70-28

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 70-28

STRUCTURAL GEOLOGY OF PORTAGE LAKES AREA, BATHURST-NEWCASTLE DISTRICT, NEW BRUNSWICK

(Report, 15 figures, 1 plate and Map 22-1970)

Herwart Helmstaedt

Price, $2.00

1971

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Herwart Helmstaedt

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Ottawa
1971

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ABSTRACT

Polyphase deformed and regionally metamorphosed rocks of the Ordovician Tetagouche Group are unconformably overlain by and in faulted contact with mildly deformed and little metamorphosed Upper Silurian-Lower Devonian rocks. Five stratigraphic units were distinguished in the Tetagouche Group; these indicate the transformation of a relatively stable platform into a highly unstable eugeosynclinal environment. The Tetagouche Group was affected by three penetrative phases of deformation, at least two of them pre-Upper Silurian, i.e. manifestations of the Taconian Orogeny. The first phase was accompanied by a low-grade regional metamorphism and caused a penetrative foliation, which except for some shallow dips in the northern part of the area, has generally steep overall dips. A mineral lineation is locally developed. Mesoscopic folds of the first phase are rare, but the rocks were folded on the macroscopic scale. The second phase of deformation caused microscopic and mesoscopic crenulations of the foliation and bedding and imposed a near-horizontal crenulation cleavage in large parts of the area. Metamorphic recrystallization was minimal. The third phase was least penetrative on the mesoscopic scale but resulted in a regional antiform with a vertical north-northwesterly striking axial surface and a shallow northerly plunge.

A slaty cleavage, the only penetrative secondary structure in the fine-grained rocks of the molasse-type Siluro-Devonian sequence, was formed under nonmetamorphic conditions, probably prior to lithification. Further deformation of the Siluro-Devonian rocks was restricted to brittle faulting and fracturing. At present no definite conclusions can be reached regarding the behaviour of the Tetagouche basement during the deformation of the Siluro-Devonian rocks.

Evidence is presented that the emplacement of the sulphide minerals of the massive sulphide deposits in the Tetagouche Group took place prior to the first phase of deformation of the Tetagouche Group. Possibly applications of structural analysis to exploration in the Bathurst-Newcastle district are discussed.

RÉSUMÉ

Les roches à déformations polyphasées régionalement et métamorphisées du groupe de Tétagouche de l'Ordovicien sont recouvertes en discordance par des roches légèrement déformées et peu métamorphisées du Silurien supérieur et du Dévonien inférieur avec lesquelles elles sont en contact faillé. Cinq unités stratigraphiques ont été distinguées dans le groupe de Tétagouche; elles indiquent la transformation d'une plate-forme relativement stable en un milieu eugéosynclinal très instable. Le groupe de Tétagouche a subi trois phases de déformation par pénétration dont au moins deux sont antérieures au Silurien supérieur, c'est-à-dire qu'elles sont des manifestations de l'orogenèse du Taconien. La première phase a été accompagnée d'un faible métamorphisme régional et a causé une foliation par pénétration qui présente des pendages dominants généralement accentués, sauf quelques-uns peu prononcés dans le nord de la région. Une linéation minérale s'est développée par endroits. Les plis mésoscopiques de la première phase sont rares, mais les roches ont été plissées à l'échelle macroscopique. La seconde phase de déformation a causé des chiffonnages microscopiques et mésoscopiques de la foliation et de la stratification et imposé un clivage par chiffonnages presque horizontal dans de grandes parties de la région. La recristallisation métamorphique a été minime. La troisième phase a été moins pénétrante à l'échelle mésoscopique mais a entraîné une structure anticlinale possédant une surface axiale verticale à direction nord-nord-ouest et un plongement peu profond vers le nord.

Un clivage schisteux, la seule structure secondaire de pénétration dans les roches à grain fin de la séquence siluro-dévonienne du type mollasse, a été formé sous des conditions non métamorphiques probablement antérieures à la lithification. La déformation ultérieure des roches siluro-dévoniennes a été limitée à des cassures nettes et à des ruptures. On ne peut actuellement en arriver à aucune conclusion au sujet du comportement du socle du groupe de Tétagouche au cours de la déformation des roches siluro-dévoniennes.

L'auteur tente de démontrer que la mise en place des minéraux sulfurés dans les gîtes de sulfures massifs du groupe de Tétagouche a eu lieu avant la première phase de déformation du groupe. Les applications possibles de l'analyse structurale à l'exploration du district de Bathurst-Newcastle sont aussi examinées.

STRUCTURAL GEOLOGY OF PORTAGE LAKES AREA, BATHURST-NEWCASTLE DISTRICT, NEW BRUNSWICK

INTRODUCTION

Portage Lakes area is in the northern part of the New Brunswick Highlands, approximately 40 miles west-southwest of Bathurst (Fig. 1) and directly north of Nepisiguit River.

Access to the area is provided by gravel roads of the Bathurst Pulp and Paper Company from Bathurst and of the International Paper Company from Dalhousie, about 40 miles to the north. Within the area a network of lumber and mining roads permits access by foot to all parts of the area on one-day return traverses.

The relief is moderately steep with elevations ranging from 750 feet in the Nepisiguit valley to 2,150 feet at Upsalquitch fire tower. The topography is typical of a rounded, formerly glaciated terrain. Hill tops are normally about 1,000 feet above valley floors. The major streams (Nepisiguit River, Portage Brook, Upsalquitch River) flow in relatively wide, flat-bottomed valleys whose glacial origin is suggested by their marked U-shape. Some of the valleys contain swamps and lakes (Portage Lakes, Upsalquitch Lake). Post-glacial uplift is indicated by the V-shape of the smaller tributaries and the fact that the larger streams have deeply eroded their own gravel deposits. Due to the relatively smooth topography and widespread glacial drift rock outcrops are generally scarce.

The map-area lies in the northwestern part of the Bathurst-Newcastle district which gained enormous economic importance through the discovery of massive base metal sulphide deposits in the Tetagouche Group. Since 1952 at least 26 deposits have been found of which several were brought into production and others are in the development stage. Proven resources of these deposits total well over 100 million tons.

With few exceptions previous geological field studies have been concerned mainly with lithologic mapping and outlining the regional structure. Consequently, the subdivisions of the Ordovician Tetagouche Group recognized at present have only lithologic significance, and a generally recognized stratigraphic succession for the entire Bathurst-Newcastle district has not been established. Little is known about the detailed structural history, especially about the relationship of the sulphide deposits to the structural evolution of their country rocks. While mapping the head of Middle Rivers, Wildcat Brook area (Helmstaedt, in press) in which study mesoscopic fabric elements were given particular attention, it was shown that structural analysis can provide information about the style and sequence of deformation of the Tetagouche Group even in areas with relatively little outcrop. This prompted the continuation of structural studies in the present area.

Original manuscript submitted: 8 June, 1970
Final version approved for publication: 12 June, 1970

LEGEND

Unit numbers refer to those used on Map 22-1970 accompanying this report

MIDDLE DEVONIAN

Gabbro, troctolite, diorite, granite (unit 10)

MAINLY LOWER DEVONIAN

Conglomerates, sandstones, siltstones, volcanic rocks (unit 9)

MAINLY UPPER SILURIAN

Conglomerates, sandstones, siltstones, slates, greywacke (unit 8)

PRE-UPPER SILURIAN

Metagabbro (unit 7)

Metagranite (unit 6)

LOWER TO MIDDLE ORDOVICIAN
TETAGOUCHE GROUP (units 1-5)

Massive basic volcanics (unit 5)

Slates, cherts, andesitic flows (unit 4)

Rhyolites, rhyolitic tuffs, schistose includes some metasedimentary rocks (unit 3)

Quartzites, phyllites, slates, siltstones, greywackes (units 1 and 2)

Geological boundary

Fault

F_1 anticlinorium overturned, approximate location of axis

F_1 synclinorium overturned, approximate location of axis

F_3 anticline, approximate location of axis

F Sil. Dev. syncline, approximate location of axis

F_3 monocline, approximate location of axis

SULPHIDE DEPOSITS

1. Murray Brook deposit (Kennco Explor.)
2. Restigouche deposit (Restigouche Mining Corp.)
3. Devil's Elbow deposit (Devil's Elbow Mines Ltd.)

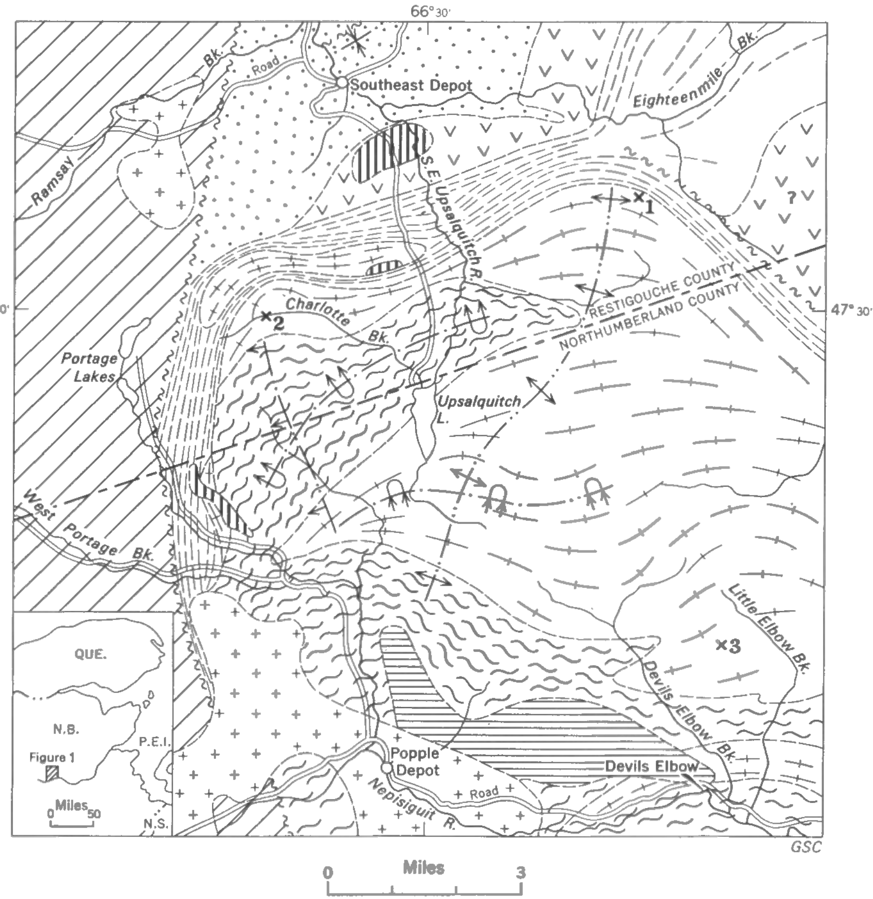

Figure 1. Generalized map of Portage Lakes area, New Brunswick.

Portage Lakes area contains all the major lithologic types of the Tetagouche Group including three known sulphide deposits (Fig. 1). In addition, it provides an opportunity to compare structures in the Ordovician Tetagouche Group with those found in adjacent Siluro-Devonian rocks. Such comparison is important to the attempt of dating the individual structural events in the Tetagouche Group.

References to early geological investigations in the general area are contained in a report by Alcock (1941). Parts of the present area were mapped on various scales by Skinner (1956a, b), Smith (1957), Sims (1961), Jones (1961), Anderson (1962) and Potter (1965). Loudon (1960) discussed the origin of the porphyries in the Devils Elbow area and included a map of that area. Petrographic data on Devonian intrusive rocks in the Portage Brook area, with a detailed map, were presented by Wolfe (1961). In addition, valuable geological information about various parts of the area can be obtained from reports of mining companies in the assessment files of the Mines Division of the Department of Natural Resources, New Brunswick.

Fieldwork was conducted during the summer of 1969 with the able assistance of W. Townsend and J. Gregory. T. Reeves of the Geological Survey of Ireland was attached to the field party during the second half of the summer and contributed to this report through his assistance and stimulating discussions. W.H. Poole helpfully discussed problems in the field and during the preparation of this report. He critically reviewed the manuscript. Valuable information in the form of drill logs and discussions was received from Iain F. Downie and C.M. Rebagliati of the Keevil Mining Group Limited.

REGIONAL GEOLOGY

Three regional geological units have been distinguished by Smith and Skinner (1958) and Davies (1966) in the Bathurst-Newcastle district:

1. The Ordovician folded belt[1], occupying the southern part of district and containing massive sulphide deposits.
2. The Silurian-Devonian folded belt, lying north and northwest of the Ordovician belt and in fault-contact or unconformable contact with it.
3. Flat-lying Pennsylvanian sediments unconformably overlying all older rocks.

The present map-area is situated on the northwest corner of the Ordovician belt and includes part of the Silurian-Devonian sequence to the north and west (Fig. 1).

The Ordovician belt is underlain by an assemblage of sedimentary and volcanic rocks (Tetagouche Group) which were metamorphosed and strongly deformed during the Middle to Late Ordovician Taconian and the Middle Devonian Acadian Orogenies (Skinner, 1956 a, b). Three known sulphide deposits occur in the area within the Tetagouche Group: they are the Restigouche deposit on Charlotte Brook near Portage Lakes (Restigouche Mining Corporation Ltd.), the Murray Brook deposit southeast of Eighteen Mile Brook and west of Camel Back Mountain (Kennco Explorations (Canada) Ltd.) and Devil's Elbow deposit north of Devils Elbow and east of the road to

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[1] The age refers to the rocks forming this belt rather than to the age of folding.

the television tower (Devil's Elbow Mines Ltd.). The rocks of the Tetagouche Group are intruded by dykes and stocks of gabbroic and granitic rocks of pre- and post-Upper Silurian age.

Silurian and Devonian rocks are correlatives of the Chaleur Bay and Dalhousie Groups respectively. They consist of conglomerates, greywackes, and slates interlayered in their upper parts with basaltic and rhyolitic flows and tuffs. These rocks are little metamorphosed and deformed in comparison with the Tetagouche Group.

The contact between the Tetagouche Group and Upper Silurian rocks in the northern part of the present map-area is an angular unconformity. Northeast of the present map-area the Tetagouche Group is separated from the rocks of the Silurian-Devonian sequence by a fault system known as the Rocky Brook-Millstream fault (Davies et al., 1969). The westerly extension of the Rocky Brook-Millstream fault crosses Upsalquitch River about 4 to 5 miles to the north of the Ordovician-Upper Silurian contact in the present area (Potter, 1965; Davies, 1968).

In the western part of the map-area the Ordovician rocks are in faulted contact with rocks of probable Early Devonian age.

Large intrusive bodies of rocks ranging from troctolites to granites and syenites occur within Ordovician as well as Silurian-Lower Devonian rocks and are Early to Middle Devonian in age.

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<tr><td>Middle Devonian</td><td colspan="2">10</td><td>Batholithic intrusions: granite, troctolite, gabbro, diorite</td></tr>
<tr><td colspan="4">intrusive contact</td></tr>
<tr><td>Early Devonian</td><td colspan="2">9</td><td>sandstone, siltstone, conglomerate, basalt, rhyolite</td></tr>
<tr><td colspan="4">fault contact</td></tr>
<tr><td>Late Silurian</td><td colspan="2">8</td><td>conglomerate, sandstone, siltstone, slate, greywacke</td></tr>
<tr><td colspan="4">unconformity</td></tr>
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Tetagouche Group

About three quarters of the map-area is underlain by rocks of the Tetagouche Group. During the present study, these rocks have been divided into 5 rock units which are numbered in what is interpreted as ascending stratigraphic order. In the following a short description of each unit is given and at the end of this section the stratigraphic sequence and age of the group as a whole are discussed.

Unit 1 Quartzites and phyllites

An assemblage of quartzites and phyllites is exposed in the core of what is interpreted as a northeast-striking anticline extending for at least 5 miles from Portage Brook to the north side of Upsalquitch Lake. Near Portage Brook these rocks join a band of similar quartzites and phyllites surrounding and in part forming the roof of a deformed granite in the southern part of the map-area between Devils Elbow and Portage Brooks.

The thickness of this unit can only be roughly estimated and is probably not less than 1,500 feet[1].

The quartzite beds range in thickness from a few inches to one foot and are interlayered with phyllite beds of about equal thickness.

The quartzites are grey, fine to medium grained and generally contain less than 5 per cent detrital feldspar. Locally, especially northwest of Upsalquitch Lake, are beds with more than 10 per cent feldspar. Muscovite and occasionally chlorite occur in narrowly spaced zones which are more or less parallel with the bedding and, where abundant, impart an incipient schistosity to the otherwise massive rock. All gradations from relatively pure quartzite to quartz-muscovite schist can be observed. Quartz veins are common in the quartzite layers.

In thin sections the quartzite is seen to consist of a fine mosaic of recrystallized quartz. Original clastic grains are preserved in places and are highly strained and normally partially recrystallized. Outlines of clastic grains can also be recognized as rounded superindividuals in the granoblastic groundmass. Detrital feldspar is generally too clouded to determine its original composition.

The silvery grey phyllites in places are well laminated and consist of quartz, sericitic muscovite, minor chlorite, some pyrite, and carbonaceous matter.

Unit 2 Slates, siltstones, greywacke

Near Upsalquitch Lake the quartzites and phyllites are conformably overlain by an assemblage of slates, siltstones, and greywackes. The transition from the quartzose to the argillaceous facies appears to be gradational over a thickness of at least 200 feet. In the present area the thickness of this unit varies markedly laterally and probably does not exceed 1,500 to 2,000 feet.

The siltstones are grey-green flaggy, well laminated and interlayered with an approximately equal amount of olive-green to almost black slates

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[1] Thickness estimates are based on outcrop widths combined with the writer's interpretation of the structure.

that have a slight phyllitic sheen. Beds are generally less than 1 foot thick. Bedding is more easily recognized in the siltstones and in many cases is oblique to the dominant cleavage. Graded bedding was recognized locally but recrystallization and crenulation of the cleavage planes tend to obliterate the primary grading and reliable top determinations can only rarely be made. Small crystals of pyrite are especially common in the slates so that upon weathering the rocks acquire a rusty stain. Normally the siltstones are bleached by weathering to a light grey colour.

Beds of poorly sorted feldspathic greywacke have approximately the same thickness as the siltstone beds but are less abundant.

Unit 3 Rhyolitic volcanic rocks

Rocks of predominantly volcanic origin and of rhyolitic to dacitic composition underlie most of the central and eastern parts of the map-area and comprise by far the greatest volume of the Tetagouche Group in this region.

This unit is very diverse and consists of ashfall tuffs, welded tuffs (possible ignimbrites), volcanic flows, and related intrusions, plus some waterlain volcanic and sedimentary rocks. Rapid lateral and vertical facies changes as well as intensive interfingering are apparently common. Most primary igneous and sedimentary features have been obliterated by intensive recrystallization during regional metamorphism. The unit includes the so-called "Bathurst porphyries" which are important as country rocks of the massive sulphide deposits and as such have been the subject of considerable investigation and discussion. A predominantly pyroclastic origin for the porphyries in the Devils Elbow area has been proposed by Loudon (1960).

A conformable contact between units 2 and 3 exists at Charlotte Brook, northwest of Upsalquitch Lake. There, unit 2 contains, in its upper parts, several intercalated volcanic layers. Elsewhere the lower contact of the rhyolitic volcanic rocks is also thought to be predominantly conformable. However, it is likely that this contact was the locus of differential movement during deformation of the Tetagouche Group.

The thickness of the rhyolitic rocks is by no means uniform - values range from nil to several thousands of feet - nor is their lateral extension continuous. Fairly rapid pinching out of volcanic layers can be observed near Portage Lakes and Portage Brook.

Unit 3 is subdivided into two lithologic subunits, 3a and 3b, corresponding to the Siliceous Volcanic Division and Augen Schist Division respectively of Davies (1966). These subunits have no stratigraphic significance.

Subunit 3a. Massive rhyolitic volcanic rocks. Rocks of this unit are fine grained, hard and compact, and in places show conchoidal fractures. Easily visible phenocrysts (>1 mm) are generally lacking. Although the groundmass is sericitized, a schistosity is normally not developed. Colour varies within grey and brownish hues; colour banding can be observed locally. Stilpnomelane has been recognized in some of these rocks.

Although most of these rocks appear to be of tuffaceous origin (Loudon, 1960; Jones, 1964), no distinction can be made in the field between actual volcanic flows and welded tuffs.

Massive fine-grained rhyolitic rocks are more abundant near Devils Elbow than in the remainder of the area. They occur at the margin of a vastly thicker pile in the centre of volcanic activity which was probably situated to the east and northeast of the map-area.

Subunit 3b. Augen schists, quartz-chlorite schists, quartz-muscovite schists. Rocks of this subunit have a much more variable appearance than those of subunit 3a. They all show a well developed schistosity but differ widely in composition and texture. The most common rock type is a quartzofeldspathic schist containing variable amounts of quartz and/or feldspar porphyroclasts (augen). Also grouped with this subunit are chloritic schists with quartz augen, and quartz-chlorite and quartz-muscovite schists without obvious augen. The schists grade into and are intercalated with layers of slate and greywacke which in most cases are too thin to map separately.

The groundmass of the schists is normally completely recrystallized and consists of a mosaic of granoblastic quartz (plus some albite and microcline) and lepidoblastic muscovite and chlorite in varying proportions. Stilpnomelane was recognized in some thin sections. The medium-grained augen (1-5 mm) are remnants of phenocrysts (porphyroclasts). They consist of pink and white feldspar (mostly perthite) and strained and partially recrystallized quartz. Feldspar porphyroclasts are generally somewhat larger than those of quartz. In most cases the longer dimensions of the porphyroclasts are aligned parallel with the schistosity. Disseminated pyrite as well as limonitic stains are common. Sphene, zircon, apatite, and calcite are accessory minerals.

The colour of the rocks varies between brownish and greenish grey.

Some rocks exhibit a gneissose structure, the gneissosity being caused by an alternation of quartzofeldspathic and micaceous (muscovitic and/or chloritic) layers. It is not known whether this layering reflects the original bedding of the rock or is caused by metamorphic differentiation.

Owing to the intensive recrystallization it is often not possible to distinguish between rocks of volcanic and sedimentary origin. However, most of these rocks appear to represent nonwelded tuffs.

Schistose rocks of subunit 3b are more abundant in the present area than the massive flows and welded tuffs of subunit 3a.

Unit 4

Unit 4 contains a variety of rock types (ferruginous and manganiferous slates and cherts, graphitic slates and cherts, andesitic flows and tuffs, minor iron-formation) that because of their close association have been grouped together. This unit can be traced for more than 10 miles from the eastern boundary of the map-area to Portage Brook area (Fig. 1). It varies in thickness between one thousand and several thousands of feet. Rocks of this unit overlie those of unit 3 with generally concordant attitudes, but the actual contact was not observed.

The best marker beds of unit 4 are layers up to about 100 feet thick of red and maroon, banded slates and cherts which are thinly bedded and rich in iron and manganese. Characteristic of these rocks are abundant pink nodules that contain rhodochrosite. Although rarely observed in outcrop such layers can be traced fairly accurately by their distinctively weathering float. Weathered specimens have a brown colour, contain abundant black secondary manganese oxides, and show banding more pronounced than in the fresh rocks. The discontinuous distribution of the manganiferous slates and cherts suggests that they do not form one laterally continuous bed but a series of lenses which are nevertheless in the present map-area bound to a particular stratigraphic level.

The manganiferous slates and cherts are invariably associated and interlayered with light to dark green and purple, commonly vesicular andesitic lavas and tuffs. Individual flows are about 50 to 100 feet thick. These andesites are distinguished from the massive basic volcanics of unit 5 by their generally well developed cleavage or schistosity. Chloritic schists, which are thought to be metamorphosed andesitic tuffs, occur in the northeast part of the map-area and reach a thickness of more than 500 feet.

Dark grey to black graphitic slates, thinly bedded grey cherts, and phyllitic slates are interlayered with the manganiferous rocks and andesites. Locally the slates grade into subgreywacke. Outcrop conditions do not permit an estimate of the relative proportion of the different rock types.

Magnetitic iron-formation was found in contact with fine-grained cleaved andesite in a small outcrop 4,000 feet east-northeast of the sulphide body near Charlotte Brook.

Lenses of limestone conglomerate and grey, coarsely crystalline, bituminous limestone are interlayered with green andesites and phyllitic slates near Eighteen Mile Brook, north of Camel Back Mountain. The bituminous limestone contains crinoid stems, some trilobite fragments, and possible brachiopod fragments (see section on stratigraphic relations, age and origin of Tetagouche Group; see also Sims, 1961, and Skinner, in preparation).

Unit 5 Massive basic volcanic rocks

Massive volcanic rocks of andesitic to basaltic composition overlie the slates and andesitic flows of unit 4 at their northern contact. The contact was not observed and has been interpreted as a fault by Sims (1961). It is marked in part by a morphologic escarpment which, however, may reflect differences in resistance to weathering rather than a fault. The volcanic rocks are unconformably overlain by Upper Silurian conglomerates. The maximum outcrop width of the massive volcanic unit is about one mile, the thickness not less than 2,000-3,000 feet.

The rocks of this unit are dark green, dense and unfoliated greenstones which are generally fine to medium grained. Numerous small fractures are filled with light green epidote. Hematitic stains are common on joints. The normal weathering colour of this rock is brownish grey but near the upper contact reddish oxidation colours can be observed.

The main constituent minerals are albite (which in part appears to be primary), chlorite, and epidote. Actinolite occurs in places and a few crystals of a blue amphibole are present in some of the thin sections studied. The mineral is a member of the glaucophane-riebeckite series and was noticed previously by Skinner (1956; in preparation). Its optical properties are those of crossite. Ilmenite altered to leucoxene is very common. Some sheaf-like aggregates of stilpnomelane occur in the groundmass. Small veinlets contain epidote, albite, some quartz, fibrous golden brown stilpnomelane, and some pumpellyite (?).

The greenstones of the present area show a strong resemblance and are interpreted as a continuous unit with greenstones crossing Tetagouche and

Middle Rivers in the Tetagouche Lake map-area (Skinner, 1956, in preparation; Helmstaedt, in press). Excellent pillow structures in this unit have been exposed recently in a road-cut three miles west of Imhoff, a settlement about 11 miles west of Bathurst. Pillows have not been observed in the present map-area, a fact probably due to lack of outcrop rather than to an absence of pillows. Most, if not all of the greenstones in the present area are thought to be either submarine extrusives or hypabyssal rocks.

Stratigraphic relations, age and origin

Although vital for a sound structural interpretation, the stratigraphic succession of the Tetagouche Group in most of the Bathurst-Newcastle district is still obscure. The reasons are the scarcity of outcrops, the apparent lack of marker beds, and the intense deformation common to the entire Ordovician folded belt. Enough reliable top determinations from graded beds were made in drill cores near Brunswick No. 6 mine to indicate that in this area the steeply dipping strata become younger in a westerly direction (Stockwell and Tupper, 1966; Skinner, 1956, in preparation). However, in the northern and northwestern part of the Ordovician folded belt reliable top determinations are rare and the Tetagouche Group is divided merely on a lithologic basis (Skinner, 1956; Davies, 1959, 1966, 1968; Sims, 1961; Jones, 1961; Helmstaedt, in press). Accordingly, structural interpretations varied: for instance, the large regional fold in the Tetagouche Lake map-area (Skinner, 1956; Helmstaedt, in press) has been variously interpreted as an anticline (Skinner, 1956; Jones, 1964; Tupper, 1969), syncline (Davies, 1966, 1968), or antiform in which the rhyolitic rocks of the core represent the youngest strata (Skinner, in preparation).

The Middle Ordovician age generally assigned to the entire Tetagouche Group in the Bathurst-Newcastle area is based on two fossil localities: graptolites in black slate and chert on the Tetagouche River near Bathurst (Alcock, 1935), and trilobites in limestones near Eighteen Mile Brook north of Camel Back Mountain.

In the present area, the quartzites and phyllites of unit 1 are structurally in the lowest position in the sequence of the Tetagouche Group. Since this by itself does not prove that they are also the oldest rocks of the group this evidence has to be discussed in a regional context. It can be seen that lithologically very similar rocks occur near the Brunswick Mines area (Skinner, oral communication 1969), in the southern part of the Bathurst-Newcastle district in the vicinity of Mullins Stream (Shaw, 1936; Anderson, 1961), and in central New Brunswick (Poole, 1963). In all these localities the quartzites and phyllites are either close to or at the base of the sequence. In addition, Poole (1963) found shelly fossils indicating a Lower or early Middle Ordovician age for the quartzites (Neuman, 1968). The areal distribution of this unit suggests then that an orthoquartzitic assemblage forms the substratum of much of the Bathurst complex, an interpretation that finds further support from the fact that in these widely separated areas (except Brunswick Mines area) the quartzite-phyllite unit is intruded by deformed granitic rocks ("older granites" of Poole, 1967; unit 7 of this report), that are conspicuously absent in the remainder of the Tetagouche Group.

The idea of an orthoquartzitic substratum of the Bathurst complex was advanced by Poole (1967) by projecting northward the evidence from central New Brunswick (Poole, 1963). During Lower and early Middle Ordovician times the Bathurst area was part of a relatively stable platform that at the end of the early Middle Ordovician became the site of a eugeosyncline (see also Poole, 1963).

Oncoming instability in the present area is indicated by the appearance of turbidite-like sediments (unit 2) and the start of volcanic activity (at first mostly rhyolitic) which soon completely overshadowed normal sedimentation (unit 3). Top directions in unit 2 between Upsalquitch and Portage Lakes suggest that the volcanic rocks (unit 3) overlie the sedimentary rocks (unit 2).

Within the rhyolitic volcanics (units 3a and 3b) an age division cannot be drawn with any certainty. Relatively massive welded tuffs and/or flows occur close to the bottom of the sequence in the Devils Elbow area but, although in minor amounts, they appear also higher in the sequence elsewhere. Welded tuffs, flows, and ashfall tuffs undoubtedly were deposited contemporaneously and interfinger with one another. The massive rhyolites form a thicker pile east of the present area where the centre of volcanic activity must have been situated, whereas in the present area schistose rocks (probably ashfall tuffs with varying proportions of sedimentary material) predominate. Loudon (1960), Davies (1966), and Skinner (in preparation) interpret the rhyolitic volcanics at least in part as ignimbritic deposits, and the latter two authors consider them to be the youngest members of the Tetagouche Group.

The ignimbrite problem with respect to the Bathurst-Newcastle district is examined at length by Skinner (in preparation), and only a few aspects will be discussed here. Characteristic of ignimbritic deposits is their spatial connection to metamorphic basement complexes (van Bemmelen, 1963; Ustijev, 1961; McBirney and Weill, 1966), a fact that led many investigators to believe that they originate by large scale melting of siliceous crustal material (McBirney, 1969). Although disputed by Battey (1966) this proposed mode of origin is consistent with experimental evidence (Brown, 1963). The high potassium, alumina, and silica contents of ignimbrites can be explained as a result of fusion of clay- or mica-rich quartzose sediments or metamorphic rocks. The rhyolitic rocks of the Bathurst-Newcastle district are relatively rich in potassium (Loudon, 1960; Davies, 1966) and are spatially related to a proposed but unidentified older metamorphic platform of possible Hadrynian age (Poole, 1967). Therein, as well as in the petrographic characteristics that survived the regional metamorphism, they resemble ignimbrite deposits elsewhere (Loudon, 1960; Jones, 1964; Skinner, in preparation).

However, most rhyolitic rocks recognized as ignimbritic deposits elsewhere in the world are thought to have formed late in an orogenic cycle, i.e. during uplift following the geosynclinal stage of a mountain chain (Rittmann, 1962; van Bemmelen, 1963). This time concept does not fit the Bathurst area where present evidence quite clearly establishes that the rhyolitic rocks are interlayered and interfingered with a sequence of eugeosynclinal sediments and have been deformed together with this sequence. Thus, their deposition took place in an early stage of the Paleozoic orogenic history of this area comparable to the pre-flysch stage of Aubouin (1965).

The pelagic rocks of unit 4 indicate further subsidence of the geosyncline. At present there are not enough data to be certain that this unit is younger than unit 3 in all cases. It is possible that pelagic sediments were deposited contemporaneously with the tuffaceous rocks in the geosyncline.

The black graphitic slates resemble the Middle Ordovician graptolite-bearing slates near Bathurst (Alcock, 1935, 1941) and in central New Brunswick (Poole, 1963). In the latter locality Poole (1963) recognized that the graptolite-bearing black slates are stratigraphically above the red manganiferous cherts and slates in part of the Hayesville map-area. No such rule can be established for the present area. Manganiferous slates are closely associated with andesitic volcanics and probably genetically connected with them (Sampson, 1923). However, they do not consistently lie stratigraphically belos the black slates. A probable Middle Ordovician age for unit 4 is provided by the trilobite assemblage in the bituminous limestone lens near Eighteen Mile Brook. A collection (GSC Locs. 84292 and 84293) by the present writer in 1969 was identified by W.T. Dean of the Geological Survey of Canada (pers. comm., 1969) as: Remipyga? sp.; Illaenus (s.l.) sp.; Proetid gen. et sp. indet.

The massive basic volcanic rocks (unit 5) have been interpreted as Lower Silurian or Ordovician by Sims (1961) and Lower Devonian by Potter (1965), whereas Skinner (1956, in preparation) correlated them with the Tetagouche Group. The writer can confirm Sims' upper age limit as he located the hitherto supposed angular unconformity between the volcanics and Upper Silurian conglomerates in an outcrop 800 feet south of Eighteen Mile Brook approximately 4,200 feet east of the mouth of the brook on Upsalquitch River. From correlation with the massive greenstones at Tetagouche and Middle Rivers (see description of unit 5), which according to the writer's opinion are overlain by the graptolite-bearing slates near Bathurst, it can be concluded that the greenstones in the present area are also of Middle Ordovician age.

The writer concurs with Skinner's view (1956, in preparation) that the greenstones are metamorphosed spilites. The high sodium content (preponderance of albite, much of which appears to be primary, and the sodic amphiboles), high titanium content (leucoxene which is probably altered ilmenite may amount to as much as 20 per cent), pillow structures, and the intimate association with pelagic sediments, especially cherty rocks (Skinner, 1956, in preparation; Helmstaedt, in press) are all criteria of spilitic sequences recognized in other geosynclinal belts (Turner and Verhoogen, 1960). A genetic relationship between the submarine extrusions and the gabbros which have intruded them (unit 6) is considered possible.

In conclusion it can be said that the Tetagouche Group ranges from at least Early Ordovician to the Middle Ordovician. Its sediments and volcanic rocks document the transformation of a tectonically semistable platform into a highly unstable eugeosynclinal belt of a kind comparable to present-day island arcs (Kay, 1951; Mitchell and Reading, 1969).

Pre-Upper Silurian Intrusive Rocks

The Tetagouche Group has been intruded by gabbro and granite which can be found as pebbles in Upper Silurian conglomerates. In contrast to the Middle Devonian intrusive rocks of the area those of pre-Upper Silurian age are deformed and regionally metamorphosed.

Unit 6 Metagabbro

A stock of metagabbro occurs within the greenstones of unit 5 at Upsalquitch River, south and southeast of Southeast Depot. The intrusive contact with the greenstones is exposed in an outcrop on the south side of Upsalquitch River about 2,000 feet southeast of the mouth of Eighteen Mile Brook. Clasts of metagabbro occur in the Upper Silurian conglomerates (unit 8) nearby. The gabbro produces a distinct positive anomaly of about 3,700 gammas on aeromagnetic maps (Geol. Surv. Can., Map 7046 G, Campbellton, 1965).

Where relatively unaltered the medium- to coarse-grained, greenish grey rock consists essentially of green clinopyroxene (45 per cent) and greenish white plagioclase. The clinopyroxene is prismatic (average length 7 to 10 mm) and shows diallage parting. In thin sections it is colourless to light brown. Twinning along (100) is common. The feldspar is labradorite with irregular polysynthetic twins and is interstitial to the clinopyroxene prisms. Accessory leucoxene amounts to as much as 10 per cent of the rock.

In places a crudely defined stratification can be recognized. The long axes of the diallage prisms are aligned in the plane of stratification but have no preferred orientation within this plane. The boundaries between pyroxene-rich and pyroxene-poor layers are gradational.

Alteration varies locally from the development of patchy chlorite to strong saussuritization and uralitization.

Epidote-prehnite alteration was observed in outcrops along the Ordovician-Silurian boundary approximately 2,500 feet southeast of the road between Southeast Depot and Upsalquitch Lake. There the plagioclase is completely saussuritized and large epidote crystals have developed. Much of the saussurite is replaced by prehnite which appears as a fine-grained mosaic and as large crystals. The diallage is highly strained, and it shows kink bands and fractures that are filled with serpentine. Some chlorite, traces of talc, and accessory leucoxene make up the rest of the rock. Zoisite-prehnite alteration in gabbros similar to the one here described was reported from the Baie Verte area in Newfoundland by Watson (1942, 1943).

Small stocks of strongly uralitized and deformed gabbro occur in sedimentary rocks and schistose porphyry west of the road between Southeast Depot and Upsalquitch Lake, 2 miles north of the lake, and in basic volcanics 2 miles south-southwest of Camel Back Mountain.

An elongated gabbroic body north and east of Portage Brook consists of clinopyroxene, some enstatite, completely saussuritized and sericitized feldspar, epidote, chlorite, and accessory apatite and magnetite. The pyroxenes are particularly uralitized. The grain size increases markedly from the margins to the centre of the body, and in places a secondary planar fabric is developed.

Numerous small dykes of gabbroic composition showing various degrees of alteration and deformation as well as a small, strongly altered and deformed dioritic intrusion approximately 1,500 feet southwest of the sulphide deposit at Charlotte Brook were also grouped in this unit.

Unit 7 Metagranite

A body of deformed granite is situated north of the Nepisiguit River between Portage and Devils Elbow Brooks. It has intruded quartzites of the Tetagouche Group along the northern contact, and in the south it is in turn intruded by troctolite of the Middle Devonian intrusions south of the Nepisiguit River. Several patches of quartzite and schist on the granite are interpreted as roof pendants. The northern contact of the granite is more or less conformable with the trend of the foliation (S_1) of the quartzite (unit 1) of the Tetagouche Group.

The major part of this body consists of a fine- to medium-grained, pink granite that in many places has a characteristic sugary texture. It is composed of quartz, cloudy perthitic microcline and some acidic plagioclase. The latter is generally sericitized. Mafic minerals are completely altered to aggregates of fine-grained chlorite and opaque minerals. Biotite is rare, is greenish brown, and of either metamorphic or primary origin.

Some large quartz anhedra are strained, but most quartz is recrystallized. Many of the feldspars are fractured. The fractures are filled with quartz or albite. Albite occurs also as exsolved blebs in potassium feldspar and as separate crystalloblasts. Locally excellent granophyric textures are developed.

The granite is extensively veined by quartz and pegmatite veins, and in places shows a crude cataclastic foliation.

East of Whitebirch Brook the pink granite grades into a darker grey to brownish gneissose variety containing more chlorite and some green biotite.

The granite had been included with the Middle Devonian intrusions of the area (Smith, 1957; Anderson, 1962). However, the deformed nature and the structural conformity with the Ordovician rocks distinguish it from the undeformed and discordant granitic intrusions of Devonian age. From the fact that it intrudes unit 1 of the Tetagouche Group and has been deformed and metamorphosed with the Tetagouche Group the age of the granite can be bracketed between Early to Middle Ordovician and the Late Silurian if the age of the Tetagouche deformational episodes as proposed below is correct.

Silurian-Devonian rocks

Rocks of Upper Silurian to Lower Devonian age occupy the northern and western parts of the present map-area. In the north they unconformably overlie greenstones of the Tetagouche Group; a fault (here referred to as the Portage Brook fault) marks the contact with the Tetagouche Group in the west. Details of the stratigraphic succession of these strata are not yet known. Potter (1965) and Greiner and Potter (1966) correlate several unnamed units of the northern part of the Upsalquitch Forks map-area to subdivisions of the Chaleurs and Dalhousie Groups in the Charlo and Point Verte map-areas that had been established by Greiner (1960, 1965). However, the relationship of these strata to those of the southeastern part of the Upsalquitch Forks map-area – including the present map-area – is uncertain. Fossils in the present area indicate the presence of Upper Silurian (correlatives of the Chaleurs Group) and Lower Devonian (correlatives of the Dalhousie Group)

(Potter, 1965; Anderson, 1962). No significant structural break is apparent in the stratigraphic succession of the Silurian and Devonian though numerous conglomeratic horizons suggest the possible presence of stratigraphic disconformities.

In this map-area there are indications that the strata west of the north-trending fault separating the Tetagouche Group from the Silurian-Devonian sequence are of Lower Devonian age, whereas Upper Silurian strata occur east of this fault in the northern part of the area.

Unit 8 Upper Silurian conglomerates and lithic greywacke assemblage

This unit includes rocks of units 5a and 7 of Potter (1965). It is composed mainly of conglomerates, grit, and lithic greywacke (8a) forming a sequence at least 3,000 feet thick that dips moderately to the northwest between the Silurian-Ordovician contact and Southeast Depot. A sequence containing similar conglomerates folded into an asymmetric syncline occurs along Upsalquitch River northwest of a northeast-trending fault at Southeast Depot (cross-section, Fig. 5).

The grey-green to maroon basal beds of the conglomerate, directly above the unconformity, lack stratification. They consist of coarse, angular to subangular pebbles of the underlying epidote-rich greenstone, metagabbro, various diabases, and some jasper. Higher in the sequence (above about 100 feet) the pebbles are somewhat better rounded and smaller, and clasts of various sedimentary rocks and rhyolites (probably all of Silurian age) become more common. The conglomerate grades upward into massive grits consisting of an argillaceous matrix and abundant medium- to coarse-grained lithic fragments that have no preferred orientation. In places the matrix of both conglomerate and grit is calcareous and the rocks contain numerous brachiopods, crinoids and corals of Ludlovian age (Potter, 1965; pers. comm. A.J. Boucot to Potter, 1965). The fossils are irregularly distributed and apparently not deposited in their living environment.

Provided no major faults occur between the Silurian-Ordovician unconformity and Southeast Depot, there are at least two more conglomeratic layers in this sequence at approximately 1,300 and 1,800 feet above the base (Fig. 5). Both attain a thickness of more than 100 feet and grade upward into grey-green grits followed in turn by lithic greywacke, some slaty siltstone, and slate. Lithic greywacke with characteristic rhythmic bedding was encountered north of Eighteen Mile Brook.

The conglomerate directly north of Southeast Depot resembles the basal conglomerate. Highly immature coarse conglomerates consisting mainly of basic volcanic clasts grade upwards into finer grained conglomerates with more-rounded pebbles. Upward in the sequence conglomeratic sandstones, sandstones, and grey-green siltstones become more common. Milky quartz pebbles which are entirely lacking in the basal beds become relatively common in the finer conglomerates. Clasts of manganiferous slates of the Tetagouche Group are locally encountered and have previously been reported by Potter (1965). Some exhibit a cleavage which is discordant to the cleavage in the matrix of the conglomerate.

Whereas cleavage is generally absent in the conglomerate south of Southeast Depot it is well developed in the folded conglomerates, sandstones and siltstones northwest of the fault at Southeast Depot. Flat and elongated pebbles show an imbrication due to alignment parallel to the cleavage at oblique angles to bedding. Cleavage is refracted where it cuts across beds of different lithology or grain size.

Approximately 3,000 feet northwest of Southeast Depot the conglomerates are faulted against purple and grey-green, banded siltstones (8b) which, in the present area, attain a thickness of about 2,000 feet. Nodules of dark grey, impure, bituminous limestone are common in the banded grey-green siltstones about 2,000 feet south of the mouth of Murray Brook on Upsalquitch River. The strata are steeply inclined and in places contain a slaty cleavage that intersects the bedding obliquely. Since the movement sense of the fault is not known, the age relationship of the siltstones to the conglomerate is uncertain.

Unit 9 Lower Devonian, sandstones, siltstones, conglomerates, interlayered basalt and rhyolite

Strata of mainly Early Devonian age occur west of the Portage Brook fault. They are grey-green to brown, thin- to thick-bedded sandstones and siltstones that contain numerous conglomeratic beds. The conglomerates differ from those of Silurian age in being finer grained and containing numerous well rounded quartz pebbles. The siltstones contain abundant carbonaceous matter and are locally fossiliferous.

The sedimentary rocks are interlayered with thick flows of amygdaloidal basalts, agglomeratic layers, reddish brown spherulitic rhyolite, and pink rhyolitic tuff.

The present division between Upper Silurian and Lower Devonian is based on structural as well as some paleontological evidence. However, it must be regarded as tentative and much more detailed work is needed to determine the exact nature and location of the boundary.

The strata west of the Portage Brook fault are downthrown relative to the Tetagouche Group and Upper Silurian rocks in the east. The Upper Silurian conglomerates are truncated by the fault and the downthrown strata on the west side of the fault are therefore younger than the conglomerates.

Fossils found in the conglomerates and interlayered rocks on the east side of the Portage Brook fault are definitely Upper Silurian (Potter, 1965), but fossils from the west side of the fault are somewhat younger and probably all Lower Devonian. The following localities are known:

GSC Loc. 50899, one quarter mile north of McCormack Brook, about 2 miles west of parish line. Collected by R.R. Potter, identified by A.J. Boucot:
schizophorid
Cyrtina sp.
terebratuloid? sp.
Atrypa "*reticularis*"
Boucot (pers. comm. to Potter, 1965) considers fauna as Dalhousie Formation equivalent, i.e. Lower Devonian.

GSC Loc. 50892, two and one half miles west of Southeast Depot, on road to Budworm City air strip. Collected by R.R. Potter, identified by L.M. Cumming:
Scyphocrinus sp.
Camarocrinus sp.

an inadunate? crinoid related to ? Cyathocrinus
Cumming (pers. comm., 1963) considers this fauna to be Silurian or younger.

GSC Loc. 27576, east of Second Portage Lake. Collected by C.H. Smith, identified by L.M. Cumming:
Leptaena rhomboidalis (Wilchens)
Meristella sp. cf. M. princeps Hall
Spirifer sp. cf. S. cyclopteris Hall
Camarotoechia sp. cf. C. neglecta Hall
Actinopterella sp.
Fenestella sp.
? Pinnatopora
This fauna suggests a Lower Devonian age (Cumming, pers. comm., 1957).

GSC Loc. 37347, from a drill core (D.D.H. Z1, New Jersey Zinc) 1,000 feet east of north end of First Portage Lake. Identified by L.M. Cumming:
Cladopora cf. cryptodens Billings
Atrypa cf. nevadana Merrian
According to Cumming (pers. comm., 1959) the age of this fauna is definitely Devonian and probably Lower Devonian.

GSC Loc. 37911 and 37912, east of Moose Brook (Anderson, 1962). Identified by L.M. Cumming:
Leptostrophia blainvilli Billings
Stropheodonta cf. magnaventra Hall
Actinopteria sp.
Nanothyris sp.
Spirifer sp.
Platyorthis cf. angusta Amsden
Strophonella sp.
Eatonia sp. cf. exserta Amsden
crinoid columnals
Both faunas indicate a Lower Devonian age (Cumming, pers. comm., 1960).

Although it is certain that the strata on the west side of the Portage Brook fault are younger than the Upper Silurian conglomerate, neither the exact age difference is known, nor is it certain whether there was continuous sedimentation across the Silurian-Devonian time boundary. According to paleogeographic maps by Boucot (1969) and Boucot and Johnson (1967) the present map-area was land during the Early Helderbergian (early Lower Devonian) implying the presence of a disconformity between Ludlovian and Middle Helderbergian. Future studies, especially fossil collections at more densely spaced localities, may solve this problem.

Post-Lower Devonian intrusive rocks

Post-Lower Devonian intrusive rocks are of two types:
1) large intrusive bodies of gabbroic to granitic composition (unit 10)
2) various basic dykes (unit 11)

Both types intrude Tetagouche Group rocks as well as the Silurian-Devonian sequence. Most of them are little altered and virtually undeformed. The large intrusions are related to the batholithic intrusions located in the northern New Brunswick Highlands and are considered to be of Middle Devonian age. No upper age limit can be given for the basic dykes. Most are probably also Devonian, but some may be as young as Triassic.

Unit 10 Batholithic intrusions

Most of the rocks belonging to this unit occur in the southwest part of the map-area. They are part of a composite batholith lying mainly south of Nepisiguit River.

Detailed petrographic studies by Wolfe (1961) south of West Portage Brook revealed the presence of a differentiated series ranging in composition from gabbro in the eastern part through a central diorite into granodiorite in the west. For a description of these rocks the reader is referred to Wolfe (1961).

Granitic rocks occur at the chilled western margin south of West Portage Brook and as major body (unit 10a) in the extreme southwest corner of the map-area.

Troctolite (unit 10b) was encountered around Popple Depot. It is a medium-grained rock which in places shows alternating bands of dark grey to black olivine and light grey plagioclase. The banding is vertical in an outcrop east of Popple Depot. On weathered surfaces the olivine has the reddish brown colour typical of troctolites. The troctolite is composed essentially of olivine anhedra (negative 2V) which show incipient serpentinization along fractures, and labradorite which is largely unaltered. Olivine-poor layers contain some interstitial clinopyroxene. Clinopyroxene mantles some olivine. Phlogopite and opaques are accessory minerals. The rocks show an interesting micro-fracture pattern; fractures radiate from olivine crystals into adjacent plagioclase in such a fashion that a network of fractures extends between olivine. Such fracture patterns are known from other troctolites (Read, 1923; Stewart, 1947). They are apparently caused by the expansion of olivine grains during serpentinization and are not the consequence of tectonic deformation. Apart from the incipient serpentinization of the olivines the troctolite is unaltered. Wolfe (1961) reported very little alteration in the gabbros although he noticed a considerable increase in alteration towards the west and southwest in the more acidic parts of the intrusion. None of the rocks, however, exhibits signs of penetrative deformation and it is concluded that the alteration is caused by hydrothermal solutions.

The relationship of the Portage Brook intrusion studied by Wolfe (1961) to the troctolite as well as to the granite in the southwest corner of the map-area is not known. It is possible that the troctolite represents an even more basic member in the differentiation sequence established by Wolfe. Wolfe interpreted the Portage Brook intrusion as a sill that was emplaced along the contact of the Ordovician and Silurian-Devonian rocks. From the present study it appears, however, that it is situated largely within Ordovician rocks and cuts across the strike. Several small dykes of light coloured granite have been seen in the dioritic rocks of the Portage Brook intrusion indicating that the granite in the southwest corner of the map-area may have intruded the differentiated rocks. Hydrothermal solutions connected with this granite could be responsible for the relatively strong alteration in the western and southwestern part of the Portage Brook intrusion.

A somewhat altered, biotite-rich gabbro has intruded rocks of probable Early Devonian age west of the Portage Brook fault between Southeast Depot and Budworm City air strip.

Unit 11 Basic dykes

Narrow diabase dykes are common in the Silurian rocks along Upsalquitch River. They are little altered and apart from joints and some mesoscopic fractures appear undeformed. A rather fresh diabase dyke in rocks of the Tetagouche Group directly south of the sulphide deposit on Charlotte Brook probably belongs to this group. Contact metamorphic effects around these dykes are slight.

METAMORPHISM

Rocks of the Tetagouche Group and the pre-Upper Silurian intrusions have undergone a low-grade regional metamorphism that was synchronous with penetrative deformation (D_1) and resulted in the development of a schistosity in most rocks. On the other hand, the rocks of the Siluro-Devonian sequence underwent a burial metamorphism in the sense of Coombs (1961); they are in general texturally undeformed and metamorphic reconstitution is invariably incomplete. Locally the effects of regional as well as burial metamorphism are overprinted by contact metamorphism related to the Middle Devonian intrusions.

Regional Metamorphism

The main phase of metamorphic recrystallization of the Tetagouche Group and pre-Upper Silurian intrusions was a synkinematic event, i.e. it was accompanied by an episode of penetrative deformation (D_1) and led to a preferred mineral orientation resulting in the formation of a widespread cleavage and schistosity (S_1) and locally a mineral lineation (L_1). Metamorphism continued beyond D_1 as shown by porphyroblasts of stilpnomelane which cut across the foliation but essentially subsided before onset of the second phase of deformation (D_2) during which the stilpnomelane became deformed. During D_2 previously formed metamorphic minerals were plastically strained, and apart from local pressure solution on mineral interfaces, some new growth of mica along cleavage planes (S_2), and limited recrystallization of quartz in fold crests, metamorphic reactions appear to have been negligible.

Metamorphic recrystallization was most complete in the quartzo-feldspathic and pelitic rocks in the central and southern part of the area (units 1 to 3). In the nonporphyritic schistose rocks of unit 3b it virtually obliterated all primary textures so that no definite conclusions about the original nature of the rocks can be made. In porphyritic varieties of the same unit, quartz and feldspar phenocrysts survived recrystallization to a varying degree and are preserved as porphyroclasts whose longer dimensions are aligned in the schistosity. The lenticular quartz porphyroclasts are invariably plastically strained and/or fractured. Incipient recrystallization is

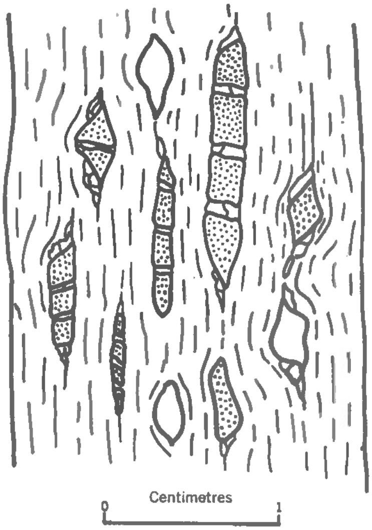


Figure 2. Feldspar porphyroclasts (stippled) fractured perpendicular to lineation (L_1). The fractures are filled with quartz (blank). Quartz-feldspar augen schist, Devils Elbow.

common along the fractures and at the ends leading into the train of recrystallized minerals in the "pressure shadows" of the porphyroclasts. Feldspar porphyroclasts are commonly fractured, the fractures being filled with recrystallized quartz and albite (Fig. 2). Minerals recrystallized in the "pressure shadows" are generally coarser grained than the finely recrystallized matrix. The schistosity is a result of the preferred orientation of muscovite and chlorite.

The following mineral assemblages have been observed:

Quartzites:	Quartz-muscovite (-epidote-albite)
Phyllites:	Quartz-muscovite-chlorite
Metagreywacke:	Quartz-chlorite-albite (-epidote-muscovite)
	Quartz-muscovite-albite-chlorite (-microcline-biotite)
Rhyolitic volcanic rocks, schistose:	Quartz-muscovite-chlorite-albite (-stilpnomelane)
	Quartz-muscovite-chlorite (-stilpnomelane-calcite)
	Quartz-muscovite (-stilpnomelane-chlorite)
	Quartz-muscovite-albite-biotite (-microcline)
	Quartz-chlorite-pyrite

Most of the mineral assemblages are typical of the quartz-albite-muscovite-chlorite subfacies of the greenschist facies (Fyfe, Turner, and Verhoogen, 1958; Turner, 1968). Assemblages transitional to the biotite subfacies occur only very locally.

Biotite is considered by Loudon (1960) to be a relatively common constituent in the porphyries of the Devils Elbow area. This biotite is reported to be brown and not to have the typical greenish colour of low-grade metamorphic biotite (Loudon, 1960, p. 103). The writer found biotite to be rare, however. It occurs in contact metamorphic aureoles of Devonian intrusions and is also found in the deformed granite and adjacent schists north of the Nepisiguit River. In the deformed granite as well as in the adjacent schists it has random orientation and a greenish colour. It is not certain whether this biotite is a product of progressive metamorphism or is a pre-metamorphic relict. Outside the area influenced by intrusions traces of biotite - also with dark green colour and without apparent preferred orientation - have been identified in only two localities: in schists (unit 3b) north of Upsalquitch fire tower, and in a metagreywacke (unit 2) northwest of Upsalquitch Lake. If a product of progressive regional metamorphism the growth of this biotite must postdate the main phase of deformation (D_1).

A mineral easily mistaken for biotite is stilpnomelane which in thin sections has a golden brown colour. It occurs in acidic as well as basic rocks and is invariably a product of mimetic or post-kinematic crystallization. Stilpnomelane appears in the higher grade zone of the prehnite-pumpellyite metagreywacke facies (Coombs, 1960) and is a typical mineral of the chlorite subfacies (Fyfe, Turner, and Verhoogen, 1958). Although not unknown, it is rarely recorded from the biotite subfacies (Turner, 1968; Niggli, 1956; Rost and Stettner, 1969).

In the basic rocks of the northern part of the area (including unit 4, but especially units 5 and 6) metamorphic recrystallization is much less complete and schistosity is weak or entirely absent.

The following mineral assemblages were observed:

Albite-epidote-chlorite-actinolite-leucoxene-calcite

Albite-epidote-chlorite-actinolite-leucoxene (stilpnomelane-crossite-calcite-quartz)

Epidote-zoisite-chlorite-albite ((?) pumpellyite-stilpnomelane-quartz)

Albite-epidote (?) pumpellyite-chlorite-quartz (in veinlets)

Epidote-prehnite-chlorite

Only the first assemblage: albite-epidote-chlorite-actinolite-leucoxene-calcite is typical of the chlorite subfacies of the greenschist facies. In the other assemblages significant departures from normal greenschist facies assemblages are evident. Prehnite and pumpellyite are not stable in the chlorite subfacies (Coombs, 1960, 1961) but are typical of the prehnite-pumpellyite metagreywacke facies, whereas crossite may indicate the higher pressure glaucophane schist facies. According to Winkler (1965) stilpnomelane also indicates a rather high pressure in deeply subsided geosynclines. The large number of phases shows that the assemblages are transitional from the prehnite-pumpellyite metagreywacke facies to the chlorite subfacies of the greenschist facies on one hand, and - if the crossite is not a product of sodium metasomatism - possibly to the glaucophane schist facies on the other hand. Owing to the complexity and overlap of mineral assemblages and the limited attention that could be paid to this problem during the present study it was not possible to outline the areal extent of the different facies.

There are difficulties in comparing the metamorphic grade of the predominantly acidic rocks of the central and southern part of the map-area with that of the basic rocks in the northern part. It is possible, for instance, that the assemblage quartz-albite-muscovite-chlorite is not only stable in the greenschist facies but also in the upper parts of the prehnite-pumpellyite metagreywacke facies (Coombs, 1960). Only very tentative conclusions can be reached therefore from this study. The sporadic occurrence of biotite and metamorphic microcline indicates that slightly higher temperature conditions prevailed during metamorphism in the central and southern part of the area than in the northern part, suggesting that the metamorphic grade decreases upwards in the stratigraphic sequence of the Tetagouche Group.

Burial Metamorphism

Metamorphism of the Siluro-Devonian strata is of a much lower grade and different character than the regional metamorphism of the Tetagouche Group. Whereas penetrative deformation played a decisive role in the metamorphic recrystallization of the rocks of the Tetagouche Group, metamorphism of the Siluro-Devonian rocks was essentially a static process probably caused by the load of the overlying strata. This type of metamorphism was termed burial metamorphism by Coombs (1961).

Textural and mineralogical changes in most rocks are minimal. In the cleaved siltstones along Upsalquitch River illite has not been reconstituted to muscovite indicating the metamorphic grade was below the laumontite-prehnite-quartz zone of the zeolite facies (Coombs, 1960; Winkler, 1965). The clay minerals in the rock (about half chlorite and half illite) were identifield by X-ray diffractometry by R. N. Delabio of the Geological Survey of Canada.

In the coarser sedimentary rocks clastic quartz has not recrystallized to any significant degree. Spherulitic textures in the Lower Devonian rhyolites are excellently preserved and only incipient recrystallization of quartz can be observed. Lower Devonian basalts have a very fresh appearance and some of the amygdules are filled with zeolites.

The survival of assemblages indicative of the lowest grade of metamorphism (heulandite zone of the zeolite facies (Coombs, 1960)) from the Lower Devonian to the present suggests that the sedimentary rocks have never been covered by more than 5,000 metres of rock.

Contact Metamorphism

Narrow contact metamorphic aureoles surround the Middle Devonian intrusions. The scarcity of outcrop precludes outlining exactly the extent of the aureoles, but the width normally does not exceed one half mile. Lower Devonian sandstones and siltstones have been transformed into brown hornfels. Thin sections from rocks approximately 200 yards west of the granite contact in the southwest corner of the map-area show the assemblage quartz-albite-epidote-biotite. A metasedimentary rock of the Tetagouche Group (unit 1) 100 yards from the troctolite contact east of Popple Depot has the assemblage quartz-muscovite-biotite-cordierite-andalusite. Poikiloblastic andalusite and cordierite have overgrown the regional schistosity (S_1) as well as the crenulation cleavage (S_2). Cordierite has also been reported from Ordovician contact rocks on the eastern contact of the gabbro south of West Portage Brook (Wolfe, 1961).

STRUCTURAL GEOLOGY

The map-area straddles the boundary between the regionally metamorphosed intensely deformed Ordovician fold belt (Tetagouche Group) and the only mildly metamorphosed, relatively little deformed Silurian-Devonian fold belt. The structures of each of these units will be described separately. Following this, both units are compared and possible correlations of structures in the two are discussed.

Table I

Table of Fabric Elements in Portage Lakes area, N. B.

		Planar Fabric	Linear Fabric	Folds	Faults
Tetagouche Group	primary structures	s_0 -bedding			
	1st phase of deformation	s_1 -schistosity slaty cleavage phyllitic cleavage	L_1 -mineral lineation elongation lineation intersection s_0/s_1	F_1 -mesoscopic macroscopic	possible thrust faults along lithologic contacts
	2nd phase of deformation	s_2 -crenulation cleavage	L_2 -axes of crenulations intersection s_1/s_2, s_0/s_2	F_2 -crenulation millimetre to metre scale	?
	3rd phase of deformation	s_3 -fracture cleavage crenulation cleavage	L_3 -axes of minor folds microcrenulations	F_3 chevron folds, crenulations, kink bands } microscopic, mesoscopic, macroscopic	faults associated with upwarping
Silurian-Devonian Rocks	primary structures	s_0 -bedding			
	secondary structures	s_1 -slaty cleavage	L_1 -bedding/cleavage intersection	F_1 mesoscopic, macroscopic } rare	
		s_2 -fracture cleavage			high angle faults

Structural Fabric of the Tetagouche Group

Three phases of deformation plus younger faulting were distinguished by the writer (in press) in Tetagouche Group rocks about 20 miles east of the present area in the head of Middle River and Wildcat Brook area. There the first phase (D_1) was accompanied by a low-grade regional metamorphism and resulted in a steep regional foliation (S_1) and a mineral lineation (L_1). The foliation is axial planar to abundant small scale subisoclinal folds (F_1). Major F_1 folds could not be outlined. The second phase of deformation (D_2) caused a crenulation cleavage (S_2) that is less steeply inclined than S_1. Crenulations (F_2) are developed from the millimetre to metre scale and the crenulation axes define a delineation (L_2). Larger F_2 folds are rare. A third phase of deformation caused relatively few minor structures but resulted in a large neutral fold, the Tetagouche Lake anticline (Skinner, 1956) or antiform (Skinner, in preparation).

Three phases of deformation were also recognized in the Tetagouche Group rocks of the present area (Table I). There are variations in orientation of fabric elements and in intensity of deformation, but it is likely these phases are equivalent in both areas.

First phase of deformation (D_1)

The earliest recognizable phase is the main phase of deformation of the Tetagouche Group. Extensive recrystallization during synkinematic regional metamorphism resulted in a penetrative planar and, in places, linear fabric. Folding was the predominant mode of deformation on the macroscopic scale, although it is difficult to outline the folds themselves. Differential movements along lithologic contacts undoubtedly accompanied folding.

Planar fabric (S_1)

The planar fabric is essentially defined by oriented platy muscovite and chlorite. However, the development of this fabric varies greatly with different rock types and degree of recrystallization. Metasedimentary rocks have a slaty and phyllitic cleavage, whereas the pyroclastic rocks exhibit an excellent schistosity. In highly siliceous rhyolites S_1 is only faintly developed and in some is not recognizable at all - at least not mesoscopically. In most of the massive greenstones S_1 is absent.

Porphyroclasts in augen-schist are generally flattened in the plane of schistosity and the phyllosilicate fabric characteristically curves around them. The planar fabric is accentuated by trains of recrystallized quartz extending between the porphyroclasts. Even where porphyroclasts are absent, the orientation of the phyllosilicates is not ideally planar. In many cases micaceous layers describe slightly sigmoidal paths and only their average orientation results in a planar fabric.

Excellent strain markers are vesicles in andesitic flows which are flattened in the plane of schistosity.

The characteristics of S_1 in the ore-bearing horizons will be discussed in the section on economic geology.

Except in fold crests (F_1) the planar fabric is more or less parallel to the lithologic layering. This is especially obvious in the banded metasedimentary series near the base of the Tetagouche Group. Several authors have

Except in fold crests (F_1) the planar fabric is more or less parallel to the lithologic layering. This is especially obvious in the banded metasedimentary series near the base of the Tetagouche Group. Several authors have therefore interpreted S_1 as bedding schistosity or as lithologic layering (Jones, 1964; M.E. Smith, 1967). This, however, is a gross oversimplification of the structure of the Tetagouche Group. Besides the fact that S_1 is axial planar to folds that fold the bedding surface (Fig. 4), transposition of bedding along the schistosity can be abundantly demonstrated in interlayered sedimentary rocks and rhyolitic tuffs in the Charlotte Brook area, northwest of Upsalquitch Lake. In small, little-folded domains, S_1 may be representative of lithologic layering, but maps of larger domains that accurately record the schistosity (S_1) are by no means accurate documentations of the bedding surfaces or lithologic boundaries.

The strike of S_1 varies from northwest to northeast and the dips in most of the central and eastern part of the map-area are moderately steep (Fig. 3b). Since D_1 structures are generally modified by D_2, in many outcrops S_1 has shallow dips which do not represent its mean orientation but are merely on one limb of an F_2 crenulation. The danger of not recognizing the mean orientation is especially great when only small isolated outcrops are available for measurement. Moderate and shallow dips of S_1 (mainly to the north and northwest) are present in the area northwest of Upsalquitch Lake (Fig. 3a). In many cases the outcrop conditions do not permit exact dip measurements and only the strike of S_1 can be obtained.

<u>Linear fabric</u> (L_1)

A mineral lineation (L_1) is best developed near Upsalquitch fire tower but can locally be recognized in other parts of the map-area. It has the characteristics of an extension lineation. Recrystallization trails in pressure shadows of elongated quartz and feldspar porphyroclasts have a definite linear alignment. Feldspars show extension fractures approximately perpendicular to the lineation that are filled with recrystallized quartz (Fig. 2). Quartz veins are rodded in the direction of the lineation.

In the quartzite-phyllite unit (unit 1) an intersection lineation between S_0 and S_1 is developed.

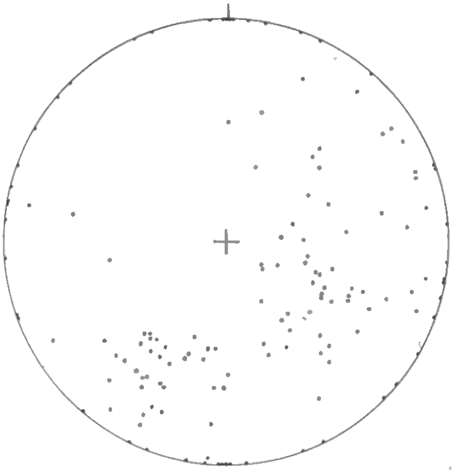
In the field this lineation can be measured exactly only if the S_1 plane on which it appears is not too severely deformed. Since in nearly all cases S_1 is folded the plunge of L_1 changes through the vertical and generally only the azimuth of the strike can be obtained. Not enough measurements of L_1 could be taken during the present study to warrant a statistical plot. If L_1 and L_2 occur together, they are nearly at right angles to one another.

L_1 is much less penetrative in the map-area than in other parts of the Bathurst-Newcastle district (Helmstaedt, in press) because:

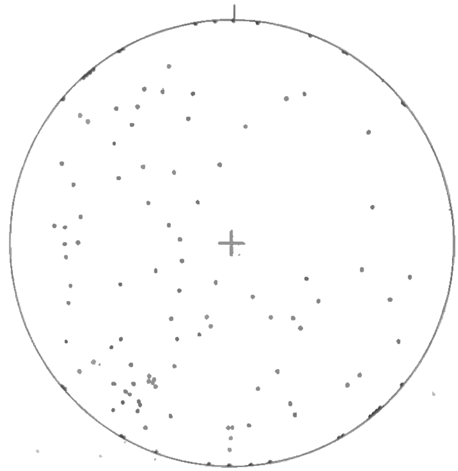
1) In many outcrops the effect of the second deformation is so strong that it may have obliterated earlier linear features. In addition, in places a crenulation lineation (L_3) which is almost parallel to L_1 further obscures L_1.

2) In much of the area L_1 was probably never formed.

The absence of L_1 does not imply a different deformation history, but merely indicates a different response of the rocks to the same deformation (D_1). Flinn (1965; 1967) has shown that in many metamorphic rocks lineation

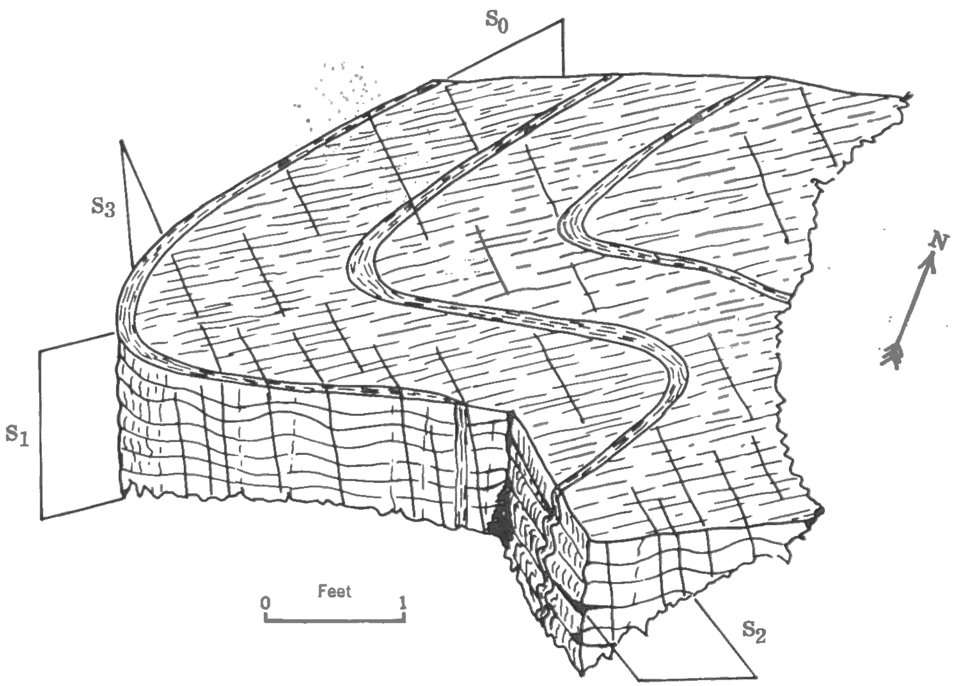


a. 119 poles to S_1
Area northwest of Upsalquitch Lake



b. 104 poles to S_1
Central and eastern part of map-area

Figure 3. Orientation of S_1.



S_0 is outlined by colour banding; S_1 is axial planar to F_1 folds; the crenulation cleavage S_2 is horizontal; and S_3 is the axial plane cleavage to undulations of S_2 (F_3)

Figure 4. Outcrop of folded tuff in Devils Elbow area illustrating relationship of the various planar fabrics.

and schistosity are not two independent structures but one single structure. Variations from planar (S-tectonite) to linear (L-tectonite) fabric can be related to changes in shape of the deformation ellipsoid. In perfect S-tectonites mica poles form a maximum perpendicular to an ideally planar schistosity. The strain configuration is that of an oblate ellipsoid with the short axis perpendicular to the plane of schistosity (flattening). A lineation is not developed. In perfect L-tectonites mica poles form a great circle girdle whose axis is the lineation. The strain ellipsoid is prolate, the long axis being parallel with the lineation (constriction). A schistosity cannot develop. In common L-S-tectonites the mica fabric is a partial great circle girdle, consequently both a schistosity and a lineation can develop. The strain ellipsoid is triaxial, the longest axis being parallel with the lineation and the shortest axis perpendicular to the schistosity. The intermediate axis is either shortened or elongated, depending on whether the fabric approaches the L- and S-type respectively.

The rocks of the present area are L-S and S-tectonites. Typical L-tectonites have so far not been discovered.

<u>Folds</u> (F_1)

Mesoscopic folds of the first phase of deformation are rare and not immediately obvious in the field. This is why the tectonic nature of S_1 has not always been recognized. Folded quartz stringers with S_1 as axial plane cleavage are relatively common, but folds that deform S_0 such as on Figure 4 are rarely observed in outcrops even when potential marker horizons are present. Such lack of folds indicates relatively homogeneous deformation within individual lithologic units.

The lithologic distribution on the present map indicates folding on the macroscopic scale during the first phase of deformation. The quartzite-phyllite unit (unit 1) forms the core of a northeast-striking anticline (Upsalquitch Lake anticline) that is overturned to the south (cross-section on Fig. 5) and has an overall northeastward plunge. The core of a complex syncline following to the south is occupied by schistose tuffs and rhyolitic rocks (unit 3). The quartzite-phyllite unit is exposed again on the south limb of this syncline where it is intruded by deformed granite (unit 7). Modification by later phases of deformation (D_2 and D_3), especially smaller scale F_2 folds, do not change the overall geometry of the macroscopic F_1 folds, but complicate the outcrop pattern.

The folding on the macroscopic scale of the larger units was probably accompanied by the development of slip surfaces ("bedding shears") along major lithologic contacts. Evidence for relatively low-angle thrusting on the northwest limb of the Upsalquitch Lake anticline are brecciated horizons along the sediment-porphyry contacts that are cemented with milky quartz. The existence of such thrusts has been recognized in other parts of the Bathurst-Newcastle district and was demonstrated to the writer by D. Rutledge during a visit of the Brunswick Mining and Smelting Corporation Ltd. No. 12 mine. There, massive sulphides and adjacent sedimentary rocks are separated by a thrust fault on which it is difficult to estimate the amount of displacement. The correlation of this structure to the first phase of deformation is based on the fact that the thrust plane has been folded by F_2 folds which are considered to be equivalent to the F_2 folds of the present area.

Thrusting probably took place also along the contact of the sediments (unit 4) with the massive greenstone unit (unit 5).

Second phase of deformation (D_2)

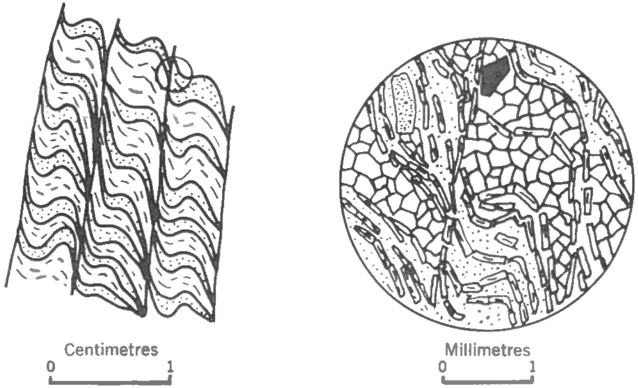
Structures formed by the first phase of deformation are almost invariably modified and in places obliterated by second generation structures. Although of a very penetrative nature, the second structures, however, do not contribute as much to the regional geometry as the first phase structures. The second structures must be regarded as superimposed structures that complicate the pattern established during the first phase of deformation. D_2 took place under considerably lower temperatures than D_1. Minerals show extensive plastic strain, and annealing has occurred only locally. Crystallization of new minerals is restricted to limited growth of muscovite and chlorite along S_2 planes. Quartz in crests of folded quartz stringers is only partly recrystallized.

Planar fabric (S_2)

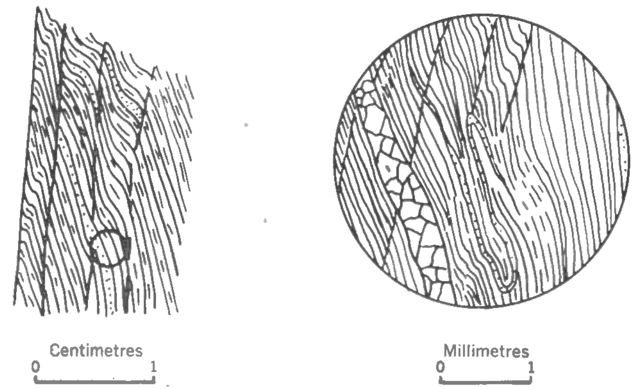
In schistose rocks S_2 is a widespread crenulation cleavage. Normally it intersects S_1 at oblique angles and is readily recognizable as a cross-cutting structure. In some rocks, however, S_1 is almost completely transposed along S_2 so that the latter becomes the dominant S-surface of the rock. In such cases S_2 can be misidentified as S_1. In the field S_2 can also be mistaken for S_1 or even S_0 (bedding) in homogeneous rocks which have only a weakly developed S_1. In some of the metasiltstones (unit 2) northwest of Upsalquitch Lake, S_2 is defined by dark narrow surfaces that can be misidentified as primary compositional layering. In most cases thin section studies on oriented samples helps to identify the S-planes. Figure 6 illustrates the various possibilities and may aid in the identification of the different planar fabrics.

The spacing of S_2 varies in different rock types. Generally it is more widely spaced than S_1 although not in some of the metasediments. In the porphyries the average distance between two mesoscopically visible S_2 planes varies between 5 to 10 millimetres. In such samples there are, however, more narrowly spaced microscopic cleavage planes. In mesoscopic folds the distance between cleavage depends on the thickness of the folded competent layers and becomes larger with increasing thickness of the folded competent layers. S_2 does not transect thick competent units and is also not immediately obvious in massive sulphide horizons (see section on economic geology).

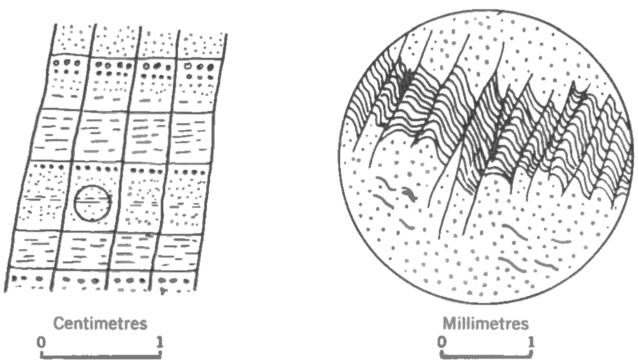
The orientation of S_2 can be seen on Figure 7. Dips are generally shallower than those of S_1. Three subareas can be recognized in which the orientation is relatively homogeneous. The first is the area around Devils Elbow where S_2 has shallow to moderate dips to the southeast (Fig. 7c). Large areas around Upsalquitch fire tower have an almost horizontal crenulation cleavage, whereas in the western part moderate to steep dips to the west and northwest are prevalent (Fig. 7a, b). It will be shown below that this systematic change in orientation is probably caused by the third phase of deformation.



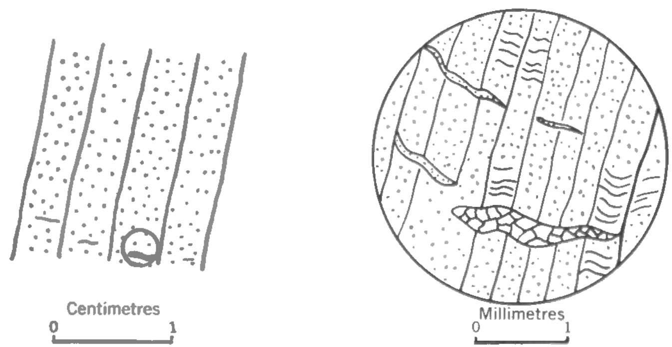
a. $S_1 \wedge S_2$ oblique; S_1 and S_2 are easily distinguished



b. $S_1 \wedge S_2$ small to zero; S_1 may be transposed along S_2

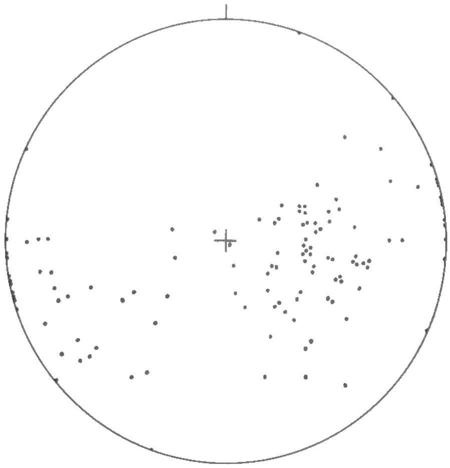


c. $S_0 \wedge S_2$ large; S_1 faintly developed and mesoscopically difficult to recognize; S_2 can be mistaken for S_1

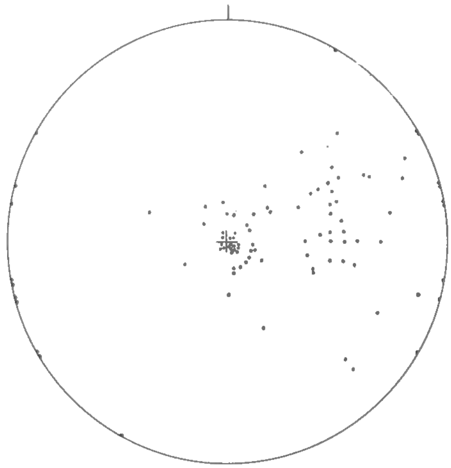


d. $S_2 \wedge S_0$ variable; S_0 and S_1 mesoscopically difficult to recognize; S_2 can be mistaken for S_0

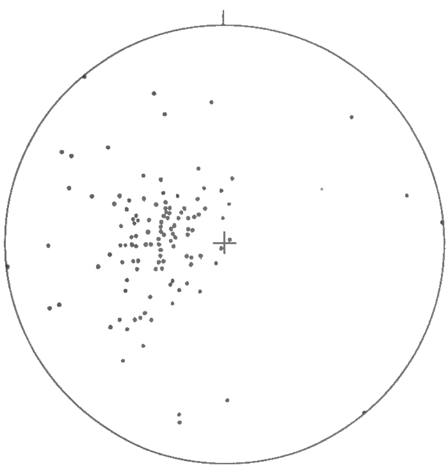
Figure 6. Various relationships of S_2 to S_1 and to S_1/S_0.



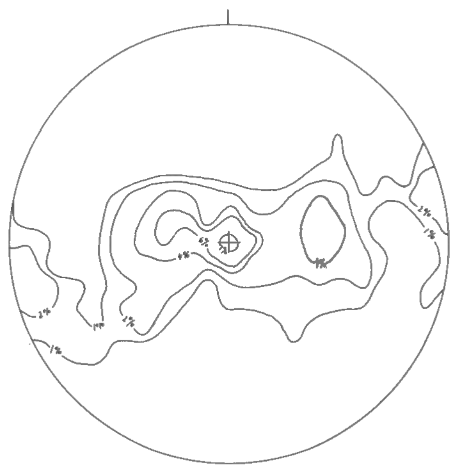
a. 108 poles to S_2
Area northwest of Upsalquitch Lake



b. 86 poles to S_2
Area around Upsalquitch Firetower and near Portage Brook, southwest of Upsalquitch Lake



c. 116 poles to S_2
Area around Devils Elbow and Little Devils Elbow Brooks



d. 310 poles to S_2
Contours: 1%, 2%, 4%, 6%, 7%
Combined a, b and c

Figure 7. Orientation of S_2.

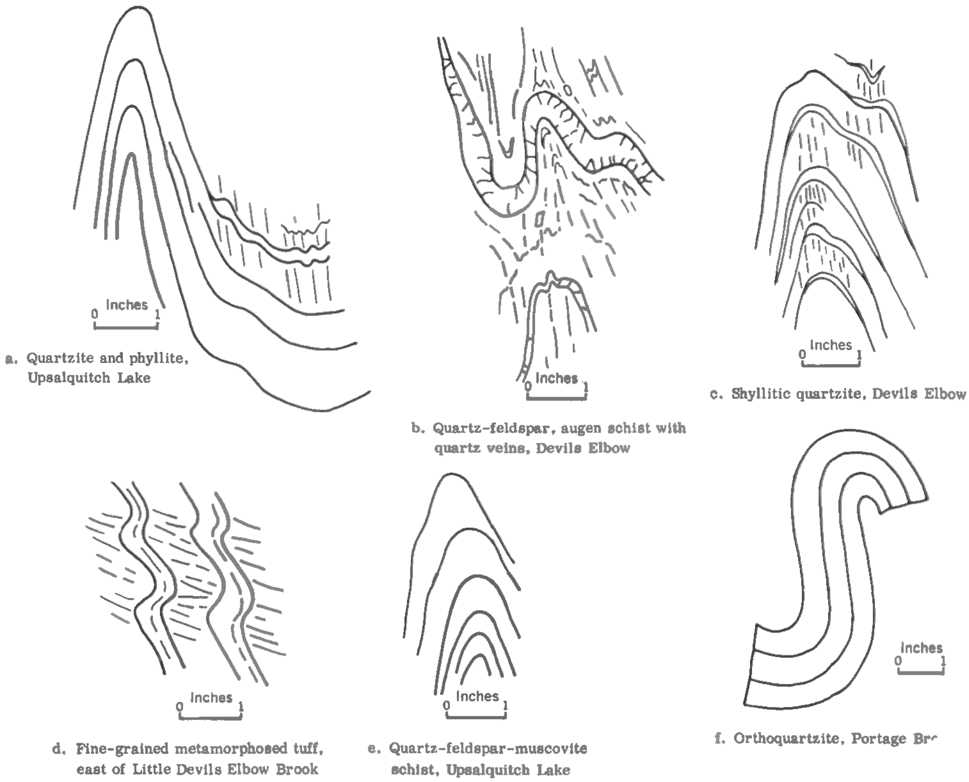


Figure 8. Styles of mesoscopic F_2-folds.

In phyllitic slates of unit 4 west of Upsalquitch River and directly south of the contact with unit 5, the second recognizable cleavage has a nearly northerly strike and is more or less vertical, an orientation very similar to the S_3 attitude (Figs. 7, 10). Although a refraction of S_2 in horizons of different lithology has been observed in places, this does not appear to be a satisfactory explanation for the abnormal S_2 attitude in this case. It is possible that this cleavage is in fact S_3, and S_2 has not been recognized.

Not enough measurements are available from the northeast part of the area to extend these observations. In chlorite schists north of the Murray Brook sulphide deposit conjugate sets of S_2 were identified.

<u>Linear fabric</u> (L_2)

Linear fabrics result from an intersection of S_2 with S_0, S_2 with S_1 and the axes of F_2 crenulations.

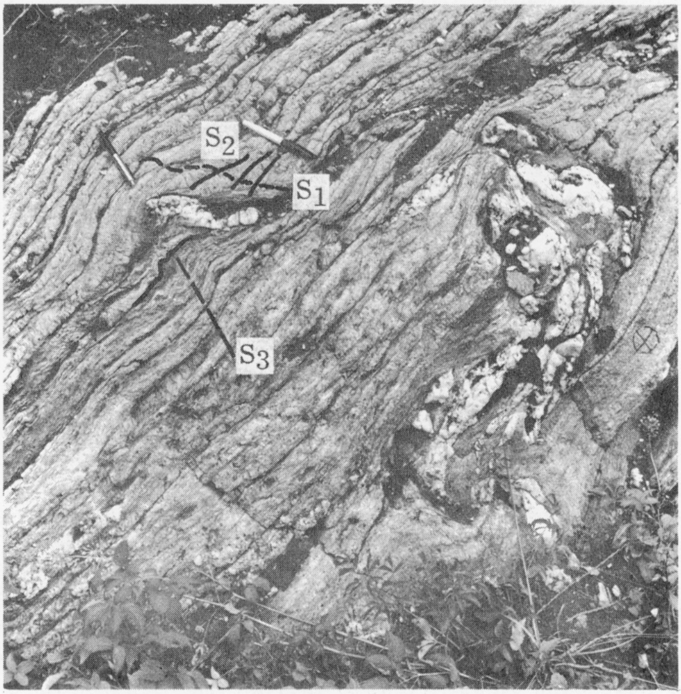


Plate I. Photograph of outcrop showing 3 planar fabrics. The folded quartz vein is approximately parallel with S_1. S_2 is axial planar to this fold. S_3 is axial planar to crenulations of S_2. Photograph by W.H. Poole. (GSC photo 153852)

Folds (F_2)

Most of the readily recognizable folds in the area are folded S_1 surfaces with S_2 as their axial plane cleavage. They are therefore products of D_2. Their size ranges from the scale of a millimetre to that of several tens of metres. They vary greatly in shape and style (Fig. 8) mainly dependent on competency and thickness of the folded layers. The sense of asymmetry is generally constant over fairly large areas. Plunges are shallow to the southeast and east, varying to horizontal in the southeast and central parts of the map-area. In the western part where the axial planes of the F_2 folds are generally steeper, the plunges change from horizontal to vertical. This is especially common in metasedimentary horizons in which axial planes are almost vertical. Figure 9 illustrates the change in plunge of a folded quartzite layer north of Portage Brook.

The largest F_2 folds that have been observed in the present area have wave lengths of up to 100 feet and possibly even more. They occur in quartz-chlorite schists just east of the television tower north of Devils Elbow.

Third phase of deformation (D_3)

As elsewhere in the Bathurst-Newcastle district this phase is the least obvious on the mesoscopic scale, but is responsible for the large-scale fold patterns which are evident from compilation maps of the area (e. g. Davies, 1968). Locally, however, folding on the mesoscopic scale and a set of minor structures of remarkably constant orientation can be recognized throughout the whole of the present area.

Planar fabric (S_3)

S_3 is a fracture cleavage or crenulation cleavage that can only be safely identified as S_3 if it is seen to intersect S_2. Plate I shows an outcrop in which all three planar surfaces (S_1 to S_3) are developed. S_3 is a crenulation cleavage, S_2 being the crenulated surface much in the same manner as the relationship of S_2 and S_1 elsewhere.

Although developed only very locally (parts of the Devils Elbow area, near Upsalquitch Lake and the fire tower, and south of Charlotte Brook) the orientation of S_3 is constant in all these localities. The average strike is slightly west of north and the dip is nearly vertical (Fig. 10).

Linear fabric (L_3)

Besides the axes of mesoscopic folds, small crenulations on S_2 as well as on S_1 have been classified as L_3. They are found in the same areas as S_3 and they strike parallel with S_3. L_3 is generally measured as pitch on the relatively shallow dipping S_2 planes (Fig. 10).

Folds (F_3)

Mesoscopic F_3 folds are kink and chevron folds with steep axial planes (parallel with S_3) and variable plunges (Fig. 10). Their influence on the regional geometry is thought to be of only minor importance. Slight undulations of S_2 with S_3 as axial plane are relatively common throughout the area. Conjugate kink bands of the type encountered in the Middle River-Wildcat Brook area (Helmstaedt, in press) are very rare in this area. Mesoscopic folds of this phase correspond to folds of the second phase of deformation recognized by M. E. Smith (1967) in the Devils Elbow region.

F_3 folding on the macroscopic scale is recognized by:

1) The arcuation of the lithologic units which is best seen on the distribution of Unit 4. This arc represents the northern half of a shallow north-plunging anticlinal structure whose axial plane corresponds to the orientation of the S_3 cleavage in the area.

2) The regional variation of orientation of S_2 large-scale folding can be corroborated by macroscopic analysis of S_2. A combined S_2 plot of the whole area (Fig. 7d) shows a great circle to which S_3 is axial planar and the maximum of L_3 the axis (Fig. 10). In an east-west cross-section (Fig. 5) S_2 forms an asymmetric antiform. The eastern limb has a shallow southeast dip, whereas the western limb steepens towards the Portage Brook fault. The attitude of S_2 prior to D_3 is difficult to determine. Judging from the fact that its present orientation is nearly horizontal over such a large area it seems reasonable to assume that S_2 had shallow dips prior to D_3.

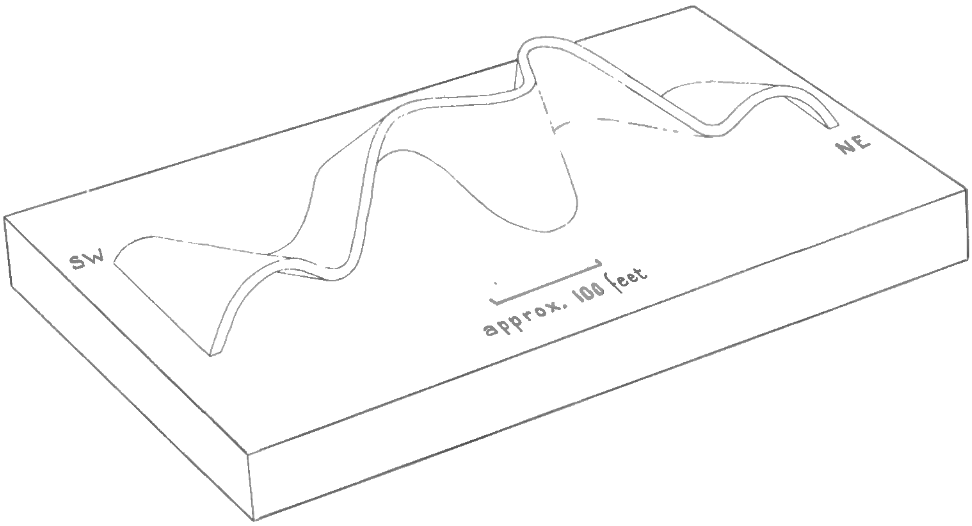


Figure 9. Schematic drawing of folded quartzite bed northeast of junction of West Portage and Portage Brooks. Note the variable plunge of the F_2-folds.

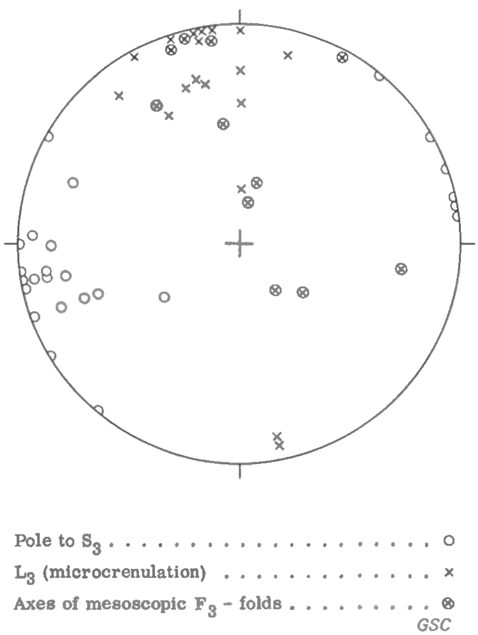


Figure 10. Orientation of D_3-structures.

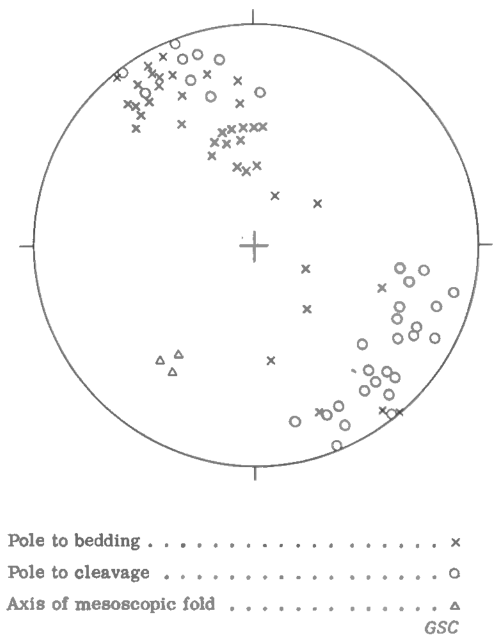


Figure 11. Orientation of structures in Silurian strata along Upsalquitch River, north of Southeast Depot.

Structural fabric of Silurian-Devonian rocks ($D_{Sil-Dev}$)

Although the Silurian and Devonian rocks are relatively little deformed compared to the Tetagouche Group, the scarcity of outcrops, lack of stratigraphic control, and numerous faults make the elucidation of their geometry difficult. For the present study it is sufficient to describe the type and style of structures present in these rocks in order to compare them to the structures of the Tetagouche Group. It appears that the Silurian-Devonian rocks were affected by only one relatively penetrative phase of deformation. Younger structures are only locally developed and confined to the vicinity of faults and intrusive bodies.

Planar structures

Cleavage is present in the Upper Silurian rocks near Upsalquitch River and best developed as slaty cleavage in the grey-green siltstones north of Southeast Depot. It is imperfectly developed or wholly absent in the Upper Silurian rocks close to the unconformity at Eighteen Mile Brook and only locally present in the Lower Devonian rocks in the western part of the area.

In the siltstones, sandstones, and conglomerates along Upsalquitch River, north of Southeast Depot, this cleavage has commonly a northeasterly strike (Fig. 11). It is everywhere oblique to bedding planes and refracted on layers of different grain size. Transposition of bedding was not observed.

Phyllosilicates (chlorite and illite) in the siltstones have a preferred orientation, and irregularly shaped clasts in some of the conglomeratic beds are crudely oriented parallel with the cleavage. Such rotation of clasts requires a state of high mobility in the rocks and suggests a formation of this cleavage prior to lithification. The condition necessary is lateral compression under a high pore-fluid pressure to offset the frictional resistance due to lithostatic pressure (Handin et al., 1963). It is most probable also that the phyllosilicates attained their preferred orientation by mechanical reorientation rather than by recrystallization.

The metamorphic grade of these rocks is so low that high mobility could not have existed after lithification. The lithified (fully consolidated) rocks responded to brittle deformation as witnessed by a fracture cleavage which is locally found and intersects the slaty cleavage.

The formation of slaty cleavage under nonmetamorphic conditions has been discussed and supported by Maxwell (1962), Carson (1968), and Braddock (1970).

Linear structures

A bedding-cleavage intersection lineation is developed everywhere the cleavage is present. It plunges to the southwest in the rocks along Upsalquitch River.

Folds

Mesoscopic folds are very rare and were seen only in the siltstone sequence on Upsalquitch River directly south of the mouth of Murray Brook. The axial planes of these folds are parallel with the slaty cleavage and the axes plunge parallel with the intersection lineation.

In places the bedding as well as the cleavage is kinked and warped, but no consistent orientation could be detected in these very localized later folds.

The only macroscopic fold that was outlined during the present investigation is a syncline in the conglomerate sequence along Upsalquitch River, north of Southeast Depot (cross-section on Fig. 5). It trends northeast, and is slightly overturned to the northwest. It is bounded by faults that also have a northeasterly strike. The slaty cleavage can be considered axial planar to this fold.

Faults

The possible existence of thrust faults along lithologic contacts of units of different competency connected with the first phase of deformation of the Tetagouche Group was pointed out earlier in this report. Differential movement along lithologic contacts in the Tetagouche Group almost certainly occurred also during later phases of deformation.

Faults can be seen in drill cores of Tetagouche Group rocks, but are rarely recognizable in outcrop and almost impossible to outline by ordinary lithologic mapping.

Numerous faults have been proposed by previous authors along lineaments apparent on air photographs (e.g. Skinner, 1956 a, b; Sims, 1961; Potter, 1965; Davies, 1968). For many of these lineaments no evidence of faulting can be found on the ground, and in some cases it appears that differential erosion along the contacts of rocks with different resistance to weathering rather than faulting was the cause.

A suspected thrust was outlined by Loudon (1960) southeast of Upsalquitch Lake. No evidence was found during the present study to support this interpretation.

At least one large northwesterly striking fault appears to be present in the Camel Back Mountain area. The straight fault-trace is parallel with the trend of S_1 southwest of this fault. No trend is obvious in the massive volcanic or intrusive rocks that form Camel Back Mountain to the northeast. It is possible that this fault is related to the large scale folding during the D_3 phase of the Tetagouche Group. However, amount and sense of displacement could not be determined.

A north-trending fault (Portage Brook fault) separates the Tetagouche Group from Devonian strata in the west. This fault has been observed in outcrops at two places: on the south side of West Portage Brook and east of Third Portage Lake. It appears to continue northward beyond Third Portage Lake and separates Upper Silurian strata to the east from presumed Lower Devonian strata to the west. A shear zone can be observed where it crosses the road between Budworm City air strip and Southeast Depot. Farther north this fault joins a fault mapped by Sims (1961) that crosses Ramsay and McCormack Brooks. Movement on the Portage Brook fault is probably related to the upwarping of the Tetagouche Group during D_3. The large intrusions in the southwest corner of the map-area appear to cut across this fault.

Numerous northeast-striking faults cut the Silurian-Devonian sequence. Their age and sense of displacement are mostly not determinable by lithologic mapping. Tension fractures near some of these faults (for instance near Southeast Depot) are at high angles to the fault trace. The brittle response of the rocks indicates that faulting postdates the formation of the slaty cleavage.

Correlation of Fabric Elements and Age of Episodes of Deformation

According to Skinner (1956 a, b) the early structures in the Tetagouche Group were caused by the Taconian Orogeny during Late Ordovician and the large-scale folds are Acadian (Middle Devonian) structures. The Ordovician fold belt has therefore been classified as Taconic folded zone that has been refolded during the Acadian Orogeny (Neale et al., 1961; Poole, 1967). Deformation in the Silurian-Devonian fold belt is attributed to the Acadian Orogeny (Skinner, 1956 a, b; Smith, 1957; Neale et al., 1961; Davies, 1968; Poole, 1967).

Evidence for the Taconian Orogeny was mainly indirect. The contact between the Upper Silurian conglomerates and rocks of the Tetagouche Group near Upsalquitch River was interpreted long ago (Ells, 1905) as an angular unconformity although it was not seen. Alcock (1935) argued for a Taconian Orogeny on the basis of the higher degree of deformation and metamorphism of the Ordovician rocks as compared to the Silurian-Devonian sequence. He wrote, however, that nowhere was the actual contact found (Alcock, 1935, p. 103). Unconformable relationships between Ordovician and Silurian rocks are suggested by Sims (1961). Potter (1965) also cites evidence that ferruginous chert clasts of the Tetagouche Group were found in the Upper Silurian conglomerate.

The possibility that the entire deformation of the Tetagouche Group may be Acadian was raised by Helmstaedt (in press) because the existence of a structural unconformity between the Tetagouche Group and the Silurian-Devonian rocks had never been proven conclusively. Since the northern contact of the Tetagouche Group with the Silurian is a fault in most places, it was considered possible that highly deformed Tetagouche rocks were brought into place against little deformed and metamorphosed Silurian rocks along these faults, and that the difference in deformation and metamorphism could be a function of different response to deformation at different structural levels.

However, during the present study, an outcrop of the actual unconformity between Upper Silurian conglomerates and Middle Ordovician greenstones (unit 5) was located. A study of the clasts in the Upper Silurian as well as Lower Devonian conglomerates, and a comparison of the structures in the Ordovician and the Silurian-Devonian furnishes evidence that at least the first two phases of deformation in the Tetagouche Group (D_1 and D_2) are pre-Upper Silurian events and a manifestation of the Taconian Orogeny. There are still problems, however, as to the correlation of the D_3 event in the Tetagouche Group and the deformation of the Silurian-Devonian fold belt.

Ages of D_1 and D_2

The unconformity at Eighteen Mile Brook documents a stratigraphic hiatus between the Middle Ordovician and the Upper Silurian. The massive Ordovician greenstones (unit 5) beneath the unconformity are regionally

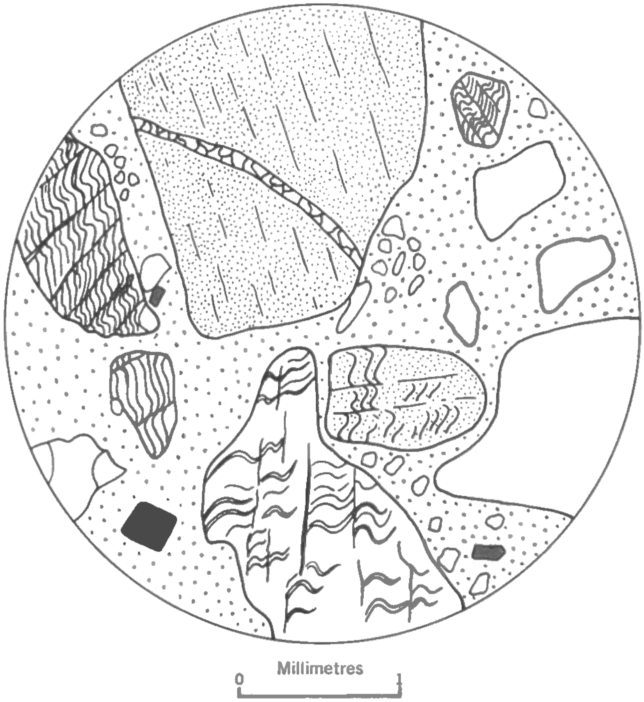


Figure 12. Drawing of thin section of Lower Devonian (?) conglomerate showing pelitic clasts with two planar fabrics, both of pre-depositional age.

metamorphosed. The matrix of the overlying conglomerate, on the other hand, is virtually unmetamorphosed. The conglomerate contains pebbles of the Ordovician greenstones, metagabbro (unit 6) that intrudes the greenstones, and various diabasic pebbles. Stratigraphically higher, the quartz content of the conglomerates increases and locally pebbles of ferruginous slates of the Tetagouche Group (unit 4) occur containing a pre-deposition slaty cleavage (S_1). This is taken as clear evidence for a pre-Upper Silurian age of D_1 and the accompanying regional metamorphic event.

Clasts of Tetagouche Group rocks containing two fabrics (S_1 and S_2) visible to the naked eye have not yet been found in the Silurian and Devonian conglomerates. However, thin sections of the Lower Devonian(?) quartz-pebble conglomerate at West Portage Brook show several small pelitic clasts that exhibit two planar fabrics, a foliation and a crenulation cleavage, both being pre-depositional (Fig. 12). If these clasts were derived from the Tetagouche Group (as is most likely) the two fabrics correspond to S_1 and S_2 and indicate that D_2 is also a Taconian event. The quartz pebbles in the same conglomerate show similar textures, plastic strain, and state of recrystallization as the milky quartz veins in the Tetagouche Group that have been folded by D_2.

Ages of D_3 and $D_{Sil-Dev}$

The age of D_3 in the Tetagouche Group can be bracketed between the Late Ordovician and the Middle Devonian (the age of the undeformed granites). Since it is not likely that D_3 postdates $D_{Sil-Dev}$ this time span can be narrowed down further to the Early Devonian. An Early Devonian age of $D_{Sil-Dev}$ is concluded because this deformation is thought to have taken place prior to the lithification of the Upper Silurian-Lower Devonian sequence. This means that D_3 could be a Taconian event predating the deposition of the Upper Silurian-Lower Devonian sequence, or an Acadian event coeval with the deformation of that sequence. The difference in orientation of structures caused by D_3 and $D_{Sil-Dev}$ is in conflict with the latter possibility. At present there are insufficient data to answer this question.

ECONOMIC GEOLOGY

One objective of this study is to relate the structural elements and evolution of the country rock to the massive sulphide deposits in the Tetagouche rocks of the Bathurst-Newcastle district. Most important are the questions of possible structural controls and the age relationship of the sulphides to the observed fabric elements. Structural information is not only useful in describing the geometry of a particular deposit but, if leading to a regional structural understanding, may also be of significant help in the search for new deposits.

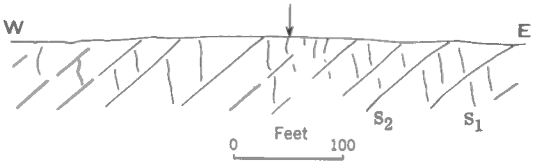
Although the first year of this project was devoted mainly to a study of the structural style, sequence and age of deformation in part of the Tetagouche Group, some conclusions pertaining to the sulphide bodies can be discussed at this stage.

There are three known sulphide deposits in the present area (Table II). Exploration is active at the Restigouche deposit of Restigouche Mining Corporation Ltd., and the Devil's Elbow deposit of the Devil's Elbow Mines Ltd. Unfortunately, only a small part of the Restigouche orebody at Charlotte Brook outcrops. However, a comparison of the fabrics contained in the country rocks with that seen in the ore outcrop as well as in drill cores that have been examined with the kind permission of the Keevil Mining Company provided the opportunity to estimate the extent to which the different structural fabric elements are developed in the ore.

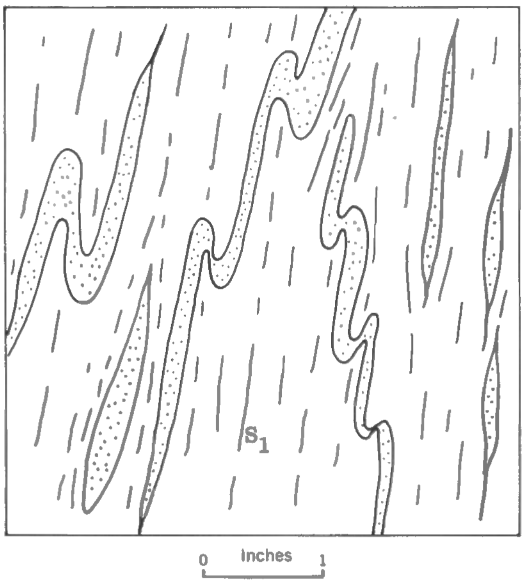
Planar Fabrics in the Ore

The most striking planar fabric is the banding that occurs in some parts of almost every deposit in the Tetagouche Group. It is defined by alternating layers of sulphides and gangue minerals, of different sulphide minerals, and of different ore grade (see also McAllister, 1960).

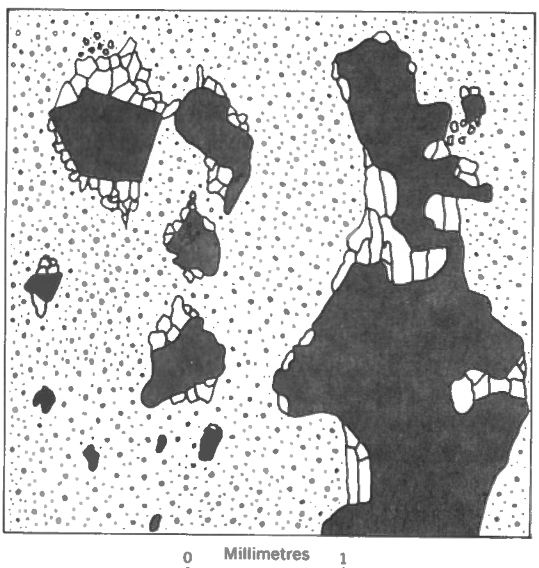
In the outcrop at Charlotte Brook the banding is caused by alternating layers of sulphide (mostly pyrite) and silicates (mostly quartz). The relation of the banding to the planar fabric in the surrounding rocks is illustrated in Figure 13. It is immediately obvious that the orientation of the banding corresponds to that of S_1 in the country rocks. The S_2 fabric, the dominant



13a. Schematic drawing showing orientation of S_1 and S_2 in E-W section along Charlotte Brook near south end of Restigouche sulphide body. The arrow indicates the location of sample illustrated in 13b and 13c.



13b. Sample of siliceous pyritic ore from south end of Restigouche body outcropping in Charlotte Brook. Sample consists of fine-grained quartz and pyrite with several folded quartzose layers (stippled). S_1 in axial planar to small-scale folds defined by the quartzose layers. S_2 is not visible.



13c. Drawing of polished thin section of fine-grained quartz and pyrite. Pyrite (black) exhibits few crystal outlines. Quartz (blank) has recrystallized in pressure shadows of pyrite which are oriented in S_1. This indicates that the pyrite was present prior to the regional metamorphism of the rock. S_2 is not recognizable, but the effects of D_2 can be seen as plastic strain in the recrystallized quartz.

Figure 13. Relationship of planar fabric in ore to mesoscopic fabric in country rocks, Restigouche deposit.

Table II. Data on Sulphide Deposits

Deposit Location	References	Mineralization	Dimensions	Host Rock	1. Hanging Wall 2. Footwall	Orientation	Outcrop conditions at surface around orebody
Murray Brook (Kennco Explor.) SE of Eighteen Mile Brook, W of Camel Back Mt.	McAllister, 1960 Fleming, 1961 Davies, 1966 Skinner, in preparation	FeS_2, PbS, ZnS, $CuFeS_2$, almost no pyrrhotite	Orebody about 1,000-1,300 ft. long, average width 300 ft. (max. 600 ft.). Depth up to 800 ft. Approx. 23,000,000 tons with average grade: 0.44% Cu, 0.68% Pb, 1.95% Zn, 0.91 oz./ton Ag.	1,500 ft. wide zone of sericitic chlorite and graphitic schists. (lower part of unit 4, upper part of unit 3	1. Chloritic schist, quartz-chlorite schist (lower part of unit 4) 2. Quartz-feldspar augen schist (upper part of unit 3b)	Longest dimension strikes NE, plunges NE.	very poor
Restigouche (Restigouche Mining Corp.) At Charlotte Brook between Upsalquitch and Portage Lakes	Davies, 1966 Unpublished data	FeS_2, PbS, ZnS, $CuFeS_2$	Orebody about 1,500 ft. long up to 500 ft. wide, thickness up to 100 ft. Depth up to 700 ft. Approx. 3,000,000 tons with average grade: 5% Pb, 9% Zn, 3 oz./ton Ag.	Rocks of rhyolitic and dacitic composition, partly schistose. No definite sedimentary rocks (unit 3b)	1. Unit 3b 2. Lower part of unit 3b.	Orebody strikes NNW, plunges about 20° NNW	moderate
Devil's Elbow (Devil's Elbow Mines). North of Devils Elbow, east of television towers road	McAllister, 1960 M. E. Smith, 1967	FeS, FeS_2, $CuFeS_2$, minor PbS, ZnS	Approx. 350,000 tons averaging 1.2% Cu.	Sericite schist (unit 3b)	1. Quartz-feldspar augen-schist (unit 3b) 2. Fine-grained siliceous rhyolite or tuff (unit 3a)	Strike roughly east	moderate

parting plane in the country rocks, is not recognizable mesoscopically in the relatively competent alternating quartz and sulphide layers of the orebody. Close examination of the outcrop reveals that the quartzose layers (which are most prominent due to differential weathering) show small-scale folds (Fig. 13a). The axial plane of these folds parallels S_1 of the country rocks. In a polished thin section, pyrite appears to have a cataclastic texture (Fig. 13b), and only in a very few instances were imperfect cube faces observed on the pyrite. Quartz is finely recrystallized between the pyrite and attains coarser grain sizes in the pressure shadows of pyrite (Fig. 13b).

For the purpose of comparison a polished thin section of banded pyritic ore from the Brunswick No. 6 orebody was examined. The sample was taken in the open pit from the footwall of the orebody. The host of the pyrite is a quartz-chlorite schist. Pyrite shows more euhedral crystal faces than in the sample from Charlotte Brook, imperfect cubes being the most common shape (Fig. 14). The relationship of the gangue minerals to the pyrite is significant. Chlorite defines a planar fabric (S_1) in the chlorite-rich layers and is generally fine grained. The chlorite fabric curves slightly around the pyrite grains. In embayments and pressure shadows of the pyrite the chlorite attains a much coarser grain size than in the matrix. This very strongly suggests that the pyrite was present when chlorite crystallized, i.e., the pyrite is pre-metamorphic.

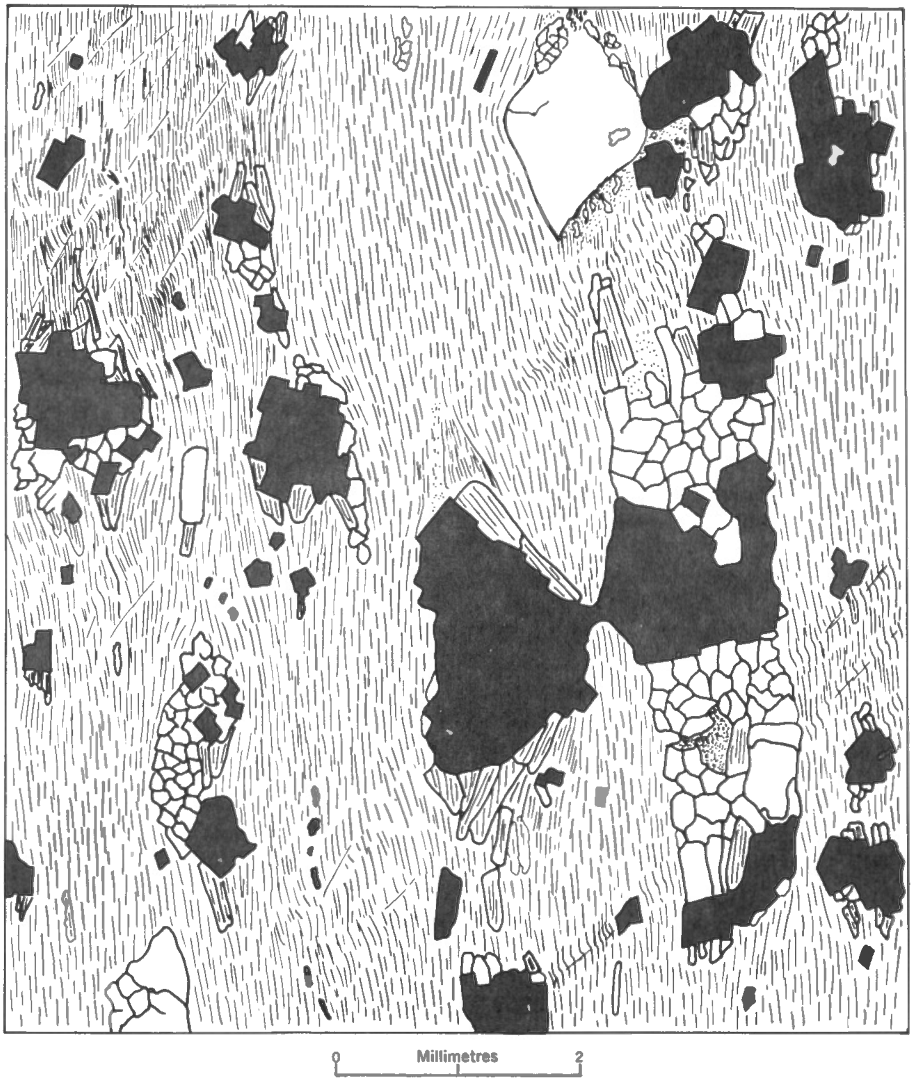
Vokes (1968) describes and illustrates how pyrite progressively recrystallizes with increasing grade of metamorphism in stratiform Norwegian sulphide deposits. The texture of the Charlotte Brook sample resembles that of cataclastic pyrite in a deposit where the country rocks have been metamorphosed to the lower greenschist facies (Fig. 3 of Vokes), whereas the more cube-shaped pyrite crystals from Brunswick No. 6 resemble the next higher stage (Fig. 4 of Vokes). These observations are also in agreement with statements by Ramdohr (1960, p. 621) that pyrite remains cataclastic at low-grade metamorphism and granoblastic textures start to appear in the deeper mesozone of regional metamorphism. Kalliokoski (1965) found slightly different degrees of metamorphism in different deposits of the Bathurst-Newcastle area.

From the above the writer feels justified in assuming that the pyrite was present during the first phase of deformation (D_1) which coincided with the peak of the regional metamorphism in the area. The banding of the ore may represent original compositional layering (bedding) in some places, but is probably transposed bedding in the majority of cases, as in the country rocks.

S_2 is normally not recognizable as planar fabric in the ore itself. It has, however, been observed in the polished thin section of the specimen from Brunswick No. 6. It transects S_1 at an angle of about 25 to 30 degrees and crenulates S_1 slightly. The microcrenulations also affect the coarse chlorite close to the pyrite grains, clearly indicating that S_2 was formed later than the pyrite and coarse chlorite.

Folds in the Ore

Studies of fold structures in the ore are restricted mainly to outcrops created by mining operations. Therefore, except for the already mentioned small-scale folds of the banding at Charlotte Brook (Fig. 13a), no observations could be made in the present area. However, if we accept that



Note cubic outlines of pyrite (black). Chlorite (dashed) defines S_1 and is coarse in pressure shadows of pyrite. Quartz (blank) is mostly recrystallized but strained porphyroclasts (right upper part of picture) are preserved. S_2 (as crenulation cleavage) can be recognized in left upper corner.

Figure 14. Drawing of polished thin section of pyritic quartz-chlorite schist from footwall of Brunswick No. 6 orebody.

S_1 has been superposed on the ore we would expect the folds connected with all three phases of deformation to occur in the ore. Examples of F_1-folds have been pointed out to the writer by D. Rutledge of Brunswick Mining and Smelting Corporation Ltd. during a visit of the Brunswick No. 12 mine. They are isoclinal folds with limb lengths of about 10 feet and more, which have S_1 as their axial plane surface. F_2 folds causing undulations of the ore layers were also seen during this visit. It is interesting to note that the S_2 fabric, which is very pronounced in the country rocks, does not continue as planar fabric into the ore itself, although the ore is folded by F_2. This is analogous to the situation in the country rocks in which competent folded layers show internal strain but are not transected by a planar S_2 fabric.

The Question of the Origin of the Ore

No published accounts are known to the writer that discuss specifically the origin of the three deposits in the map-area. However, there are numerous papers dealing with the origin of other, similar deposits in the Bathurst-Newcastle district. An epigenetic origin was supported by Lea and Rancourt (1958), Benson (1960), Tupper (1960, 1969), Boyle (1965), and Stockwell and Tupper (1966). A syngenetic or at least pre-metamorphic origin was concluded by McAllister (1960), Stanton (1959, 1960), Kalliokoski (1965), and Lusk and Crocket (1969). Of the Orvan Brook deposit Tupper (1969) stated that the evidence is not clearcut and neither entirely refutes nor supports a syngenetic or epigenetic origin.

The most contrasting views are cited below for the sake of comparison. Kalliokoski (1965) stated that the ore may be of Ordovician age and may have been deposited or dumped under slight lithostatic or hydrostatic load, forming replacements in consolidated or unconsolidated sediments. The ores were originally fine grained and have been metamorphosed at fairly high temperatures. The sequential deposition of minerals or introduction of metals cannot be deduced from textural studies. On the other hand, Boyle (1965) stated that the deposits are epigenetic, they were formed at the same time as the vein deposits in the Silurian rocks (north of the Rocky Brook-Millstream fault) "during a late stage of shearing associated with the major tectonic and metamorphic processes that affected the belt as a whole".

A comparison of the structural fabric elements and metamorphic effects in the wall-rocks with those found in the sulphide deposits help to narrow down the choice between the above quoted alternatives considerably. The data provide evidence that the regional S_1 fabric was imposed on the ore. The formation of this fabric has been shown to coincide with the regional metamorphism of the area and has been dated as pre-Upper Silurian. Disconformable relationships of ore and country rocks can be explained by differential movement during the first phase or even later phases of deformation (see also McDonald, 1967). They must not be taken as proof for an epigenetic origin of the ore. The same is valid for local migration of ore into fractures which may result from remobilization of the ore during later phases of deformation.

The present findings do not rule out an epigenetic origin of the ore prior to metamorphism. However, Boyle's (1965) epigenetic origin coinciding with the emplacement of vein deposits in the Silurian rocks north of the Rocky Brook-Millstream fault cannot be supported.

Structural Analysis in Exploration

Besides leading to improvements of the regional structural understanding which may aid exploration in choosing new target areas, there are numerous applications of structural analysis on a smaller scale that can be of significant help to the exploration geologist.

Mesoscopic secondary fabric elements such as cleavages, lineations, and folds have remarkably constant orientations over relatively large areas compared with the rapid lateral and vertical lithologic changes that, combined with the general lack of marker beds, make lithologic mapping so difficult in this area. Changes in orientation are often systematic (see also Helmstaedt, in press) so that it is possible to predict attitudes over limited distances where outcrops are scarce. A clear distinction of the different fabric elements and their systematic recording is important to establish subareas which are homogeneous with respect to certain fabric elements. If drilling takes place in such areas the orientation of drill cores can be greatly simplified by a knowledge of the regional orientation of these fabric elements. The usefulness of fracture cleavage (probably the equivalent of the S_2 of the present paper) for the orienting of drill cores was mentioned previously by Stockwell and Tupper (1966) in the area around the orebodies of Brunswick Mining and Smelting Corporation Ltd. Also very important in this respect are the lineations, especially L_2, but in places also L_3. Apart from orienting drill cores, a knowledge of the various mesoscopic structures can aid in the construction of cross-sections based on drill logs. From the angular relationship of two planar fabrics, for instance, the asymmetry of possible folds can be deduced, and when correlating particular beds from one drillhole to another, certain possibilities can be eliminated as unfeasible.

An example of possible interpretations of a cross-section through the Restigouche deposit based on drill logs and using knowledge of the S_1 and S_2 orientations from surface outcrops is given in Figure 15.

It is also important to assess the relative importance of the folds caused by the different phases of deformation. Also with respect to abundance of folds and their orientations, relatively homogeneous areas can be outlined by structural mapping.

Nevertheless, even the most detailed structural analysis has limits to its usefulness in understanding the geometry of rock-units. Still, structural analysis can help in the selection of the most reasonable model from many possible geometric configurations.

SUMMARY OF GEOLOGICAL HISTORY

During Early and early Middle Ordovician times the map-area was relatively stable. Continent-derived quartz-rich sediments with signs of rhythmic sedimentation were laid down on a submerged platform or a continental slope in an Atlantic-type geosyncline (Mitchell and Reading, 1969).

In the Middle Ordovician this stable region was transformed into the highly unstable, eugeosynclinal environment of an island arc-type geosyncline. The early Paleozoic history of this area is therein comparable to the Tertiary history of the Aleutian arc, where an island arc was formed on turbidites of an older abyssal plain and continental rise (Mitchell and Reading, 1969; Hamilton, 1967).

Volcanism in the Bathurst-Newcastle district was acidic at first and of the explosive type resulting in the deposition of huge volumes of pyroclastics mixed with rhyolitic flows and immature sediments. The massive sulphide deposits were formed at this stage, probably in a number of restricted basins.

The deposition of pelagic sediments and the extrusion of submarine spilitic lavas apparently postdates most of the rhyolitic volcanism. Intrusive gabbros, in part layered, are probably genetically related to the spilitic lavas.

In the interval between Middle Ordovician and Late Silurian (Ludlovian), the rocks of the Tetagouche Group were deformed in at least two distinct phases (D_1 and D_2), both manifestations of the Taconian Orogeny that led to the formation of the Miramichi Geanticline (Poole 1963, 1967). The main phase of deformation (D_1) was accompanied by a low-grade regional metamorphism and granite intrusion, and resulted in large scale folds, thrusts, and a penetrative foliation with mostly steep dips. Metamorphism continued slightly beyond the end of D_1. D_2 caused a near-horizontal crenulation cleavage and crenulations from the millimetre to metre scale which modified D_1 structures. Metamorphic recrystallization during this phase was very limited.

The present-day distribution of formations of the Tetagouche Group was established during D_3 which caused a major antiform with a near-vertical north-northwest-striking axial plane and a shallow northerly plunge. It is possible that this phase of deformation is connected with the uplift of the Tetagouche rocks prior to the deposition of the Upper Silurian. However, at present there is no definite proof for the age of D_3.

The upper Silurian conglomerates are molasse-type sediments that rest with angular unconformity on the deformed Middle Ordovician strata. Near their base these conglomerates contain mainly pebbles of Ordovician basic volcanics and various diabasic rocks. There is an increase in quartz content stratigraphically higher in the sequence and some Lower Devonian (?) conglomerates are composed mainly of milky quartz pebbles. This may indicate gradual exposure by erosion of the lower, more quartz-rich strata of the Tetagouche Group.

It is still questionable whether there was continuous sedimentation across the Silurian-Devonian boundary. A disconformity in the early Helderbergian is indicated by paleontological evidence of Boucot and Johnson (1967). Farther southwest this disconformity has been interpreted as the Salinic Disturbance (Boucot, 1962; Pavlides et al., 1964). If such a disconformity indeed exists in the present area it is unlikely to represent a significant diastrophic event, but merely a period of uplift.

The Upper Silurian-Lower Devonian sequence was mildly folded and deformed shortly after deposition. The behaviour of the Tetagouche Group basement during this very high-level deformation is not known. It is reasonable to assume that this deformation was connected with the uplift of the previously folded Tetagouche Group either synchronous with the D_3 event or postdating D_3 and controlled by faults penetrating the Tetagouche basement. Intrusions of batholithic proportion in mid-Devonian times welded the Late Silurian to Early Devonian molasse foreland to the Miramichi Geanticline. Deformation thereafter was restricted to faulting that is difficult to date, but probably continued well into post-Carboniferous times.

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