level, and 200 to 300 feet below the general level of the surrounding hills. It drains for the most part to a very narrow and steep valley on the southwest, which is the only other breach of the outer cliffs and steep slopes of the massif. West of the hollow is the highest peak rising about 1,750 feet above sea level; northeast and southeast of the hollow two other peaks rise to about 1,550 feet. Most of the remainder of the crest is 1,200 to 1,300 feet high.

The two massifs are monadnocks which, like the other Monteregian Hills, stand high above the surrounding land because the igneous rocks of which they are composed, and the very hard baked enclosing rocks of their hornsfels collars, and in some cases "caps" have resisted erosion very much better than the surrounding sedimentary rocks.

Petrography of the Brome Pluton

The Brome pluton consists, in the Shefford map-area, of the northwestern "horn" of a crescentic mass of essexite which makes up most the southern part of the pluton in the adjoining Sutton quadrangle, and a much larger mass of alkaline syenite containing smaller areas of mica diorite--hornblende-biotite syenite, a small mass of essexite on the west flank of Brome Mountain, and an area of fine-grained porphyritic rocks of the composition of tinguaite or laurdalite on the east side of the Brome Pond-West Shefford road. Associated dykes are rare.

Monteregian-Essexite

The typical gabbroic rock is an equigranular, medium to coarse-grained aggregate composed essentially of basic plagioclase (An_{65-70}, Pouliot, 1962) and 35-40 percent monoclinic pyroxene with varying smaller amounts of other dark minerals. The rock is dark grey on fresh surfaces, and dull brown on clean weathered ones. Weathering is rapid and deep in this rock, and in open fields the bedrock surface is commonly broken down to an aggregate of almost cubic fragments ranging in size from one-eighth of an inch to one half inch in diameter. Dresser reports that a quarry on the Shefford massif showed weathering to a depth of eight feet. The southern part of the Brome massif is largely covered with a rubble of the type just described, and fresh exposures of unweathered rock are not common.

Dresser termed the gabbros of Brome essexites on the basis of the presence of a few interstitial areas of secondary material, which he states represent nepheline. No explanation is given of what is meant by secondary material. The essential minerals are given by him as basic labradorite with a few large crystals banded by coarse microperthitic intergrowths which he considered orthoclase; pyroxene, olivine and biotite with accessory magnetite, apatite and sphene. Hornblende appears in many parts of the rock in amounts equal to the pyroxene, although in other parts it is altogether wanting. The chemical analysis of his essexite shows only 0.45 percent potash, which would suggest that orthoclase, if present at all, is minute in amount. No orthoclase was seen in their own thin sections of the essexite by the present authors, and Pouliot reports none (1962).

The thin sections lent by the Geological Survey of Canada have resolved the differences between the present determinations and those reported by Dresser very satisfactorily. His essexite sections containing orthoclase, hornblende and biotite all correspond to thin sections of the mica diorite-- hornblende-biotite syenite. If these are set aside, his remaining sections of essexite are identical with the present ones. According to Pouliot (1962) the essexite of the

Brome Pluton is an extremely variable rock in composition which ranges from an olivine-titaniferous augite gabbro through titaniferous augite gabbro to hornblende-augite diorites. The mica diorite of the present mapping thus represents partly the acid end member of Pouliot's essexite series, the hornblende-biotite syenite, and partly the basic end of his alkali syenite series.

Basic plagioclase makes up about 50 percent of the rock with as noted above 35-40 percent monoclinic pyroxene, 0-8 percent olivine, 2-10 percent iron oxides, and minor amounts of red-brown hornblende, prominent apatite crystals, and biotite. The pyroxene is the light-purplish brown titaniferous variety. The iron oxides are often surrounded by kelyphytic rims of biotite, and the olivine is surrounded by alteration products: antigorite and ore, or iddingsite.

As Pouliot (1962) has noted, a mineralogical layering is present in the main mass of the essexite, which dips towards the centre of the pluton at angles of twenty to seventy degrees. This layering may be thin enough to exhibit in hand specimens, but it also occurs in layers up to a hundred feet thick.

Mica Diorite--Hornblende-Biotite Syenite

Six isolated small masses of these intermediate types were mapped on the Brome massif. In contrast to that of the essexite, weathering is very shallow in the mica diorite, penetrating little over an inch. Microscopically the rock is syenitic with varying amounts of hornblende and biotite; the ratio of mafic minerals to feldspars is on the average 1:4. The rock is holocrystalline, and the grains are about an eighth of an inch across, a little smaller than in the essexite or the later syenite.

Thin sections show that the feldspar constitutes about 40 to 60 percent of the rock, including orthoclase and plagioclase some of which has a composition of An_{25}. The other principal minerals are biotite, 25 to 50 percent, altered amphibole, nil to 15 percent, and occasional colourless pyroxene. One section showed zoned feldspar ranging from An_{25} in the core to An_{60} in the outer parts. Accessories are magnetite, apatite, zircon, and sphene, with calcite present in some specimens.

Another variety mapped as mica diorite-- hornblende-biotite syenite is to be seen on the side of the steep hill above the farm on the road immediately east of where the road turns off the Farnham East-Brome Township line in the northeast part of the massif. Here the rock is a light-brown weathering, medium-grained, brown aggregate of feldspar with prominent large unoriented flakes of black mica which form an irregular coarse network on the surfaces of the rock. The texture is panallotriomorphic, inequigranular, composed of large disordered alkali feldspar grains, large, long "moth-eaten" biotite flakes, diopsidic pyroxene, abundant magnetite and large prisms and needles of apatite. Some fine albitic stringers are present. The rock is definitely syenitic rather than dioritic.

North of Gale Pond in the western part of the massif, and in a few places elsewhere, veinlike bodies or tongues of mica diorite cut through essexite. In most of these occurrences the contacts with the essexite are gradational over a width of five or six feet, but one contact was on the other hand quite sharp. These relationships suggest that the mica diorite was injected into the essexite while the latter was still hot and possibly not completely solid.

Brome Syenite (Nordmarkite)

Syenite occupies the greater part of the Brome massif. It is a pale grey, coarsely crystalline rock with some feldspars as much as half an inch across; some sections are finer-grained. The rock is composed essentially of feldspar with varying small amounts of biotite and pyroxene. Thin sections reveal that feldspars comprise 75 to 90 percent of the rock; the feldspar is mostly microperthite, but some albite is present. Biotite commonly makes up to 10 percent of the rock, and is accompanied by pyroxene. Accessories are apatite, sphene, magnetite, occasionally quartz. Dresser reports the presence of hornblende and nepheline.

The syenite is the youngest rock of the series, intruding the essexite, the mica diorite, and the tinguaite (discussed below), as well as the sedimentary rocks. At a few places on Pine Mountain on the eastern side of the massif, hornfels appears to dip under the syenite, whereas other remnants of the metamorphosed sedimentary rocks overlie the syenite.

The weathering of the rock varies with the locality; in the east and northeast part of the massif, the rock at the surface is often very fresh, whereas on the road from West Shefford to Brome Pond the bedrock surface is often covered with a deep rubble of feldspar crystals and small rock fragments, and in such places it is impossible to obtain coherent specimens, let alone fresh ones. The rock is well-exposed and fresh in a small abandoned quarry in the northeastern corner of the massif, and in several places on the adjoining slopes where they have been cleared for skiing. Indeed present-day human activity is generally much improving the outcrop situation as slopes are cleared and new roads built, and old ones are graded with roadcuts.

A large road cut overlooking the northern shore of Brome Pond provides an excellent clean unweathered exposure of the syenite. The rock in the cut is a massive, medium-grained, white and black, holocrystalline aggregate of perthite (70 percent), with small black biotite books (20 percent), abundant (nearly 5 percent) amber coloured millimeter grains of sphene, magnetite and apatite.

Tinguaite or Laurdalite

Tinguaite or laurdalite underlies an irregular area roughly a half mile across in the north-central part of the massif. This area is crossed along its west side by the road from West Shefford to Brome Pond. An abandoned quarry by the roadside affords some good exposures, and there are numerous low exposures in a field on the other side of the road. The rest of the area of the tinguaite contains only moderate good outcrops, many of which have a much fragmented surface.

The rock is generally massive, dark grey, and fine-grained. A few feldspar phenocrysts are present, usually larger and more numerous in the coarser-grained varieties. In places the phenocrysts lie in all directions and give the rock a felted texture. In some of the coarser phases, however, they show a pronounced east-west preferred orientation and a semi-trachytic texture. Under the microscope the rock was found to be exactly as described by Dresser. Large phenocrysts of cryptoperthite with a few smaller crystals of sphene lie in a matrix of fine-grained feldspar with about 10 percent aegirite. A considerable amount of sodalite is present, and one section shows a large crystal of nepheline. Sphene and iron oxides are accessory in the ground mass.

Toward the north the rock is a breccia. This phase is displayed in the roadside quarry. Most of the fragments are less than a quarter of an inch in size, although a few are as large as three-quarters of an inch or larger. In general the fragments are angular, but they vary from somewhat rounded to sharp-angled shards. The matrix is dark, fine-grained, and appears to be a basic lava. Apparently the matrix is not fragmental; this is difficult to judge because of the abundance of fragments. The breccia intrudes the massive tinguaite, includes lumps of it several inches in diameter, and sends off stringers into it. Some of the breccia stringers completely surround pieces of the massive rock.

These relations suggest that the massive varieties are flows with surfaces either naturally rough or more or less broken up by weathering processes. The breccia, poured out on the rough surfaces naturally included any loose fragments and ran into all open cracks.

On its eastern side the tinguaite is associated with a small inlier of metamorphosed quartzite (Gilman ?). Most of the tinguaite here, unfortunately, is of the fragmented type, and its relations with the quartzite could not be ascertained. The presence of the quartzite suggests that the tinguaite was formed on it or was injected as sills and dykes within it as on Mount Royal.

The tinguaite area is completely surrounded by syenite. Dresser failed to find any contacts, and, therefore, believed that the tinguaite was later and either had been injected into the syenite or had broken through it as a volcanic vent or pipe. We were more fortunate, for in several places near contacts the syenite includes pieces of the tinguaite, most of them small, but one, two feet in length by one foot in width, was observed. Again, a little to the south of the foundation of an old building at the quarry, a dyke of syenite 52 feet wide cuts through the tinguaite, striking N75°E and dipping vertically. The south side of the dyke displays a chilled edge three-quarters to one inch wide, in which the normally coarse-grain of the syenite becomes so reduced that the mafic minerals appear only as fine threads less than a tenth of an inch long.

Petrography of the Shefford Pluton

The present mapping of the rocks of the Shefford massif differs considerably from that of Dresser's. The mica diorite -- hornblende-biotite syenite is largely developed underlying more than a third of the whole area underlain by intrusive rocks. Most of this mica diorite -- hornblende-biotite syenite was included by Dresser with his essexite, but a considerable part of it was included with his syenite. It follows that important differences in the petrographic descriptions must result from such a different division of the rock types present. In particular his specimen N_o. 179, "essexite", for which he gives a chemical analysis, and which he treated with Thoulet's solution for the separation of the feldspar, was taken from Morriseau's quarry which lies within the easternmost area of the present mica diorite. Under the circumstances, therefore, it seems hopeless to attempt a correlation between his descriptions and the present ones.

The pluton is essentially made up of irregular masses of mica diorite-- hornblende-biotite syenite and syenite, with a central mass of essexite and another small body of the same rock along the western contact of the pluton. An ill-defined mass of pulaskite, tinguaite, lamprophyres and associated breccias occur on the west central part of the pluton.

Monteregian - Essexite

The Shefford Monteregian-essexite is most commonly an hornblende gabbro, rather less basic than the overall mass of the Brome Pluton. Pouliot (1962) notes the characteristic syenitic differentiates of this rock towards an akeritic and monzonitic composition.

These differentiates are in part included in the present mica diorite-- hornblende-biotite syenite category.

The gabbro is confined to two areas of modest size, one near the centre of the massif, and the other along its western edge west of Coupland Lake. Their combined area is about one-fifth of that underlain by the whole pluton. In general appearance the rock is similar to the essexite of the Brome massif, but here the ferro-magnesian mineral is chiefly hornblende, hastingsite. The essexite of Shefford also contains considerable biotite, which is in sub-ordinate amounts in the Brome rock. It may be noted that the Shefford essexite contains feldspar, hornblende, and biotite as the chief constituents in many sections, as does the mica diorite. It is, therefore, probable that Dresser, who studied Shefford before Brome, saw no reason for considering the mica diorite as anything but a local acid variety of the gabbro. It happens in the present mapping that Brome was studied first, and there the more pronounced difference between the essexite and the mica diorite justified the mapping of the two types as separate units.

The Shefford essexite is made up of basic plagioclase (30 to 40 percent), biotite (25 to 35 percent), amphibole (25 percent), titaniferous magnetite (5 to 10 percent), abundant apatite, sphene, occasional zircon, olivine with altered rims, and rarely a little quartz. The amphibole is the brown strongly pleochroic variety hastingsite. Colourless augite is sometimes also present, and some of it appears to be later than the hastingsite, whereas in other cases it has altered to red-brown uralite or biotite.

A contact phase of this rock with the altered slates was observed by Dresser in a trench dug for an aqueduct conveying water from Coupland's Lake in the northwest corner of the massif to the city of Granby.

"For forty yards from the contact the rock was fine-grained, and about one half of it was made up of black hornblende. By a sharp transition, the rock then became exceedingly coarse for the next thirty yards, and the proportion of hornblende was somewhat increased. The hornblende crystals here are seldom less than half an inch in the smallest dimension. It next returned quite abruptly to the fine-grained type for two hundred and ten yards, when it passed more gradually into the normal type"(Dresser, 1903, p.14).

No sodalite or nepheline were found by us, nor does Dresser mention any except as accessory constituents in the coarser, basic marginal band just mentioned above. Thus this rock is essentially a hornblende gabbro.

Mica Diorite--Hornblende-Biotite Syenite

The mica diorite and its most acid variations of the Shefford massif is similar to the Brome variety, but unlike the latter, is generally as coarse-grained as the other rock types. It underlies a large but most irregular area which constitutes at least one third or more of the pluton. It is a medium to coarse-grained, hypidiomorphic to xenomorphic granular, holocrystalline aggregate of plagioclase feldspar comprising more than 50 percent of the rock, some microperthite, varying amounts of hornblende and biotite, with much apatite, sphene and titaniferous magnetite. Zircon is accessory, and a little chlorite and carbonate are present in some sections. Pyroxene is present in varying amounts in some phases, and one section contains grains of purplish titano-augite surrounded by rims of colourless pyroxene. A reaction between biotite and feldspar to form new feldspar and late magnetite has taken place.

A striking porphyritic contact phase occurs near the summit of the northeastern peak of the Shefford massif and to the southeast down slope where the rock is seen in contact with Gilman hornfels. It is a grey, fine-grained aggregate with large black phenocrysts of titano-augite and less common diopsidic augite and large laths of plagioclase. Large frayed flakes of biotite and coarse grains of magnetite are present in some sections of the rock. The groundmass is made up of plagioclase, alkali feldspar, hastingsite, sometimes some late green hornblende, and grains of magnetite, some with keliphytic rims of biotite. Apatite and zircon are accessory. Pleonaste was seen in one thin section. This rock is a veritable compact mineral collection of the common rock-forming minerals of the Brome and Shefford plutons.

Syenite

This rock, termed nordmarkite by Dresser, has the same granitoid texture and light grey to fawn colour as the Brome syenite. It underlies two areas in the Shefford massif, a large irregular one to the north, and a smaller one along the southern edge. A third, and very small area lies north of Coupland Lake. Altogether about one quarter of the area of the massif underlain by intrusive rocks consists of syenite.

In each area the rock is 90 to 95 percent microperthite composed of exsolved potash and soda feldspar members of the low-albite orthoclase series (Pouliot, 1962); biotite and actinolite constitute the remainder in about equal porportions. Dresser reports the presence in a few stout columnar crystals of colourless augite, some sphene, and in a few places a few grains of quartz. Our sections show only microcline and microperthite in the northern mass of syenite, but in the southern some albite (An_{20}) is also present. Analyses of the feldspar made by T.S. Hunt and quoted by Dresser (1903) show 6.39 percent K_2O and 6.67 percent Na_2O, so that the feldspar probably crystallized as anorthoclase, and its perthitic structure now is due to later unmixing.

Contact phases of this rock, according to Dresser, contain much larger proportions of hornblende, biotite and sphene with subordinate amounts of nepheline.

Pulaskite

Like the tinguaite of the Brome massif, the pulaskite is a dark grey, fine-grained rock for the most part with phenocrysts that do not exceed a quarter of an inch in diameter. It underlies an oval area on the western part of the massif somewhat more than a mile long and half a mile wide. Associated with it is a complex of fine-grained tinguaite and porphyritic black lamprophyres with intimately associated related breccias.

The phenocrysts according to Dresser consist chiefly of orthoclase and plagioclase, with a few of hornblende and widely scattered augite. Orthoclase, he states, is the most abundant in the interior of the mass, whereas plagioclase predominates in the peripheral parts and in the dykes. The plagioclase, our sections showed, is about An_{25} in composition.

The groundmass is also largely feldspar, in narrow laths packed together either in parallel to subparallel arrangement, or, in other places, in a felted mass. Both orthoclase and plagioclase are present. The mafic mineral is chiefly hornblende, and rarely exceeds 10 percent of the mass. In some places a little augite is also present, and Dresser states that in one part of the rock both hornblende and augite are almost wholly replaced by aegirine-augite. Our sections contained from 5 to 30 percent iron oxides. Apatite and sphene are accessory.

Dresser found that the spots characterized by the presence of aegirine-augite also had grains of sodalite as a fairly prominent accessory. None of our sections happened to show this.

According to Dresser, "a large number of dykes" of pulaskite penetrate the syenite, so that the pulaskite is the later intrusion. Our observations reverse this relation. We did not find any dykes of any kind cutting the syenite; on the other hand, near the peak of the mountain we found three dykes of syenite porphyry cutting the pulaskite. One is about ten inches wide; a second, considerably wider, shows narrow stringers of syenite running off into the pulaskite; the third contains a number of inclusions of pulaskite.

Chemical Composition of the Plutonic Rocks

As Dresser's reports are now out of print, and available only in large geological libraries, they are reproduced here in Table IV along with correlations with the rock designations used in the present mapping.

TABLE IV

	1	2	3	4	5	6
SiO_2	44.00	53.15	61.77	65.43	55.68	59.96
TiO_2	1.90	1.52	0.74	0.16	0.60	0.66
Al_2O_3	27.73	17.64	18.05	16.96	20.39	19.12
Fe_2O_3	2.36	3.10	1.77	1.55	2.10	1.85
FeO	3.90	4.65	1.75	1.53	1.95	1.73
MnO	0.08	0.46	0.08	0.40	0.31	0.49
MgO	2.30	2.94	0.89	0.22	0.80	0.65
CaO	13.94	5.66	1.54	1.36	1.92	2.24
Na_2O	2.36	5.00	6.83	5.95	9.18	6.98
K_2O	0.45	3.10	5.21	5.36	5.34	4.91
P_2O_5	0.20	0.65	0.15	0.02	0.06	0.14
CO_2	-	0.39	-	-	-	-
H_2O+) H_2O-)	0.80	1.10	1.10	0.82	1.50	1.10
Rest.	-	0.48	-	0.10	-	0.34
	100.02	99.84	99.88	99.86	99.83	100.17

1) Essexite, Brome Mountain
2) "Essexite" Mica Diorite, Shefford Mountain
3) Nordmarkite, Brome Mountain
4) Nordmarkite, Shefford Mountain
5) Tinguaite (Laurdalose), Brome Mountain
6) Pulaskite, Shefford Mountain.

The Emplacement of the Plutons

In almost all places where good contacts between the intrusive rocks and the enclosing sedimentary rocks can be seen, the contacts are vertical or nearly so. The few patches of sedimentary rocks within the massifs proper are suggestive of parts of original roofs, but may only be large stoped blocks which have sunk into the intruding masses. Only on Pine Mountain on the eastern margin of the Brome massif does it seem reasonably certain that the contact surface is part of the original roof of the intrusive body in that sector. The top of the hill is covered with patches of highly metamorphosed sedimentary rocks, many of which visibly overlie the syenite. In places great slabs, a few hundred feet or more in thickness, dip steeply and are surrounded on all sides by syenite, as if arrested by the consolidation of the intruding magma while in the very process of foundering in it. On the eastern side of the hill (Brome township, Range V, approximately along lot line 21-22) the baked sedimentary rocks immediately overlying the intrusive rock are intensely brecciated and form angular fragments up to two feet across. Mixed with the sedimentary fragments are a smaller number of fine-grained igneous fragments; one coarse-grained igneous fragment was also seen. Apparently the intruding magma advanced in several stages. After the first invasion a chilled margin formed against the cold country rock; a further advance shattered the chilled margin of igneous material and the brittle baked sedimentary rock adjacent to it.

There is no evidence that the intrusions of the plutons have grossly affected the earlier structural trends of the adjoining sedimentary rocks, and even locally the many small-scale structures of the country rock of the intrusions are often unaffected; the plutons are clearly discordant bodies, and could not have made their way by shouldering the country rock aside. Apart from the few patches of sedimentary rocks noted above, xenoliths large or small are very rare in the plutonic rocks, and evidence of assimilation of xenoliths or contact zones of the country rock are even rarer. The plutons must, therefore, have made their way into their present situations by lifting and punching up their cover rocks bodily or by some form of cauldron subsidence with little or no stoping or assimilation, and the complete foundering of the displaced huge blocks.

The aureole of contact metamorphism developed in the adjoining Paleozoic sedimentary rocks by the heat of the intruding magma is one of simple "baking" resulting in the fine recrystallization of the surrounding rocks to form a collar a quarter of a mile wide grading out imperceptibly into unaffected rocks. The "baked" rocks are not noticeably coarser-grained for the most part, but they have become extremely hard and tenaceous, losing any cleavage or parting they may once have had, although the traces of such earlier structures and bedding are usually clearly preserved. There is no evidence of any contact metasomatism caused by emanations from the intruding magmas, and, for that matter, dykes and sills in contrast to the peripheries of some of the other Monteregian plutons, are not at all common, and the few that are seen are thin and limited to a zone close to the main igneous mass. The Brome and Shefford plutons seem to be effectively "walled in" by their hornfels collars.

A peculiar contact metamorphic phenomenon is seen developed preferentially in certain baked beds of the St. Germain Structural Complex on the top of the low ridge west of Gale Pond on the western side of the Brome massif. Here many layers at the flat crest of a broad anticline show an abundance of tiny white oval spots about a sixteenth of an inch across on the average, so that the rock looks for all the world as if it were composed of rice grains embedded in a fine-grained reddish-brown matrix. Under the microscope the spots show no new development of any particular minerals, only the elimination of the reddish stain that pervades the remainder of the rock. The spots appear to be islets heralding the development of new minerals due to contact action, or islets which have resisted contact action that has resulted in the reddish colour.

The various rock-types making up the plutons show chilled margins and porphyritic contact phases against the surrounding country rock, and against one another. From this evidence, and the few dykes to be seen, particularly in the Shefford mass, it is clear that the earliest intrusions were gabbroic, and the intrusions became progressively more acid in time towards syenitic terminal phases. The relative age status of the tinguaite-pulaskite masses is still in doubt, although it appears that they probably are early contact phases of one or another of the main rock varieties.

Such gravitational data as are available indicate that the Brome and Shefford plutons do not join at depth, but probably have smaller vertical to sub-vertical feeding pipes which may flare upwards into crude inverted cone-shaped masses (M.M. Fitzpatrick, personal communication).

As Pouliot (1962) has pointed out, the Brome and Shefford plutons are typical in all respects of masses intruded into the shallower parts of the Earth's Crust, or epizone, and indeed "could be selected as typical examples"(p.18) of epizonal plutons.

The age of the plutons has recently been established by whole rock, Sr^{87}/Sr^{86} methods to be 112 million years old, or Lower Cretaceous (Fairbairn et al, 1963). This age agrees well with the age determined by F.F. Osborne and other workers along strictly geological lines.

Dyke-Rocks in the Paleozoic Rocks

Narrow dykes, a few feet to a few tens of feet wide and up to two miles long, have been mapped in several localities away from the Monteregian plutons. These dykes mainly have a northeasterly trend. The longest, located a half-mile northwest of Granboro in the west central part of the map-area is a fine-grained dark green rock.

The other dykes outcrop east, south, and west of South Roxton; the individual outcrops may in part be segments of one continuous body offset by faults. Here the dyke-rock is porphyritic consisting of highly altered plagioclase feldspars in a fine-grained altered matrix.

On the whole, these dyke-rocks are not similar to most Monteregian dyke varieties, and they are probably older than the Lower Cretaceous plutonism, but there is no concrete evidence in this regard.

STRUCTURAL GEOLOGY

General Statement

At first glance, the structure of the Paleozoic stratified rocks of the map-area would appear to be fairly straight forward; only when the various structural details of a smaller scale than that of the map-area as a whole are considered do a number of serious complications of structure become evident, many of which cannot be readily explained. A first problem, and one of considerable importance, arises out of the present lack of information on the stratigraphic relationships between the major sedimentary groups: information not only about relative ages, but also about original relative positions areally of the various sedimentary lithologies. Specifically we do not know the age of the Granby group, nor whether it is more or less in its original position of deposition, i.e., autochthonous; or whether it has been brought into its present position by gravitational sliding or by thrusting, i.e., allochthonous. Answers to the questions as to age and original position would clarify the structural situation. Conversely, of course, the stratigraphic problems of relative ages and the distributions of various environments of deposition, etc., would be largely solved if the structures were better understood. Considerable time has now been spent in studying the major rock relationships in the Shefford map-area, and it seems unlikely that these problems will be solved by further work in the quadrangle, except perhaps of the most detailed nature, and solutions must await studies made elsewhere in the region, and the results of regional syntheses.

A second problem, and one of more strictly tectonic nature, involves the nature and styles of deformations which have taken place in the rocks. Deformation has been strong, and locally intense and even extreme, as bear witness the torn and fragmented beds, the crumpled, mashed, and cleaved stratification, and the marked thickenings and thinnings of many units. Deformation has, moreover, been highly variable in intensity, both with regard to locality in the map-area, and also with regard to the various rock types: in the Granby group, for example, broad expanses of outcrop reveal beds flat-lying or nearly so, which are little deformed, alternating with narrow zones of intense crumpling and folding wherein the beds are folded into vertical and near-vertical positions, and even overturned and faulted; again in the Granby group, the more massive, thicker beds of sandstone show much less deformation even in the zones of intense deformations than the adjoining shales and thin-bedded sandstone-shale lithotypes; the latter are often complexly deformed with much of their original character and continuity destroyed. Indeed the massive sandstone beds have acted themselves as deforming agents locally giving rise to marked structural inhomogeneity. The contrast between mashed, crumpled shales and nearby massive sandstone beds scarcely deformed if at all internally is striking.

The overall pattern and style of deformation have, however, not been worked out mainly because of the scarcity of large continuous exposures, and because, except within the Oak Hill group, the individual internal stratigraphies of the major groups are not known, and marker horizons have not been established. Furthermore, evidence is accumulating both here and in the adjoining Sutton map-area to show that there has been considerable penecontemporaneous deformation - sliding, slumping, brecciation - in the St. Germain and Granby rocks even before they were subjected to orogenic pressures, but without doubt reflecting unrest at the time of sedimentation. Again a second phase of orogenic folding has followed upon the first: the earlier characterized for the most part by folds facing west with steep to overturned short west flanks and long gently-dipping east flanks in contrast to the open upright style of the later folds. The extent and intensity of the penecontemporaneous deformations and the second phase of folding have not been established, and this further complicates an already complicated situation in the rocks.

The grade of metamorphism is low. It increases slightly towards the east where deformation is somewhat more intense, and certainly no less complicated, than in the rest of the map-area. The greenschist facies of metamorphism is present in the Tibbit Hill formation, the oldest rock unit.

Deformation by compressive stresses has taken place under relatively light lithostatic load in a shallow zone of the Earth's crust: conditions under which local inhomogeneities with regard to the reactions of the lithologies to stress would be marked and lead to much structural inhomogeneity locally arising out of both horizontal and vertical sedimentary variations. With increasing depth, and thus increasing lithostatic load and temperature, such inhomogeneities are slowly minimized, and the deforming stresses tend to dominate in establishing the structural style, rather than the contrasts in sedimentary types, and, furthermore, more secondary structures become penetrative and homogeneously arrayed over great areas throughout all the lithologies present.

Major Structures

The only well-defined major tectonic element in the map-area is the western flank of the Pinnacle Mountain anticline (Eakins, 1964), the crest of which trends northeasterly through the centre of Brome Lake. The Oak Hill strata making up the flank of this regionally important structure are locally intensely crumpled and thrown into vertical attitudes, but overall the formations dip westerly and northwesterly at fairly low to moderate angles of between fifteen and thirty degrees. Cross warps of this flank occur immediately northeast of the Shefford massif, north of Martin Corner, and possibly east of Fulford to the south, so that broad flatlying expanses of various units are present. These cross structures are not clearly reflected in the structural patterns of the adjoining St. Germain and Granby rocks.

The Granby group appears to occur as a broad, locally crumpled plate of intertonguing sedimentary rocks with an overall flat dip in the east and central sections of its extent, and a low overall westerly dip in the western part of the map-area. The most suggestive structure in the area of the Granby outcrop (s.l.) is that of an anticline running from the eastern part of the city of Granby northeasterly through Roxton Pond, but the belt of sandstones flanked by red slates which suggests the anticlinal structure is made up locally of numerous small folds with long low-dipping east flanks and short vertical to overturned west flanks. The effect of such folds, taken by themselves, could produce as one possibility younger and higher strata towards the west; the red slates may belong to different levels of sedimentation. For the rest of the Granby outcrop the map patterns are suggestive of overall low dips, an inference which is in part confirmed by local structural observation. The complexity of the pattern formed by the various lithologic bands could be explained by intertonguing of the various rock units, by folding and low- and high-angle faulting, or both conditions. The outcrop (s.s.) relationships indicate that the combined explanation is the most likely.

The St. Germain Structural Complex contains numerous small folds of different styles, but no overall pattern has yet been discerned. The eastern strata of the St. Germain appear to lie more or less conformably above the Sweetsburg formation of the Oak Hill group, even though there is a considerable hiatus in age between them. Such a relationship is more evident in the Sutton quadrangle.

The relationships of the St. Germain Structural Complex and the Granby group are nowhere clearly and unequivocably in evidence, and numerous possibilities exist of explaining the present areal and local relationships. The Granby sedimentary rocks might be considered autochthonous, i.e., more or less in their original site of deposition, and lying as a group under the St. Germain. The outcrop relationships between the two would then be explained in terms of fairly simple tectonics, with westward thrusting of the St. Germain onto the Granby along the west-central part of the map-area. The southward extending tongue of Granby north of the Shefford massif and the main mass extending south-southwesterly out of the map-area would then be anticlinal in overall nature. Such an interpretation would maintain the gross overall stratigraphic relationships of the major units, but does not explain why the Granby group does not appear between the St. Germain and the Oak Hill. Presumably it could wedge out rapidly eastward either due to original non-deposition or to deposition and subsequent erosion before the deposition of the covering St. Germain rocks. As the distance between the present Oak Hill and Granby outcrops is in places less than a mile the first explanation hardly seems likely; the second has some merit.

Alternatively the Granby group may be considered as allochthonous, or foreign to its present position, which it has achieved by sliding or thrusting-in from somewhere farther to the east. Such an explanation has been put forward with a considerable weight of evidence for similar "foreign" lithologies or allochthones of the Taconic and Green Mountains of Vermont (Cady, 1945), and has long been recognized for the "Sillery" rocks around Quebec City. Henderson in a recent paper (1958) has reviewed the arguments pro and con for such an explanation on a regional basis, and has made a postulate which disposes of most of the arguments against it. A discussion of the regional relationships is beyond the scope of this report, and it will suffice to mention only the bare bones of Henderson's hypothesis in terms of the local context. He postulates in effect, although he does not specifically say so, that the Granby group and related rocks were deposited to the east of their present positions, and in early Middle Ordovician times, before the deposition of the earliest rocks of St. Germain Structural Complex were formed, the Granby rocks were thrust westward into their present geographic position. Folding and uplift in the Oak Hill succession took place at the same time or shortly after the westward emplacement of the Granby, cutting off the mass of the Granby rocks now lying west of the Oak Hill succession and the Sutton anticlinorium axis from their "roots" to the east of the Sutton axis. The rocks of the St. Germain Complex were then deposited on the erosion surface on the Granby group and Oak Hill succession covering the sole fault, and separating the two groups in contact along it, in Middle Ordovician times. The whole assemblage was then caught up in the major Taconic folding phase at the end of the Ordovician to create the tectonic structures presently seen.

In the light of the present state of knowledge of major relationships in the Shefford area Henderson's hypothesis is acceptable. With equal weight however from a local point of view would be an hypothesis suggesting that the Granby group was thrust or slid more or less into its present position after the deposition of the St.

Germain rocks.

Folds

As has already been indicated in the previous section, major fold structures are not well defined in the map-area except for the western flank of the Pinnacle Mountain anticline formed by the Oak Hill succession. This anticline everywhere in Quebec has as its core formation the Tibbit Hill lavas: overall the major fold axis is horizontal and trends consistently N30°E (Cady, 1960), although locally related minor folds plunge gently to moderately to the northeast and southwest. This fold has formed largely by the mechanism of multiple differential movements along cleavage planes which are penetrative on the microscopic scale in most of the rocks of the Oak Hill group. The style of folding in the eastern part of the Oak Hill succession is best seen in the Sutton map-area; locally it consists of closed to isoclinal upright folds which, however, form overall parts of much broader and open structures subsidiary in turn to the main anticline. The small folds developed in the other groups contrast in style with those in the Oak Hill: they are highly asymmetrical west-facing folds with long east flanks and short west flanks. Both styles, however, have similar axial trends and plunges, although the western folds do show a tendency towards a more northerly azimuth in some sections. Asymmetrical east-facing folds of similar style to those facing west are to be seen in several sections of the St. Germain Complex, and in the eastern part of the Granby group.

Minor folds of an open upright type are associated with zones of late vertical cleavage, and are particularly well-displayed in the Granby group in lithologies of alternating thin beds of sandstone and shale. The sandstone layers are often seen warped into tiny folds along the cleavage zones and occasionally disrupted along small faults parallel to the cleavage, whereas the overlying and underlying shale or slate is broken up by numerous vertical planes of slip cleavage. In sections of slate the earlier slaty cleavage is occasionally seen to be broadly warped by this later upright folding.

The extent and development of the late upright folding is not known, and would be hard to discern in any case because it is imposed upon already-folded layers and formations. The swings in the Granby-St. Germain contact north and northwest of the Shefford massif may reflect this later open folding, but it is difficult to prove.

The later folds and cleavages are essentially parallel in trend to the earlier structures, but often locally show a divergence of ten degrees or so. Diamond-shaped patterns on outcrop surfaces resulting from the intersection of the diverging two cleavages have been noted in a few places of favourable exposure.

Minor folds with axial plunges down the dips of the associated cleavages are seen in the Oak Hill succession associated with a mineral lineation in the cleavage in the same direction. Similar steeply-plunging cross structures are seen in the Sutton area: their origin and relationships are still enigmatic.

Cleavages

Cleavages are ubiquitous small-scale secondary structures developed in the shaly and silty rocks and thin-bedded sandstones of the Paleozoic formations of the map-area; they are absent only in the more massive dolomite, limestone and sandstone beds. All varieties of cleavage are developed: slaty, fracture and slip, and it is obvious that the deformations of the rock are closely related to their formation. Only those deformations clearly related to sliding, slumping and brecciation penecontemporaneous with sedimentary deposition are not dependent in some degree on the formation of cleavage.

Two phases of cleavage formation can be discerned throughout the map-area. The earlier is either a slaty or a fracture cleavage; the lithology of the rock determines which variety develops. The cleavages form a remarkable cleavage fan across the map-area unfolding from moderately steep west dips in the eastern part of the map-area to moderately low-angle east dips in the western part. The axis of this cleavage fan trends approximately N25°E parallel to the general trend of the folding. This cleavage fan would seem to indicate that relief to compressive stress was upwards and slightly eastward in the eastern part of the map-area, and became progressively more horizontal and to the west in the western part of the area. In the Sutton area to the south the cleavages consistently dip westward from steep east to west dips in the eastern section of the map-area westward to more gentle dips. No zone of consistently and markedly east-dipping cleavages,such as can be readily observed along Route 1 between the eastern end of the Shefford massif and the eastern outskirts of Waterloo, exists in the Sutton area. The interfering bulk of the Brome pluton and an area of very scarce exposures around it to the east intervene between the two areas of contrasting cleavage dip, and the relationships between the two are not clear.

The later cleavages are almost in all cases slip cleavages, and throughout the area they have vertical to subvertical east or west dips. Their strikes are parallel, or slightly to moderately more northerly of the strikes of the earlier cleavage. They are sometimes clearly distinguishable in the eastern part of the map-area where steep early cleavages have developed, but in other sections they appear to have completely or nearly completely obliterated the earlier cleavage, and in many exposures it is impossible to say which cleavage is present.

With the overall tectonic history of the area so uncertain, as shown in the earlier part of this chapter, it is not possible to relate the formation of cleavages to any particular folding-faulting phase at the present time.

Lineations

With so many fold styles and cleavages it is not surprising that there is no consistent pattern to be discerned in the lineations resulting from cleavage-bedding relationships, either measured directly or calculated from observations of bedding and cleavage orientations in any one outcrop. If rock exposures were of better quality a statistical study of lineations might be very revealing, but such is not the case, and original lithological and structural inhomogeneities obviously play such important roles in the style of deformation that it is fruitless to hope for much insight into the tectonics of the area from a rigorous plot of every linear feature. The Shefford map-area from a structural point of view may be confusing in many ways, but a study of its structures clearly indicates that statistical analysis, rather than simple geologic observation, will probably not succeed in delineating the overall geometry, kinematics, dynamics and history of deformation. That statistical structural analysis has succeeded in many areas is undeniable, but it is not applicable in an area of multiple deformations which took place under relatively light lithostatic loads: the consequent domains of structural homogeneity are too small in relation to the size and quality of exposures.

Tectonic "Conglomerates".

In many outcrops, particularly in the Gilman formation, it is clear that the intense development of cleavages coupled with differential displacements along the cleavage surfaces have resulted in rocks which surficially in most cases resemble sedimentary pebble and cobble conglomerates. Individual beds, from fractions of an inch to many inches thick have been disrupted by the formation of cleavages and then shifted and "eroded" by differential movements so that they appear as isolated masses in a surrounding matrix of different, usually well-foliated, rock. The sameness of the clasts, and the intermediate stages in the development of the totally-disrupted rock reveal the true nature of these tectonic "conglomerates".

They develop in rocks of strong lithic contrasts of bedding: siltstone-shales, limestone or dolomite interbeds in shales, etc.

The differentiation of such clearly tectonic "conglomerates" from those arising out of penecontemporaneous sedimentary deformations is a problem that has yet to be solved.

Cleavage Refraction

The change of attitude of cleavage planes as they pass from one lithotype to another is a common phenomenon, and one which further makes a statistical analysis difficult. The attitude of cleavages is generally lower in shaly members and steepens as the proportion of sandy material increases in a bedding unit. The refraction is sharp when the contact between the differing lithologies is sharp; when shale grades into sandstone over a few inches the cleavage planes curve smoothly from one attitude to the other characteristic of the rock type in the section.

Knick Fold Layers

An unusual deformation of the cleavages of the late St. Germain and Gilman rocks is observed in good exposures, and particularly in road cuts: a pronounced change in attitude of the cleavage for a fraction of an inch to several inches takes place along a well-defined cutting across the fabric of the rock, and in no way related to the stratification. The cleavage planes are not broken, but sharply inflected at the boundary of the layer, and then sharply inflected back to their original attitude at the other boundary. The cleavage dip may be steepened or flattened a matter of about ten to twenty degrees along such zones. The knick zones usually dip from five to twenty-five degrees, and have strikes almost around the compass. Only twelve different occurrences have been found to date; in natural exposures they are difficult to detect because they tend to form the outcrop surface. They are by no means universal, nor penetrative in development on the scale of the average outcrop; many good exposures and road cuts show that they are not present, but they are undoubtedly much more abundant and important than the limited number of observations indicates.

These knick fold layers represent incipient shear planes developing in rocks that can no longer deform by folding because of changes in their mineral make-up and consolidation due to the deformation already sustained. As such zones represent incipient faulting, and if taken in toto the amount of deformation they represent may be considerable.

Faults

On a small scale faulting is seen in many exposures; this faulting has all orientations and displays a variety of separations. Overall, however, no consistent pattern of faults and faulting is evident, even though it must be a prominent mode of deformation in the rocks of the area.

Economic Geology

General Statement

Few showings of metallic minerals have been reported from the Shefford map-area, although economic mineralization is present in the adjoining Orford map-area as for instance at the Huntingdon mine of the Quebec Copper Corporation, three miles south of Eastman. Its most profitable resources, therefore, have been road building and other constructional materials, and undoubtedly such substances will continue to be the most important mineral assets in the map-area.

Copper

A small copper prospect occurs on the property of Mr. E. Gaylor, of Foster, on lot 1133, Brome township, Brome County. The showing consists of weak disseminations of pyrite and minor chalcopyrite in doubly cleaved Tibbit Hill schists cut by irregular quartz and carbonate veins and lenses. At the time the prospect was visited in the summer of 1962, a shallow broad pit had been blasted out of a low knoll without exposing any strong controlling structure or heavy concentrations of sulphides. The showing occurs in the most favourable belt for prospecting in the map-area, underlain by the Tibbit Hill and other formations of the lower Oak Hill succession.

In Roxton township, Range III, lot 22, just beyond the north-east corner of the map-area in the adjoining Orford quadrangle chalcopyrite, bornite and chalcocite occur in sparse disseminations in a white crystalline limestone tentatively assigned to the St. Germain Structural Complex. A pit 45 feet by 27 feet and 6 to 12 feet deep has been sunk on the prospect. Elsewhere in the Orford area mineralization is associated with the various Oak Hill lithologies, so the possibilities of important mineralization in the Oak Hill and St. Germain units of the Shefford map-area should not be overlooked.

Sand and Gravel

Extensive deposits of sand and gravel are present in the area between Brome Lake and Warden. These were exploited some years ago for railway ballast, and are still being drawn upon for road material, concrete aggregate, and other purposes. Other smaller deposits are scattered throughout the area. A large deposit of moderately fine sand fills the valley of the North Yamaska River below Savage Mills. A very large knoll of sand gravel encompassed by a 500-foot contour line occurs a mile northwest of Savage Mills.

Stone Products

The syenite of the northeast corner of the Brome massif has been quarried in a small way for building stone.

On Shefford Mountain two quarries were worked about 1900 presumably for crushed rock.

Small quarries were worked years ago in the red slates of the Granby group west of the city of Granby.

Limy slates similar to those exploited at the Rioux Quarry, Sutton Area, for aggregate may be expected in the St. Germain Structural Complex.

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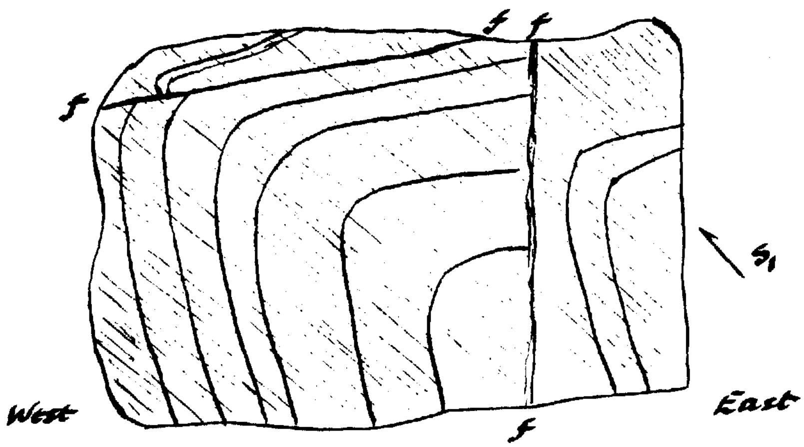

Fig. 2: slightly overturned folds in Granby green slates cut by near-horizontal and vertical faults (ff). The low-angle fault may have had a low east dip and been tipped into its present position by later folding. Southwestern suburbs of City of Granby. Exposure 5 feet high.

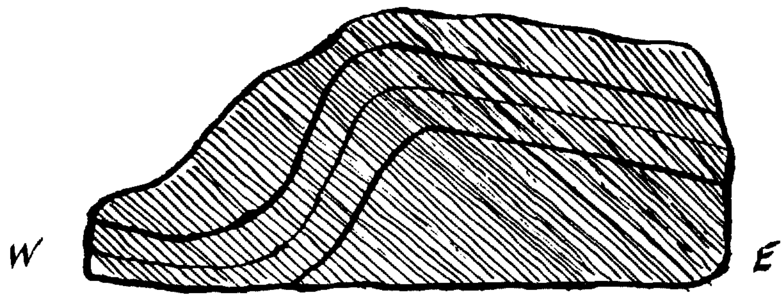

Fig. 3: typical fold in Granby red slates in small quarry west of Granby. Exposure 6 feet high.

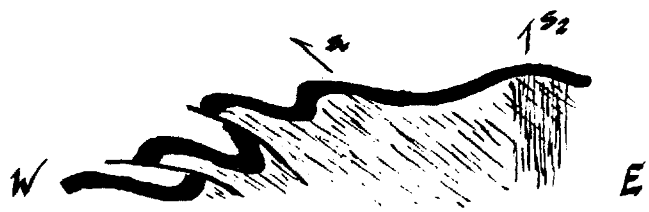

Fig. 4: schematic diagram of structural style in the Granby group.

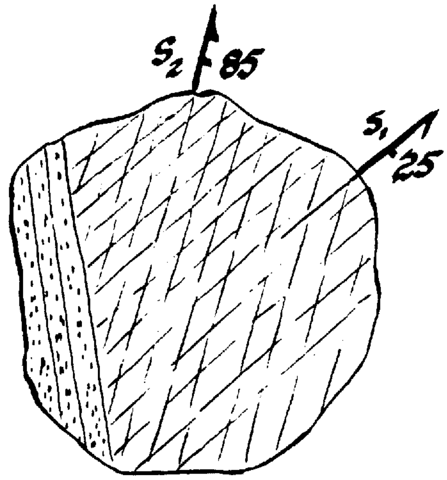

Fig. 5: intersecting earlier (S_1) and later (S_2) cleavages on small outcrop of red slates two miles north of Granby. Exposure two feet across.

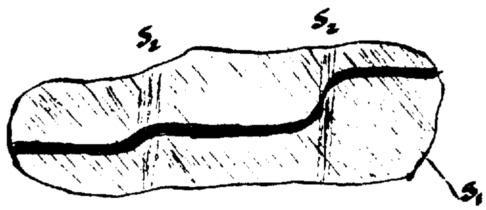

Fig. 6: later cleavage (S_2) cutting earlier cleavage (S_1) and warping bedding in Granby grey slates. Exposure 12 inches long.

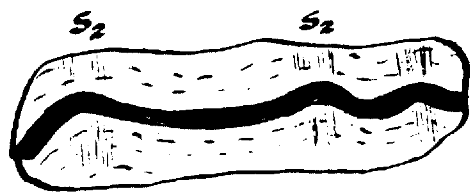

Fig. 7: later cleavage warping bedding in Granby grey sandstone and slate. Exposure 3 feet long.

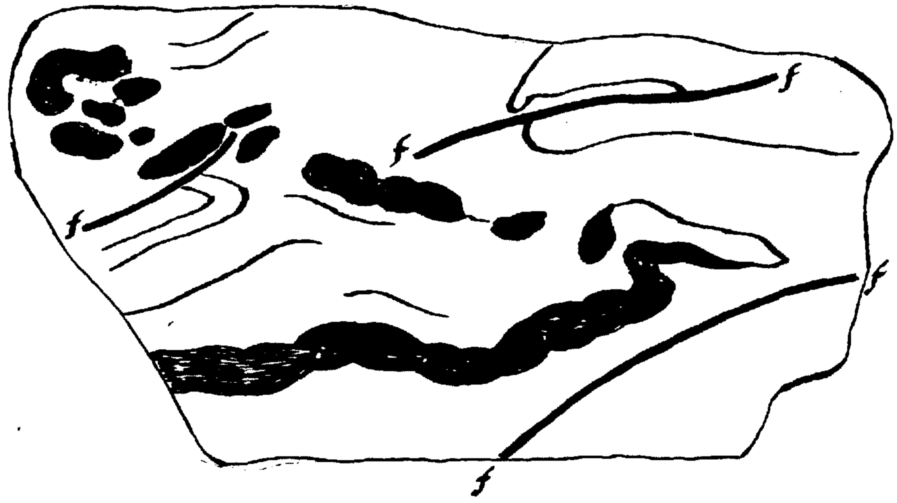

Fig. 8: Highly deformed limestone bed in slates, Rioux quarry, Cowansville. Height of exposure 6 feet. Faults (f-f)

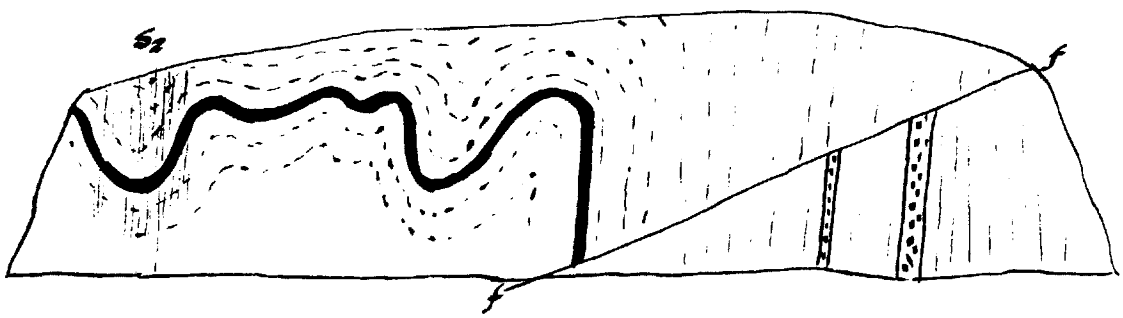

Fig. 9: Folding style in St. Germain Structural Complex northwest of the Shefford massif. Road cut 15 feet long. Late cleavage S_2, fault ff.

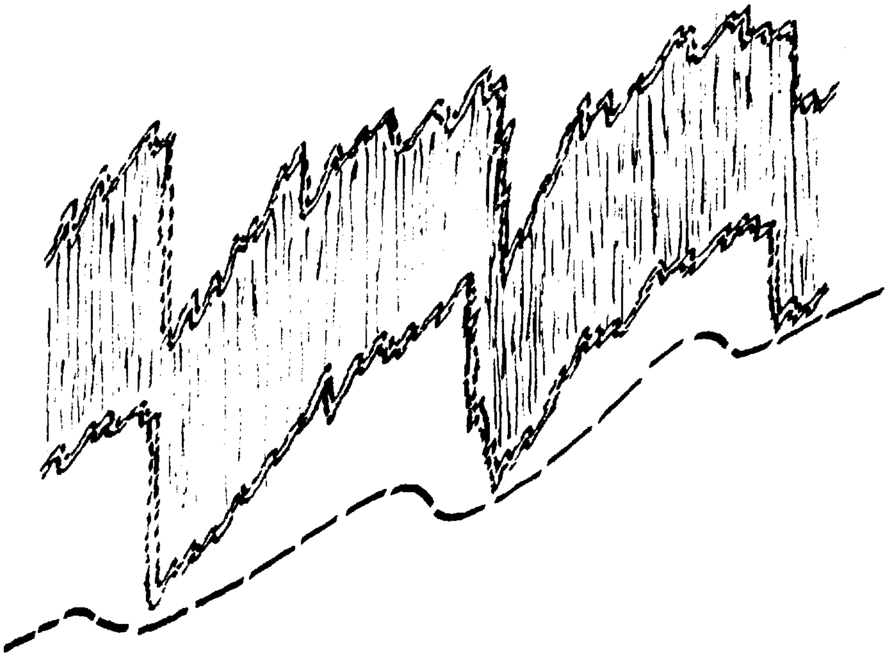

Fig.10: Schematic diagram of folding style in Oak Hill group. Length represented about 300 feet.

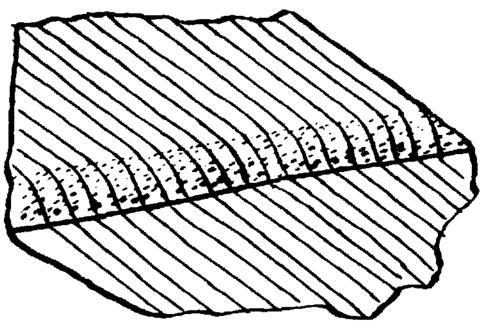

Fig. 11: Cleavage refraction in Granby green slates with sandy basal sections.

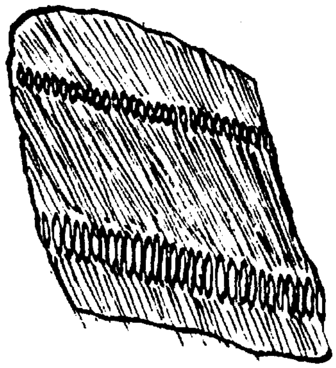

Fig. 12: cleavage refraction and incipient formation of tectonic "pebble conglomerate" in Gilman formation west of Waterloo. Height of exposure 3 feet.

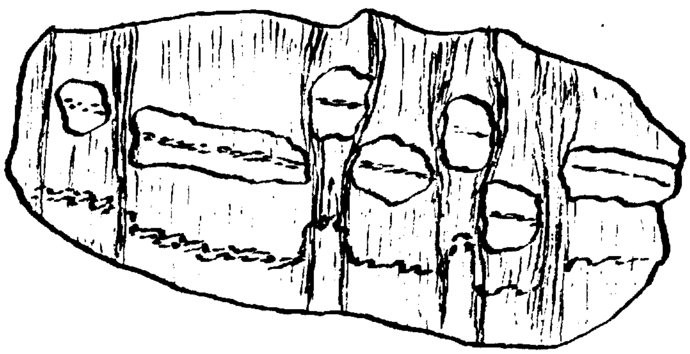

Fig. 13: typical disruption of sandstone layers in Sweetsburg formation. Specimen 1 inch long.

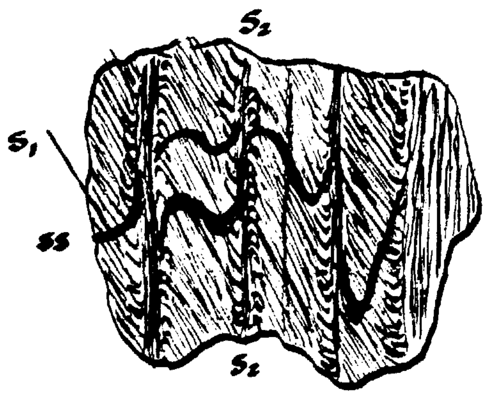

Fig. 14: early and late cleavage in Gilman formation near Warden. Specimen 1 inch across.

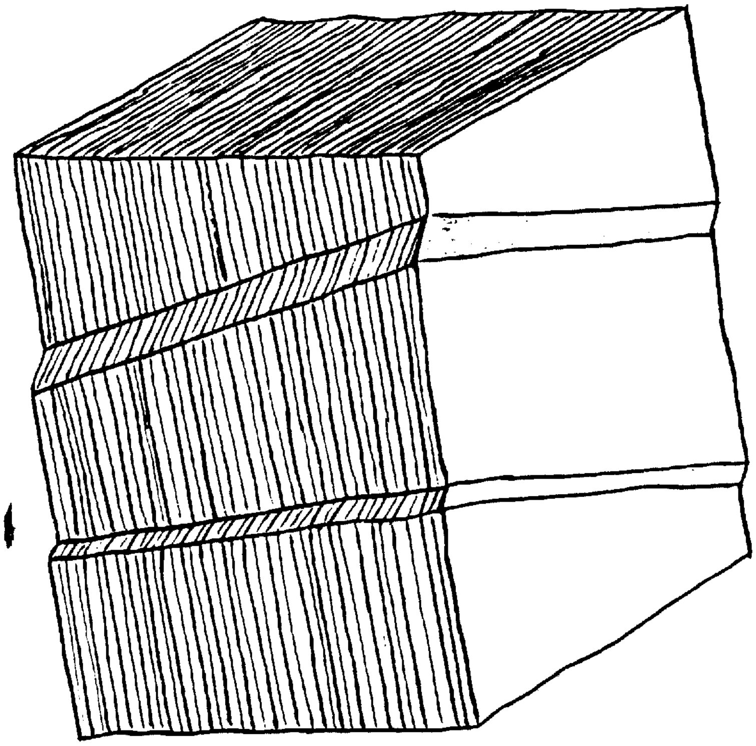

Fig. 15: Knick fold layers in St. Germain Complex west of Gale Pond in road cut. Specimen 1 foot high.