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STRATIGRAPHY, STRUCTURE AND METALLIZATION PISKAHEGAN- ROLLING DAM AREA (NORTHERN APPALACHIANS, NEW BRUNSWICK, CANADA)

BY

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ABSTRACT

The main structure in the map area is a northeasterly trending antiform: the "St David Dome". The core of this structure consists of Ordovician pelitic metasediments, which are flanked by Silurian metagreywackes and quartz wackes.

Three distinct phases of folding have deformed the metasediments in the area. The early or main phase is represented by close to sub-isoclinal cleavage folds, which trend roughly parallel with the St David Dome. The second phase folds trend approximately parallel with the first phase folds, but they are all overturned in a southerly direction and they produce typical crenulations in the first phase slaty cleavage planes. A conjugate set of chevron-type folds, which trend obliquely to the earlier folds, was produced during the third phase of deformation.

Most of the rocks in the map-area have been metamorphosed to some extent. The higher grades of metamorphism postdate the main phase folding and at least continued into the second phase of deformation.

The earliest intrusions in the area are Ordovician gabbroic rocks in the western part of the map area. Other gabbroic rocks, in the southern part of the map area, are possibly of Devonian age.

The southeastern part of the map area is occupied by a large Devonian granite mass. A number of adamellite stocks intrude the metasediments along the northern contact of this large igneous body. These small intrusions probably represent a late phase of the granitic intrusions. Moreover it is shown that they are contemporaneous with or postdate the F_3 folding phase. Northwesterly trending wrench faults are very prominent in the map area and the latest movement postdates the granitic intrusions.

The volcanism in the eastern part of the map area is related to a narrow block which is delimited by two wrench faults. Stretching of this block by a north-northwesterly tensional stress probably permitted volcanic material to reach the surface and in the final stages of volcanic activity, it provided access for mineralizing fluids. Other tin and some base metal occurrences are related to the adamellite intrusions.

In the Rolling-Dam area, arsenopyrite-gold mineralization occurs in fractures which are related to F_3 folds. These fractures occur mostly near the core, but also along the flanks of the St David Dome, which appears to be mostly intruded by adamellite. Nickeliferous pyrrhotite and some pentlandite are associated with some of the gabbroic rocks in the western part of the map area.

CONTENTS

LIST OF FIGURES AND TABLES

TABLES

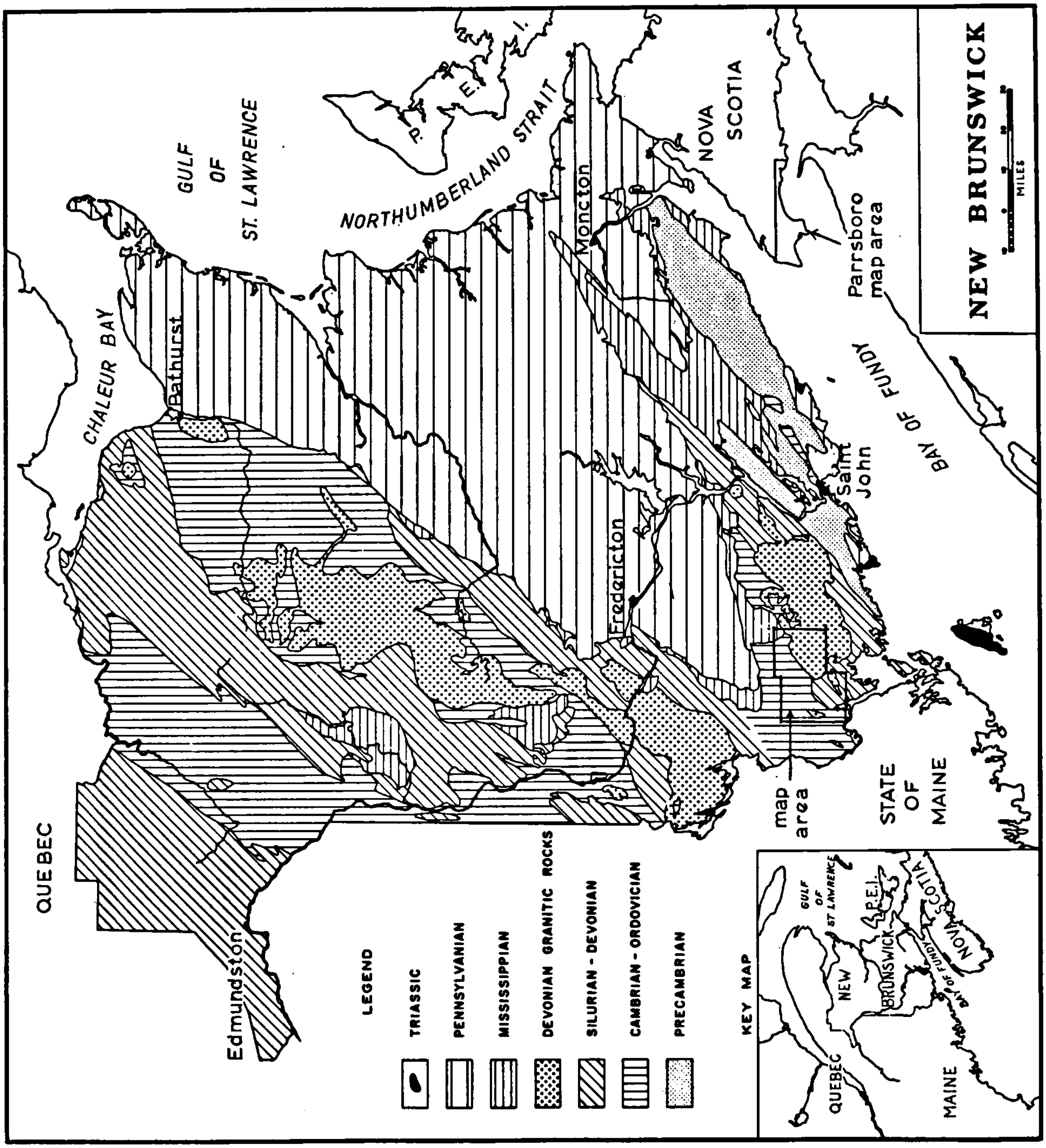

Fig. 1.1. Location of the map area and regional geology (after compilation by J. C. Smith, New Brunswick Mines Branch).

CHAPTER I

INTRODUCTION

1.1. *Location and access*

The Rolling Dam-Piskahegan map-area is situated between St. Stephen and Mount Pleasant, Charlotte County, New Brunswick, Canada (fig. 1.1). It includes about seventy percent of the area confined by latitude 45° 10′ to 45° 30′ N and longitude 66° 45′ and 67° 15′ W.
The area is accessible by paved highways from Fredericton and Saint John, while several good gravel roads extend across the area.

1.2. *Physiography*

The region has low relief and is characterized by northwesterly trending arcuate-shaped ridges separated by wide valleys. A southeasterly direction of glaciation is indicated by stoss and lee features and glacial striae. Boulder clay, gravel and outwash sands varying in thickness from a few feet to several hundred feet cover most of the area. Rock outcrops are therefore erraticly distributed and they occur mostly along streams, which have cut through the glacial overburden (fig. 1.2).

Fig. 1.2. Piskahegan River 1.5 miles east of confluence with Magaguadavic River.

1.3. *Flora and fauna*

The region is for the most part covered by forest. The main coniferous trees are spruce, balsam fir, tamarack, jack pine and eastern hemlock. The large deciduous trees are maple, birch and poplar.
Edible fruits are plentiful, and include blueberries, blackberries, strawberries, raspberries and wild cherries.
Black bears and deer are the most abundant large animals. Moose are common but not abundant in the northern part of the area.
Smaller animals include beaver, porcupine, rabit, squirrel and other small rodents.

1.4. *History and settlements*

The earliest known inhabitants of the area were the Micmac Indians, while the first Europeans who entered the area were the French explorers de Monts and Champlain. They wintered on a small island in the St. Croix River, just south of the map area, in 1604. However, only a few European settlers came to the region before the start of the American revolution in 1774. At that time, many people from British origin, who wished to remain loyal to the British Crown came to the region from the Eastern United States. Subsequently, an active timber trade developed with Great Britain, which resulted in great prosperity for the town of St. Andrews, just south of the map area. A British army winter supply road between the port of St. Andrews and the capital city of Fredericton, which crossed the map area, was built in 1789. This road, which in part still exists today (see main map) provided access for many pioneer farmers into the densely forested area (pers. comm. S. Wilson, 1966).
The main settlements in the map area are St. Stephen, Moores Mills and Rolling Dam. About one third of the southwestern part of the region has been cleared for farming, and a small portion of the northern section. Many of the small family farms have been abandoned during the last half century, while they have been replaced by a few large mechanized agricultural enterprises. The major present activities in the area, other than farming, are the cutting of pulpwood, tourist industry and manufacturing in St. Stephen.
The area has been prospected for metallic minerals since the latter part of the nineteenth century. This resulted in the discovery of several small gold-bearing showings and the St. Stephen nickel-copper deposits. Base metal mineralization was discovered on Mount Pleasant in 1954 and subsequent investigations led to the discovery of tin mineralization.

1.5. *Geological setting*

The area is part of the northern extension of the Appalachian geosynclinal belt, which developed in eastern North America from Proterozoic to Permian. Some parts of the geosyncline were folded and uplifted during the Taconic orogeny (late Ordovician). Granites intruded some parts of this belt.
During the Acadian orogeny (Middle and late Devonian), almost the entire geosyncline was deformed and intruded by granites. It is probable that

the entire belt became uplifted and subject to erosion. A broad tectonicly active zone, extending from the Bay of Fundy to White Bay, developed upon the Acadian orogen during mainly Carboniferous. Within this zone, local linear blocks were raised on bounding faults, while intervening troughs received fluviatile and lacustrine clastic sediments (Poole, 1966). Volcanism related to this deformation was active in certain areas.
The oldest known rocks, in the map area, are chiefly Lower Ordovician pelitic metasediments, which were locally invaded by basic intrusions during late Ordovician (Taconic).
These Ordovician rocks are unconformably overlain by an assemblage of poorly sorted Silurian clastic metasediments.
The Ordovician and Silurian rocks were intensely folded and invaded by granitic and basic intrusions during Middle- and Late-Devonian (Acadian). However, no evidence has been found for either Taconic or Appalachian folding, such as in some areas of Nova-Scotia (Fyson, 1964).
Volcanism was active in the eastern part of the map area during the Lower-Carboniferous (Appalachian), and therefore in the post folding period. A large northeasterly trending belt composed of Carboniferous clastic sedimentary rocks extends to the north and northeast of the map area (fig. 1.1).

1.6. *Previous geological work*

The earliest known geological work in the region was carried out by Bailey and Matthew (1870—1871).
The area west of longitude 67° 00′ was mapped by Mac Kenzie (1939) and Alcock (1945), that east of longitude 67° 00′ by Tupper (1958) and the smaller area northeast of Mount Pleasant by Harris (1964) and Tremblay (1965).

1.7. *Fieldwork*

The writer was engaged in geological mapping and mineral exploration in the area during the summers from 1961 until 1966.
Several mineral prospects were mapped in detail and some regional studies were undertaken for various mining companies. The regional stratigraphic and structural study was completed under the direction of the Geological Survey of Canada.

1.8. *Acknowledgements*

The Geological Survey of Canada supported the final fieldwork, while the New Brunswick Department of Natural Resources provided funds for the completion of the laboratory work and manuscript preparation.
The stimulating discussions with Dr. L. U. de Sitter, professor in structural and applied geology at the University of Leiden, are sincerely appreciated.
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The writer appreciates the assistance or information provided by Mr. R. B. Allen, Mr. J. A. Giddens, Dr. N. B. Gillies, Dr. P. Hay, Dr. R. Mulligan, Dr. R. R. Potter, Dr. J. E. Riddell, Mr. J. C. Smith and Mr. W. H. van de Poll.
A special word of thanks is due to the members of the St. Stephen-Milltown Development Board for their support of the project, when it was most needed.
Mr. Stanley Wilson, who still lives on one of the well maintained original homesteads, was so kind to provide most of the information about the history of the area.
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The writer acknowledges with gratitude the typing of the manuscript by Mrs. D. S. de Waal, the drafting of the maps by Mr. B. Lieffering, the drawing of the text figures by Mr. F. J. Fritz and the photograph preparation by Mr. J. Hogendoorn.

CHAPTER II

STRATIGRAPHY AND PETROLOGY

2.1. *General statement*

The main structure in the map area is the northeasterly trending "St. David Dome" (see main map). The core of this structure is composed of Lower Ordovician pelitic metasediments, which are flanked to the north and south by impure Silurian clastic sedimentary rocks. The average trend of the steeply to moderately dipping early cleavage planes, and associated minor folds is roughly parallel with this structure. Part of the early formed structures have been deformed by later cross-folding.
Those basic intrusions exposed in the western part of the map-area are related to the St. Stephen igneous complex, which is believed to be Ordovician (Mc Cartney et al. 1965).
The igneous complex in the southern part of the map-area comprises early gabbroic rocks, later granitic rocks and some late adamellite dykes. These granitoid rocks are believed to be of Devonian age, but some of the basic rocks could be older.
The Carboniferous volcanic complex in the eastern

part of the map-area, intrudes the Silurian sedimentary rocks. Extrusive equivalents are exposed to the north and east. North of the map-area, the volcanic rocks are interbedded with and overlain by Carboniferous sedimentary rocks (van de Poll, 1963).

As a result of the present mapping it has been necessary to revise most of the previous stratigraphic interpretation of the pre-Carboniferous rocks (compare figure 1.1 and present map). Previous interpretations are given with the individual descriptions of the formations.

The stratigraphic sequence is given in fig. 2.1. and the table of formations (2.2).

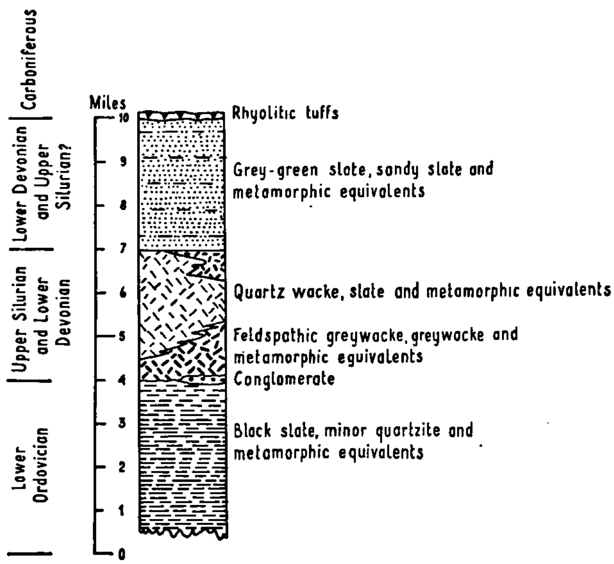


Fig. 2.1. Generalized stratigraphic sequence Piskahegan Rolling-Dam area.

2.2. *Table of formations*

Era	Period	Formation or unit	Lithology
Palaeozoic	Carboniferous	11 Seely's Formation	Banded quartz-feldspar porphyry
		11a	Angular blocks and boulders of 3a, 7, 8 and 9 in banded quartz-feldspar porphyry matrix
		11b	Intensely altered equivalents
		Disconformable and locally intrusive contacts	
		10 Rothea Formation	Latite porphyry
		10a	Intensely altered equivalents
		Conformable and locally intrusive contacts	
		9 Rothea Formation	Quartz-feldspar porphyry
		9a	Brecciated hornfelsic greywacke, and phyllite intruded by quartz-feldspar porphyry
		9b	Intensely altered equivalents
		Not in contact	
Palaeozoic	Devonian	8 Beech Hill Adamellite	Adamellite
		8a	Zone with abundant pegmatite dykes
		8b	Zone with abundant partly granitized metasediment inclusions
		8c	Micro-adamellite
		Intrusive contact	

Era	Period, radiometric dates	Formation or unit	Lithology
Palaeozoic	380 m. y.	7 St. George Granite	Granite, minor adamellite, granodiorite and diorite
		Intrusive contact	
	Devonian and earlier	6 6a	Gabbro and diorite Brecciated phyllite and schist with numerous gabbro-diorite dykes
		Not in contact	
	Lower Devonian and possibly Upper Silurian	5 Flume Formation	Slate, sandy slate and phyllite
		Conformable contact	
	Upper Silurian and Lower Devonian	4 Digdequash Formation	Quartz wacke, silty slate, slate 4a Hornfelsic quartz wacke, and phyllite
		Lateral facies change	
	Upper Silurian and Lower Devonian	3 Waweig Formation 3a 3b	Greywacke, feldspathic greywacke, and slate Hornfelsic greywacke, phyllite, spotted slate Micaceous hornfels, mica schist, minor cordierite, andalusite and staurolite, some spotted slate
		Conformable contact	
	Silurian	2 Ook Bay Formation 2a	Polymictic conglomerate and greywacke Hornfelsic conglomerate and greywacke
		Unconformable contact	
	Lower Ordovician mainly	1 Cookson Formation 1a 1b 1c	Graphitic slate, silty slate and phyllite, minor quartzite, and basic volcanic rocks Quartzite, minor phyllite Mica schist, with minor cordierite, and andalusite, minor phyllite Staurolite-, andalusite- and biotite schist

2.3 DESCRIPTION OF FORMATIONS AND MAP-UNITS

2.3.1. *Cookson Formation*

The Cookson Formation is part of the "Dark Argillite Division of the Charlotte Group" (Mac Kenzie and Alcock, 1960). The latter unit has not been used in the present mapping because it is not confined to the typical Ordovician rock assemblage in the region.
Mac Kenzie (1940) used the name "Dennis Formation" for the Ordovician rocks in the area. This name has not been retained because the Dennis stream section has an unusual high quartzite content and is mostly intensely metamorphosed.
The writer selected therefore the well exposed fossiliferous rocks (locality 1) on the north side of Cookson Island in the St. Croix River, as the type section for this formation.

Distribution. – The Cookson Formation is confined to the core of the northeasterly trending "St. David Dome", in the southwestern part of the map area. It extends from here in a southwesterly direction into the State of Maine.

Lithology. – The Cookson Formation is composed of thinly laminated black slate, silty slate, phyllite with minor interbedded quartzite (1)*, and their metamorphic equivalents. The pelitic rocks consist chiefly of white mica and quartz, while chlorite, graphite, pyrite, and biotite in the vicinity of higher grade metamorphic zones, are the common accessory minerals. Typical spotted slates or "Knotenschiefer" occur in some areas.
A narrow band composed of quartzite and minor phyllite (1a) occurs along the northern and northwestern contact of the formation. They are also exposed in the Rolling Dam area to the south. These rocks consist of slightly flattened and partly recrystallized quartz grains with minor interstitial fine white mica.
Minor dark-green fine- to medium-grained basaltic rocks are intercalated with the phyllites in the vicinity of the St. Croix River, along and north of Oak Bay and west of Rolling Dam.
Most of the rocks have a well developed cleavage, which is chiefly defined by fine white mica crystals and to a lesser extent by flattened quartz grains. Color banding, produced by alternating mica-rich and quartz-rich layers, occurs commonly in the phyllites, and it is sub-parallel to the cleavage planes. The slaty cleavage is quite commonly deformed and a secondary crenulation cleavage occurs in several localities (fig. 3.7) while chevron type cross-folds are common in most of the area (fig. 3.12).
In the central and to a lesser extent in the southwestern and northeastern part of the St. David Dome, the phyllites grade into mica schists (1b). The major constituents are biotite, muscovite and quartz, while plagioclose, zircon, apatite, andalusite and cordierite commonly occur in small amounts. The biotite and coarse white mica crystals cut across the original cleavage, where it is preserved. However, in some areas, the first cleavage has been completely obliterated by the strong development of a secondary cleavage, which is due to parallel orientation of mainly biotite with smaller amounts of white mica and to a lesser extent of irregular quartz streaks.
The mica schists grade into staurolite-andalusite-schists (1c) in the area surrounding the most western adamellite stock. The rocks consist of staurolite-and andalusite porphyroblasts (up to 3 cm) embedded in a groundmass chiefly composed of biotite, quartz, and muscovite. A few red garnet crystals occur locally. The porphyroblasts cut across the first cleavage planes (fig. 2.2), and they have locally been rotated after their formation.

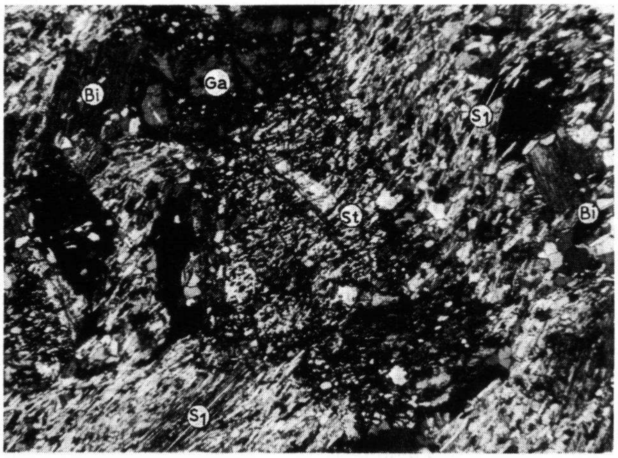


Fig. 2.2. Staurolite (St), biotite (Bi) and garnet (Ga) crystals cutting across S_1 cleavage defined by muscovite in Tower Hill area 40 ×.

Age and correlation. – Dr. R. B. Neuman of the United States Geological Survey discovered graptolite bearing rocks on the north side of Cookson Island during the summer of 1962 (map locally 1). The species was determined to be Clonograptus herrmanni Monsen 1937, which is of Lower Ordovician age. (Cumming, in press).
The rocks of the Cookson Formation can probably be correlated with the "Dark Argillite Division" of the Charlotte Group" in the State of Maine, and with the fossiliferous Ordovician rocks in the Saint John area, in New Brunswick (Cumming, in press).

2.3.2. *Oak Bay Formation*

Distribution, – The Oak Bay Formation, which is defined by Mackenzie (1940), extends from the southern contact of the Cookson Formation, from the St. Croix River to the northeast across Cookson Island and into the Rolling Dam area, where it disappears. A band of fine pebble conglomerate

* Refers to formation number on main map and table of formations.

northeast of Moores Mills is believed to be a correlative of the Oak Bay Formation.

Lithology. – The formation has a maximum thickness of about 300 feet at Oak Bay. It is a polymictic conglomerate with interbedded greywacke (2). Pebbles, which constitute about seventy percent of the rocks, are well sorted and rounded. They vary mostly in size between one and two inches, while some boulders reach diameters up to one foot. They are chiefly composed of quartzite and fine micaceous pelitic rocks, and smaller amounts of diorite, quartz, granite and rarely limestone (fig. 2.3). The metasedimentary pebbles are mostly similar to the rocks of the Cookson Formation. However, it is interesting to note that many pelitic pebbles lack the well developed cleavage, which is typical for the Cookson formation.

Fig. 2.3. Oak Bay Conglomerate, Cookson Island.

In thin sections the fine white mica crystals, which usually define the early cleavage, have a random orientation in these rocks. This suggests that at least no cleavage-folding has affected the Ordovician rocks in Taconic time. The matrix is dark grey-green and has mostly a fine-grained texture. It is composed of a poorly sorted assemblage of angular fragments of altered plagioclase, some potassic feldspar, quartz and meta-pelitic rock, embedded in mostly fine white mica, chlorite and silica. In the vicinity of higher grade metamorphic zones a little biotite is usually developed, which gives the rocks a brownish color. The well sorted and rounded pebble assemblage, embedded in a poorly sorted greywacke matrix suggests that this is a remobilized conglomerate.
The conglomerate has usually a well developed fracture cleavage, which strikes roughly parallel to the slaty cleavage in the Cookson Formation, but the dips are at a higher angle to the bedding. The pebbles are in part flattened parallel to the cleavage planes (fig. 2.3) and a secondary fracture cleavage occurs in certain areas.

Contact relationships. – Bailey and Matthews (1870—71), at first thought that the Oak Bay conglomerate rested conformably on the Silurian Waweig Formation. Matthews (1876—1877) believes that the conglomerate lies unconformably on Upper Silurian rocks. The presence of granitic pebbles, of presumably Devonian age, was part of the evidence for this relationship.
Mac Kenzie (1940) believes that the Oak Bay Formation represents downfaulted blocks of beds lying unconformably on the Ordovician and Silurian metasediments and the Devonian intrusive rocks.
In the well-exposed section on the west side of Oak Bay, the Oak Bay formation grades upwards, by decrease in conglomerate and increase in greywacke and slate, into the overlying Silurian rocks. It is therefore clear that the conglomerate is situated at the base of the Silurian rocks in the area.
The contact zone with the underlying Ordovician rocks is intensely sheared in the exposures on Cookson Island and the St. Croix River, but no intense shearing or faulting is evident in the vicinity of the exposed contact about 1000 feet west of the Waweig River. Faulting appears therefore to be only locally important along the contact, but there is no evidence for a major displacement.
The attitudes of the beds in the Cookson- and Oak Bay Formations, do not differ greatly, where they can be determined in the contact zone. It appears therefore that a simple erosional unconformity separates these two formations.

Age and correlation. – Cumming (in press) describes the occurrence of a Lower Silurian brachiopod in a limestone pebble in the conglomerate. This provides a lower age limit for the formation.
The gradational nature of the contact and the lithological similarity of the conglomerate matrix and the overlying Upper Silurian greywacke (see 2.3.3) suggests that all these rocks have a similar age.

2.3.3. *Waweig Formation*

Distribution. – Sedimentary rocks of the Waweig Formation, which is defined by Mac Kenzie (1940), are well exposed for about three miles along the east shore of Oak Bay. They extend northeastward from here into the Mount Pleasant area. The Waweig Formation is exposed on the west shore of the bay, north and south of Pagan's Cove.
Mac Kenzie (1940) states that the Waweig Formation extends to the northeast beyond the boundary of his preliminary map sheet. However, Mac Kenzie and Alcock (1960) discontinue the Waweig Formation on

the Rolling Dam map sheet, about one mile east of the Digdequash River. Tupper (1959) classified all the sedimentary rocks in the Mac Dougal West map-area, which includes the eastern part of the present map-area, as "Ordovician Charlotte Group".
The writer concluded from a careful study of the rocks in the area that the typical Waweig Formation assemblage, which is described below, extends to the Carboniferous volcanic rocks in the eastern part of the map-area. The thickness of the formation is difficult to estimate. This is because the internal structure of the formation is not well known due to erratic distribution of outcrops and the absence of a good marker horizon. However, the minimum thickness appears to be in the order of three miles.

Lithology. – The Waweig Formation is composed of greywacke with interbedded slate and metamorphic equivalents, and minor intercalated volcanic rocks. The thickness of the beds ranges from less than one inch to well over a foot. However the lithologic layering is mostly obscured due to metamorphism.
The least metamorphosed rocks in the formation are green-grey slate and greywacke (3), which are well exposed in the Rolling Dam area. The former consists of fine white mica, chlorite and quartz, but it lacks the abundant graphitic material, which is typical in the Cookson Formation. The greywacke consists of fragments of sodic plagioclase, some orthoclase, quartz and meta pelitic rock in a matrix of fine white mica, chlorite and silica (fig. 2.4). South of the St David Dome, the feldspar content increases rapidly from the lower to the upper part of the formation, where it locally exceeds 25 percent (fig. 2.5). The slate content

Fig. 2.4. Greywacke Rolling-Dam area 100 ×.

Fig. 2.5. Feldspathic greywacke Waweig area 100 ×.

on the other hand is higher in the lower part of the formation. The Silurian rocks north of the dome (Digdequash Formation) are much better sorted and they have a lower feldspar content, which suggests a north dipping regional slope.
The grade of metamorphism increases gradually towards the granite contact. The rocks first begin to show distinct medium- and dark-brownish-grey banding (3a), which is invariably parallel to the early cleavage planes and usually at a small angle to the bedding, where it is still distinguishable. The alteration is chiefly due to increased biotite content of the more pelitic beds, which are separated by partly recrystallized more silicious bands. The biotite crystals cut mostly across the original bedding and cleavage planes at a high angle. The rocks have a typical blocky appearance as a result of the partial destruction of the original cleavage. Accumulations of organic material give the pelitic rocks locally a spotted appearance. The dark brown hornfelses and intercalated schists, in the vicinity of the granite contact (3b) are composed of brown biotite, muscovite, quartz and plagioclase with usually small amounts of cordierite, andalusite and staurolite, while zircon, apatite and tourmaline are the common accessory minerals.

Contact relationships. – The contact between the Waweig- and Cookson-Formations, in areas where the Oak Bay conglomerate is absent, is not exposed in the map-area. However, outcrops on both sides of the inferred contact show an abrupt rather than a gradational change.

Age and Correlaticn. – Brachiopods, which range in age from Silurian to Devonian have been reported from the fossil localities northeast of Oak Bay (Cumming, 1963; and Bailey and Matthews, 1870—1871).
Bailey and Matthews (1870—1871) consider the Waweig Formation to be of Upper Silurian age and a tentative correlation is suggested with similar fossiliferous rocks in the Eastport area in Maine. Boucot (1966*) concludes from his studies of the Waweig Formation in New Brunswick and Maine, that it ranges in age from Upper Skala (Upper Silurian) to Lower Gedinnian (Lower Devonian). This has been accepted in this thesis for the dating of the Waweig Formation.

2.3.4. *The Digdequash Formation*

Distribution, – The well exposed section along the Digdequash River at Tryon has been selected by the writer as the type locality for the Digdequash Formation. These rocks extend from the Pleasant Ridge area to the southwest, along the northern flank of the St. David Dome, across the west boundary of the map-area, into the Woodland region on the St. Croix River.

Lithology. – The Digdequash Formation is composed of dark-grey and olive-green quartz-wacke, silty slate and slate (4). The quartz-wacke contains abundant angular quartz fragments, small amounts of sodic plagioclase and some pelitic rock fragments, which are embedded in a matrix of sericite, chlorite and silica (fig. 2.6). Small amounts of biotite are present in the metamorphosed hornfelsic quartz-wackes (4a).

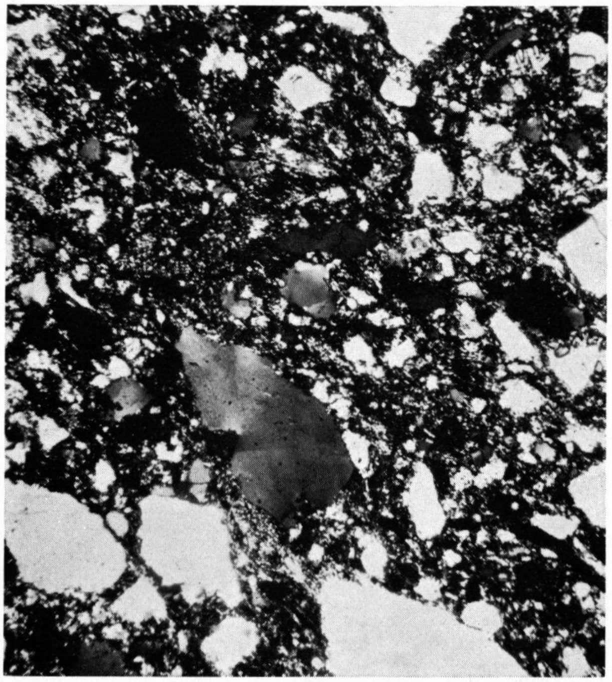


Fig. 2.6. Quartz wacke Tryon area 100 ×.

* In written communication with Mines Branch, New Brunswick Department of Natural Resources.

Most of the fissile pelitic rocks are recrystallized to phyllites, which consist of quartz, fine white mica, chlorite and commonly some biotite.
Bedding is locally well preserved and it usually varies in thickness from less than one inch to over one foot. The early cleavage is mostly sub-parallel or cuts the bedding at a small angle (fig. 3.2).

Contact Relationships. – The Digdequash Formation grades laterally into the Waweig Formation in the Pleasant Ridge area. The contact between the Digdequash- and the Cookson-Formations is a thrust fault in the map-area.

Age and correlation. – Mac Kenzie (1940) discovered poorly preserved carbonized fragments in these rocks along the Canoose River, just west of the map area. It has unfortunately not yet been possible to identify this material. However, the Digdequash Formation appears to be a facies equivalent of the Waweig Formation. Moreover, Devonian folding and regional metamorphism have affected these rocks. It is therefore quite certain that the formation is of Upper Silurian and Lower Devonian age.

2.3.5. *The Flume Formation*

Bailey and Matthews (1870—71) called these rocks collectively the "Pale Argillite Group". Mac Kenzie (1940) includes those rocks, along with the Digdequash Formation (as defined in this thesis), in the "Canoose Formation" of probable Devonian age. Mac Kenzie and Alcock (1960) include these rocks in the "Pale Argillite Division" of the "Ordovician Charlotte Group". Tupper (1959) follows the same interpretation on the Mc Dougal Lake map, which includes the eastern part of the present map area.

Distribution. – The Flume Formation covers practically the entire northern part of the map-area, and it extends westwards into the State of Maine. The well exposed section at the Flume, along the Magaguadavic River, has been selected as the type locality.

Lithology. – The Flume Formation is composed of grey-green phyllites, sandy phyllites and slates. The beds vary in thickness from one half to about two inches (fig. 3.20). The sandy components consist chiefly of slightly flattened quartz grains and mica crystals in a matrix of fine quartz, sericite and a little chlorite. The quartz grains are aligned roughly parallel to the cleavage planes. The fine-grained pelitic rocks are commonly metamorphosed to phyllites, which occasionally carry a little biotite. The rocks are locally very rusty on the weathered surface due to the presence of iron-carbonate.

Contact Relationships. – Both the Waweig- and Digdequash-Formations grade quite rapidly, by interbedding, upwards into the Flume Formation. Carboniferous conglomerate unconformably overlies the Flume Formation, a few miles north of the map area.

Age and correlation. – Bailey and Matthews (1870—1871) describe the occurrence of Lepidodendron plant fragments near Cox's Brook in these rocks. They were subsequently considered Mississipian on the basis of this fossil and a few others, which were found in similar rocks in Queen's County. It has unfortunately not been possible to relocate these fossil localities. However, since these rocks overlie the Waweig Formation (Upper Silurian and Lower Devonian), while they are also affected by varying degrees of metamorphism and pre-granite deformation, they are probably Lower Devonian and possibly Upper Silurian, rather than Mississipian.

2.3.6. *Devonian and Earlier Intrusive Rocks*

2.3.6.1. *St. Stephen Igneous Complex*

Distribution. – The gabbro and diorite bodies exposed in the western part of the map-area are related to the basic complex at St. Stephen, which is known for its nickel-copper mineralization. Smaller intrusions, which are probably also related to this complex, outcrop in the vicinity of Foster Lake and south of Moore Lake.

Lithology. – The St. Stephen basic rocks (6) are described by Mac Kenzie (1940), Dunham (1950), and in unpublished master of science theses at the University of New Brunswick by Hale (1950) and Clark (1962). Moreover Mr. P. Simpson is making a detailed petrological and sulphur isotope study of these rocks at Cambridge University.

The rocks of the main St. Stephen intrusion are mostly medium grained and the color ranges from grey-green to dark-green, depending on the ferromagnesian content. Labradorite and smaller amounts of other basic feldspars constitute about 50 to 60 percent of the rocks. The main ferromagnesian minerals are olivine, hypersthene and monoclinic pyroxene, each one of which can predominate over the others in various parts of the intrusion. Biotite is also a prominent constituent, but it is partly secondary. The ferromagnesian minerals are in part altered to serpentine, chlorite and secondary hornblende. The feldspars show mostly only little alteration. Pyrrhotite and magnetite are the usual accessories. The texture of the rock is mostly granitoid, but it is locally ophitic. Some of the more basic segregations outcrop in the Dennis Stream area. Adamellite intrudes the basic rocks at Milltown, west of the map area.

The smaller stock in the Foster Lake area is chiefly composed of similar rocks as the main St. Stephen intrusion, but coarse-grained diorite is also prominent in this mass. Diorite and gabbro also intrude brecciated Cookson Formation metasediments between Moore Lake and Oak Bay, and some narrow basic dykes are exposed in the area west of the bay.

Contact Relationships. – The rocks of the St. Stephen Igneous Complex intrude the Ordovician Cookson Formation metasediments, and they contain numerous roof-pendants composed of the latter type of rocks.

Age. – A potassium-argon age determination on biotite from a composite gabbro sample gave a value of 462 million years (Mc Cartney et al., 1965).

2.3.6.2. *The Bocabec Igneous Complex*

Distribution. – These rocks occupy most of the southern part of the map-area. They are discussed here separately because it is not known whether the basic rocks, which form the largest part of the mass are related to the St. Stephen basic complex or whether they represent a marginal facies of the St. George granite mass to the northeast.

Lithology. – This complex consists mostly of hornblende-gabbro and smaller amounts of diorite (6), which are intruded by granite and adamellite. The hornblende-gabbro is fine- to medium-grained and has mostly a grey-green color. Labradorite and small amounts of andesine constitute over fifty percent of the rocks. Large brownish-green hornblende crystals, which commonly enclose clusters of feldspar laths, are the main mafic minerals, while pyroxenes, olivine and biotite usually occur in smaller amounts. Magnetite and apatite are accessories. Diorite occurs typically along joints and irregular veins in the gabbro (fig. 2.7). In these rocks, andesine is the most abundant feldspar and oligoclase occurs in small amounts. The feldspars are commonly zoned and they are mostly altered to fine mica and clay minerals. Brownish green hornblende is the predominant mafic mineral, biotite is less abundant and pyroxene occurs only in small amounts.

The basic rocks are intruded by red and grey medium- to coarse-grained granitic rocks (7), similar to those found in the large intrusive mass which occupies the southeastern part of the map area. Narrow adamellite

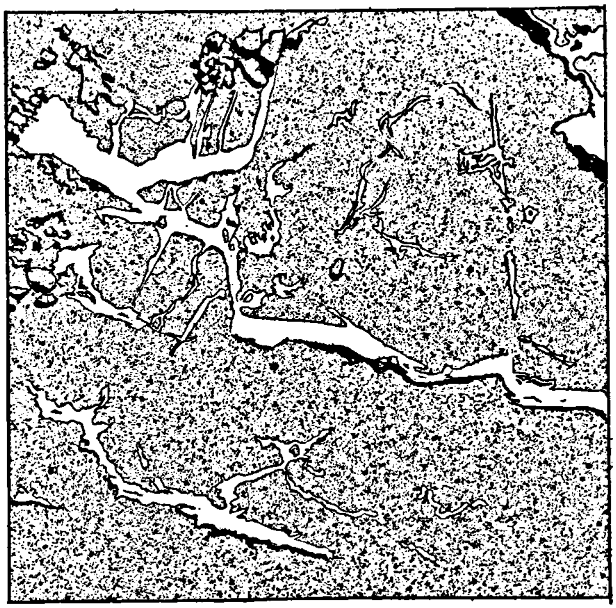


Fig. 2.7. Diorite veins in gabbro Bocabec River area (after photo).

dykes appear to be related to northwesterly trending faults in the area.

Contact relationships. – Small faults, brecciation and silicification are evident along the northeastern contact. This suggests that the contact in that area is a fault, but the relationship further to the west is poorly known due to inadequate exposure.

Age and correlation. – No absolute age determinations are available for these basic rocks. It is possible that they are a marginal facies of the Devonian St. George granite to the northeast. They could also, at least in part, be Ordovician, similar to the St. Stephen basic intrusions.

2.3.6.3. *The "St.GeorgeGranite" and "BeechHillAdamellite"*

Distribution. – The "St. George Granite" (7) covers most of the southeastern part of the map-area, and it intrudes the basic rocks further to the west (6). The entire intrusion has a northeasterly extension of about thirty miles and it is about fifteen miles wide. The later "Beech Hill Adamellite" stocks (8) occur in a zone, which is roughly parallel to the northern contact of the "St. George Granite". Similar rocks occur as narrow dykes which intrude sedimentary rocks along the Magaguadavic River, Cox brook and the small brook which enters the Digdequash River about one half mile south of Lawrence Station.

Lithology. – The "St. George Granite" consists chiefly of red and grey medium- to coarse-grained biotite granite (7). Orthoclase occurs locally as large phenocrysts and it predominates over oligoclase in the central part of the mass. Along the northern contact and in the Clarence Ridge area, in the western part of the intrusion, andesine is present as well as oligoclase, and they predominate locally over orthoclase. Both hornblende and biotite are present in these rocks. Tupper (1959) discovered rapikivi type granite in the Mc Dougal- and Sand brooks. It consists of elliptical orthoclase crystals mantled by oligoclase, with interstitial quartz, pink orthoclase, plagioclase and biotite. The same author mentions the occurrence, locally, of quartz phenocrysts in the granite. However, they have only been found, in the course of the present investigation, in the adamellite stocks and dykes which intrude the St. George Granite (fig. 2.8).
The "Beech Hill Adamellite" (8) is named after the steep hill just north of the confluence of the Magaguadavic- and Piskahegan Rivers, where these rocks are well represented. The color ranges from buff brown in the contact zones to a brownish grey and grey in the deeply eroded cores of the various stocks. The rocks are generally fine- to medium-grained, but locally they can be quite coarse. The texture is usually granular, but it is porphyritic in the contact zone of the intrusions at Beech Hill and Sorrell Ridge. Oligoclase is the dominant feldspar, while orthoclase and quartz

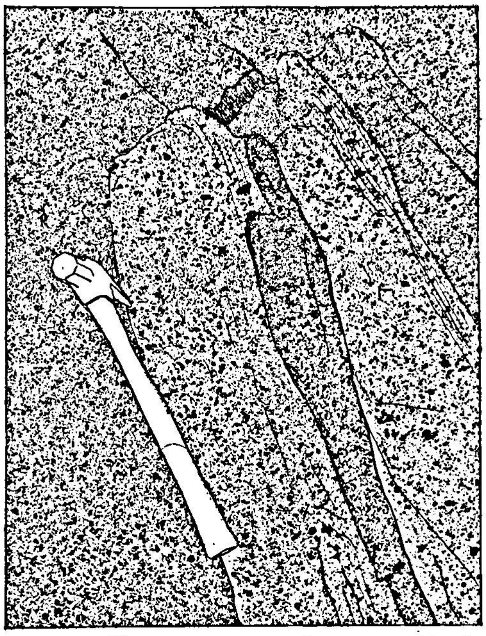


Fig. 2.8. Adamellite dyke (A) intruded into St George Granite (G) in Piskahegan River 1.5 miles east of confluence with Magaguadavic River (after photo).

usually occur in roughly equal amounts. Graphic intergrowths of feldspar and quartz are quite common. Biotite is usually slightly more abundant than muscovite (8), but particularly in the southwestern part of the Tower Hill stock muscovite predominates (8a, 8b, 8c). Hornblende, chlorite and epidote occur in small amounts, while pyrite is the main opaque accessory mineral. Some of the adamellite at Tower Hill (8b)

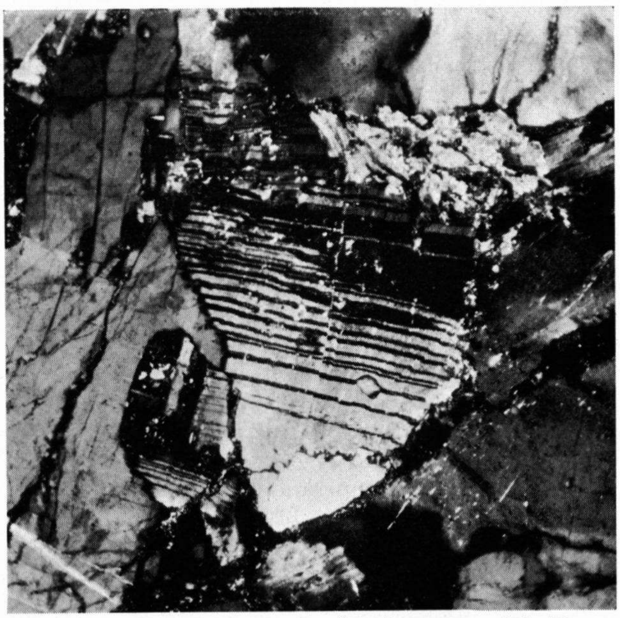


Fig. 2.9. Fractured and strained feldspar crystals in Tower Hill adamellite 125 ×.

contains abundant micaceous partly granitized metasediment inclusions, in the larger of which micro-folds have locally been preserved (fig. 3.16). The feldspar crystals are locally strained and fractured which suggests deformation contemporaneous with or after their formation (fig. 2.9).

Contact Relationships. – Veins of the "St. George Granite" in Waweig Formation rocks occur south of Mount Pleasant and they also intrude Silurian rocks in the vicinity of St. George, south of the map area (Tupper, 1959). A few "Beech Hill" type adamellite dykes, which intrude "St. George Granite", are exposed along the Piskahegan River, south of Beech Hill (fig. 2.8).

Age. – Tupper and Hart (1961) calculated an age of 380 million years from a potassium-argon determination on biotite from a composite St. George granite sample. The "Beech Hill Adamellite" is younger, but no absolute age determination is as yet available.

2.3.7. *Carboniferous Volcanic Rocks*

The Carboniferous volcanic rocks northeast of Mount Pleasant have been mapped by Harris (1964) and Tremblay (1965) for the Mines Branch of the New Brunswick Department of Natural Resources. This mapping has been checked by the writer in the course of numerous mineral exploration traverses and it has subsequently been used for this project. The writer made a detailed study of the intensely altered Mount Pleasant volcanic complex, which represents in essence the intrusive remnants and vent fillings of a major carboniferous volcanoe. It has been possible subsequently to correlate these intensely altered rocks, which comprise the volcanoe, with the extrusive rocks to the northeast. Two major periods of volcanism can be distinguished in both the extrusive sequence and the Mount Pleasant volcanoe.

Distribution. – The Carboniferous volcanic rocks extend for about six miles to the east and seven miles to the north of the Mount Pleasant volcanoe. Van de Poll (pers. comm, 1966) distinguishes two major ash flow tuff sheets in the Caboniferous volcanic sequence: the Rothea- and Seely's Formation, which are separated by a disconformity. This author also distinguishes the Carrow Formation, which lies at the base of the Seely's Formation, but this unit has been included with the Seely's Formation in this description.

Lithology. – The following descriptions have been prepared with the co-operation of Mr. W. H. van de Poll, Mines Branch, New Brunswick Department of Natural Resources, Fredericton. Rock alteration will only be briefly mentioned in this section, since this will be described in more detail in the chapter on mineral deposits.
The extrusive Rothea Formation varies in thickness between 150 and 400 feet. It consists of quartz-feldspar porphyry, which is overlain and at Mount Pleasant intruded by feldspar porphyry.
The quartz-feldspar porphyry (9) is a pink porphyritic rock with numerous small feldspar phenocrysts and quartz eyes embedded in a fine-grained matrix. Orthoclase and micro-perthite predominate over plagioclase, which occurs chiefly as sodic andesine. Quartz eyes are present in roughly similar amounts as the alkali-feldspar phenocrysts. Biotite is the most prominent ferro-magnesian mineral, while hornblende is only locally present. Epidote is rather uncommon, while zircon, zoisite and rutile are the usual accessories. The matrix is a felsophyric mozaic of quartz and feldspar with interstitial white mica, epidote, chlorite, opaque minerals, devitrified shards and flattened collapsed pumice fragments (fig. 2.10). The rocks contain numerous Waweig Formation metasediment fragments near the base.

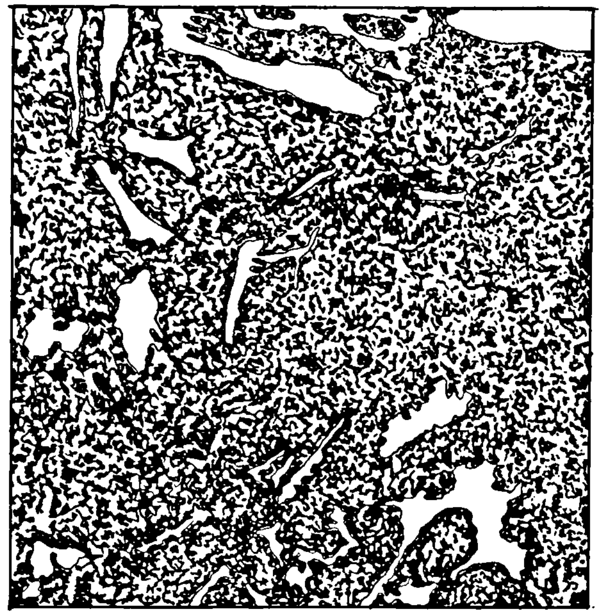


Fig. 2.10. Devitrified shards in Rothea Formation tuffs northeast of Mount Pleasant, 80 × (after photo, W. H. van de Poll).

The phenocrysts in the red feldspar porphyry (10) are usually quite large (up to 1/4 inch) and quartz eyes are only common near the quartz-feldspar porphyry contacts. Andesine feldspar phenocrysts are more calcic in those rocks and they occur in about similar amounts as the alkali feldspars. Hornblende, clinopyroxene and chloride are the prominent ferromagnesian minerals rather than biotite. The matrix consists mostly of finely intergrown quartz and feldspar. Magnetite, apatite, zircon, sphene and fluorite are the usual accessories. The feldspars in both types of porphyry are altered to clay minerals and hydromica.
The only member of the Seely's Formation (11), in this map-area, is a brownish pink quartz-feldspar porphyry, which commonly weathers to a yellowish brown color.

Small andesine- and potassic feldspar phenocrysts occur in about equal amounts, while quartz eyes are present in smaller amounts. Biotite is the usual ferromagnesian mineral.
Apatite, epidote, zircon and zoisite are the common accessory minerals. Near the base, fragments and boulders of Waweig Formation metasediments, biotite granite and Rothea Formation porphyry are locally prominent. The textures of those rocks as well as their occurrence in flat sheets suggests that they are ignimbrites or ash-flow tuffs similar to those described by Marshall (1934), Smith (1960) and van Bemmelen (1961).

Contact Relationships. – The contact relationships of the Carboniferous volcanic rocks with the older sedimentary and igneous rocks are rather complex, and the same applies to the relationships between the various volcanic rock units.
The fundamental rock units in the volcanic sequence have entirely different relationships in the Mount Pleasant volcanoe than in the extrusive tuff sheets to the north and east. At Mount Pleasant, the younger volcanic rocks intrude those of the older units and the contacts are mostly steep, while the equivalent extrusive rocks occur as gently north dipping sheets (Section FF'). The large amount of extraneous material near the base of the extrusive Seely's Formation indicates a disconformable relationship with the underlying Rothea tuff sheet.
Rothea Formation volcanic rocks intrude a northwesterly trending, steeply dipping faulted breccia zone in Waweig formation metasediments, along the west side of Mount Pleasant (9a). About one mile further to the north, volcanic rocks of the same formation unconformably overlie Waweig formation sedimentary rocks. A fault separates these rocks from the granites to the south. An interesting occurrence is also a northwesterly trending dyke, composed of Rothea-type volcanic rocks, which intrudes the "St. George Granite" northeast of Little Long Lake, which is south of Beech Hill.

Age and correlation. – The volcanic rocks are conformably overlain by Carboniferous red beds north of the map-area (van de Poll, 1963), moreover they intrude the Devonian St. George Granite. They are therefore considered to be of Carboniferous age.

CHAPTER III

STRUCTURAL GEOLOGY

3.1. GENERAL STATEMENT

The lithological characteristics of the fundamental rock units and their relationships have been described in the previous chapter. The following sections are concerned with the deformation of these rocks and related phenomena. Several generations of folds are described. The relationships between certain phases of deformation, metamorphism and igneous intrusions are demonstrated.
The joint system is very complex, but certain late stage tension-joints produce locally distinct maxima in stereograms.
The various types of faults are discussed, as well as their possible relationships to the stress system.
Certain unconformable and disconformable relationships between the major rock units are described with reference to the tectonic history of the area.

3.2. FOLDS

Several generations of folds have been identified in the field. Table 3.1 gives a generalized summary of the types and attitudes of these structures. Statistically valid sampling of the minor fold attitudes is difficult in most of the area, due to the erratic distribution of rock outcrops (see 1.2). It is nevertheless possible to distinguish definite trends. Moreover, it is possible in some areas to identify certain late phase folds on air photos, which provides an independent check on the trends.

Fleuty (1964) advocates the use of standard descriptive terms for folds, while Knill (1960) proposes a classification of cleavages. This terminology is mostly applied in the following descriptions, since it appears to agree generally with common usage.

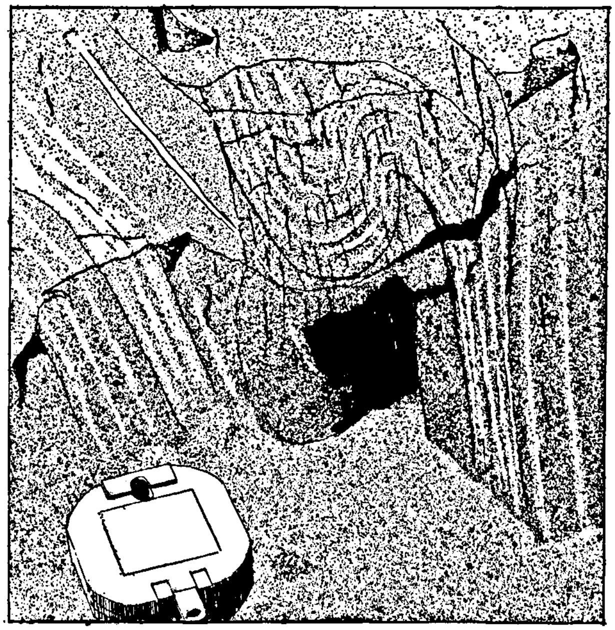
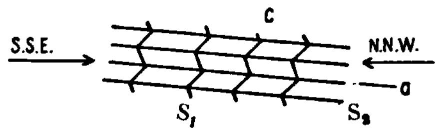
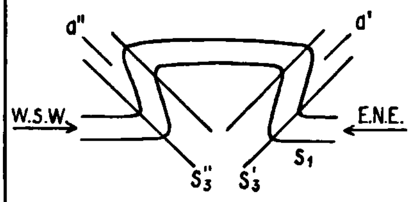
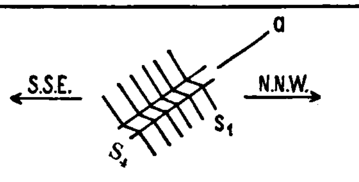


Fig. 3.1. F_1 fold in Cookson Formation (Ordovician), Dennis stream area (after photo).

Table 3.1. Table showing deformation phases.

	DEFORMATION PHASE	CLEAVAGE STRIKE DIP	FOLD AXES PLUNGE	MAIN STRESS	RELATED EVENTS	SECTION PERPENDICULAR TO B-AXIS
COMPRESSION	F1	S_1 E.N.E. steeply	B_1 E.N.E. W.S.W. gently	N.N.W. – S.S.E.		
COMPRESSION	F2	S_2 N.W. N.E. gently	B_2 E.N.E. gently	N.N.W. – S.S.E.	main period meta-morphism	
COMPRESSION	F3	S_3 N.E., N.W. steeply	B_3 N.E.-S.W., N.W.-S.E., steeply	E.N.E – W.S.W.	adamellite intrusions	
TENSION	F4	S_4 E.N.E gently S.S.E.	B_4 E.N.E. W.S.W gently	N.N.W. - S.S.E.		

3.2.1. *Main phase folds*

The St. "David Dome", which is the dominant structure in the map area, appears to be essentially controlled by a composite main phase fold, which is deformed by later folding and domed up and flattened during the intrusion of the granitic rocks.

The minor F_1 folds, which appear to be related to this main structure, vary mostly in size from about one inch to over several feet. In the Ordovician rocks, it is most common to find these minor structures in quartzite bands, which are interbedded with black slate or phyllite (fig. 3.1). The equivalent early folds in the Silurian rocks occur in greywacke or quartz wacke bands, which are interbedded with slate or phyllite (fig. 3.2).

Close to sub-isoclinal folds have been found, but the latter appear to predominate near core of the dome, where they have a distinctly flattened appearance. The hinge lines are mostly rounded, but the degree

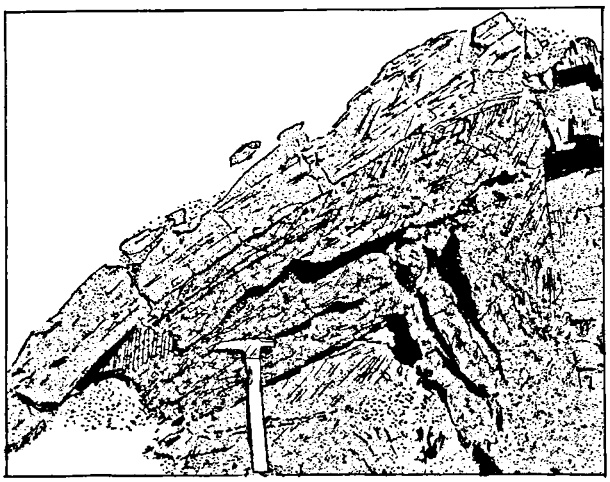


Fig. 3.2. F_1 fold in Digdequash Formation (Silurian), Tryon area (after photo).

of curvature appears to vary with the relative thickness of the competent beds in a certain area. The limbs are attenuated and the hinge lines are locally detached. Most of the small F_1 folds are interfolial (as defined by Turner and Weiss, 1963), but in other areas they affect several layers. The latter occur in zones where competent- and incompetent layers are relatively thin and of roughly equal thickness. The folds are asymmetric in cross-section, which assists in the determination of the major structure. However, later deformation of these early folds has partly obscured this relationship.

Fine crinkles in the slates form lineations which are parallel to the B_1 fold axes.

A slaty cleavage (S_1) is developed parallel to the axial planes of the F_1 folds in the pelitic rocks. It parallels or cuts the bedding planes at a high angle.

Fig. 3.3. Early fold Rolling Dam Station area.

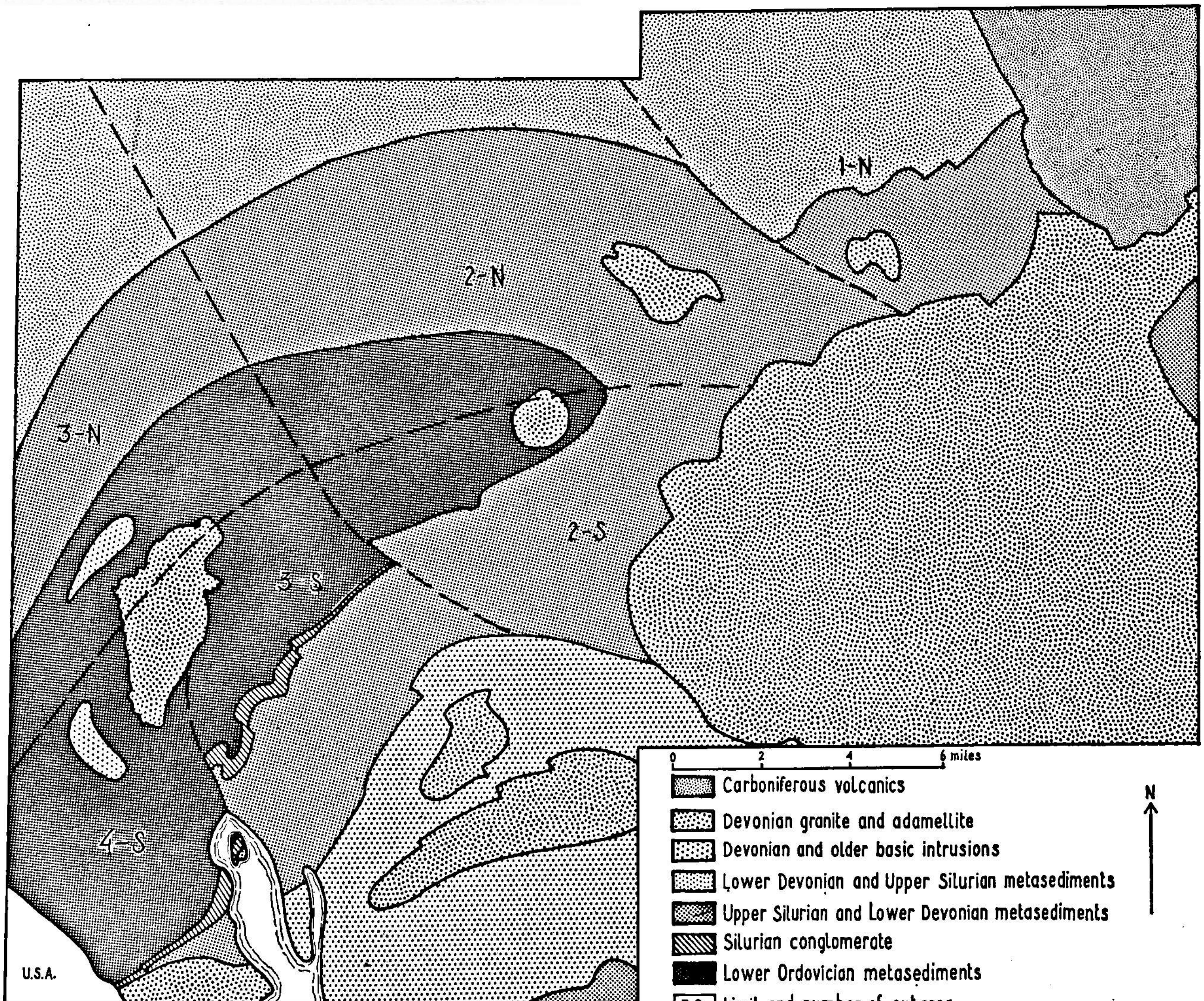


Fig. 3.4. Geological sketch of map-area showing subareas represented by diagrams in figures 3.5 and 3.6.

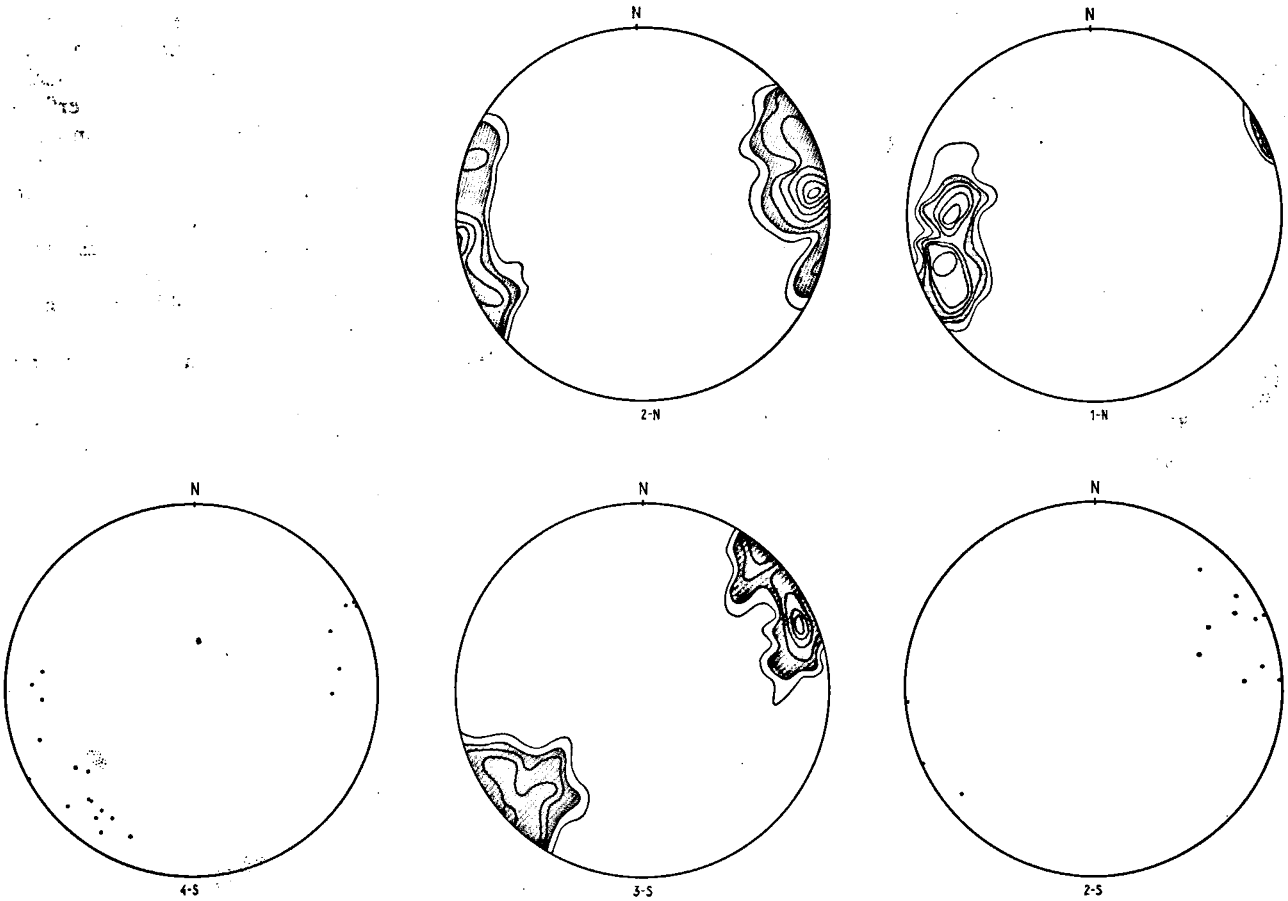


Fig. 3.5. Diagrams showing attitudes of B_1 and l_1. The numbers of the diagrams correspond with the subareas indicated by fig. 3.4.

Diagram	number B_1, l_1	Contours in % per 1 % area
1—N	33	3, 6, 9, 12, 15, 18
2—N	66	1.5, 3, 6, 9, 12, 18, 21
2—S	11	
3—S	52	2, 3, 6, 9, 12, 15
4—S	20	

In the latter case, the slaty cleavage is locally deflected into a fracture cleavage, which developed at a steep angle to the competent beds.
It is interesting to note that a few folds have been found which have a concentric cleavage and they also show a poorly developed superimposed slaty cleavage (fig. 3.3). They represent probably the earliest forms of F_1 folds. This agrees with the usual transition between folds with concentric cleavage and slaty cleavage described by De Sitter (1964).
The attitudes of the F_1 fold axes (B_1) and the axial planes (S_1) are shown in figures 3.5 and 3.6 for several small areas north and south of the St. David Dome (fig. 3.4). It can be seen that the maxima in each sub area indicate roughly the local trend of the main dome. The deviations from the mean trend are due to deformation by later folds, as well as doming related to the intrusion of granitic rocks into the core of the main structure, while deflection by competent beds was locally important. The F_2 folding has in some areas greatly affected the present attitudes of the S_1 planes, but it is evident in the field that the simultaneous effect of the F_3 folding (see 3.2.3) and the doming of the granitic intrusions has produced the greatest change in the attitudes of these structures. It appears that during the latter deformation, the limbs of the main antiform have been rotated outward in a northerly and southerly direction (see 3.2.3) and the minor folds have been flattened near the core of the main structure. The rotation of the S_1 planes is suggested by the change in attitudes of these planes across the antiform (fig. 3.6).

3.2.2. *Second phase folds*

The F_2 folds deform the bedding (S_s) and the slaty cleavage (S_1). They vary in size from a fraction of one inch to at least one hundred feet. The smallest are crenulations which deform the early cleavage and thin bedding planes (fig. 3.7). The larger folds occur

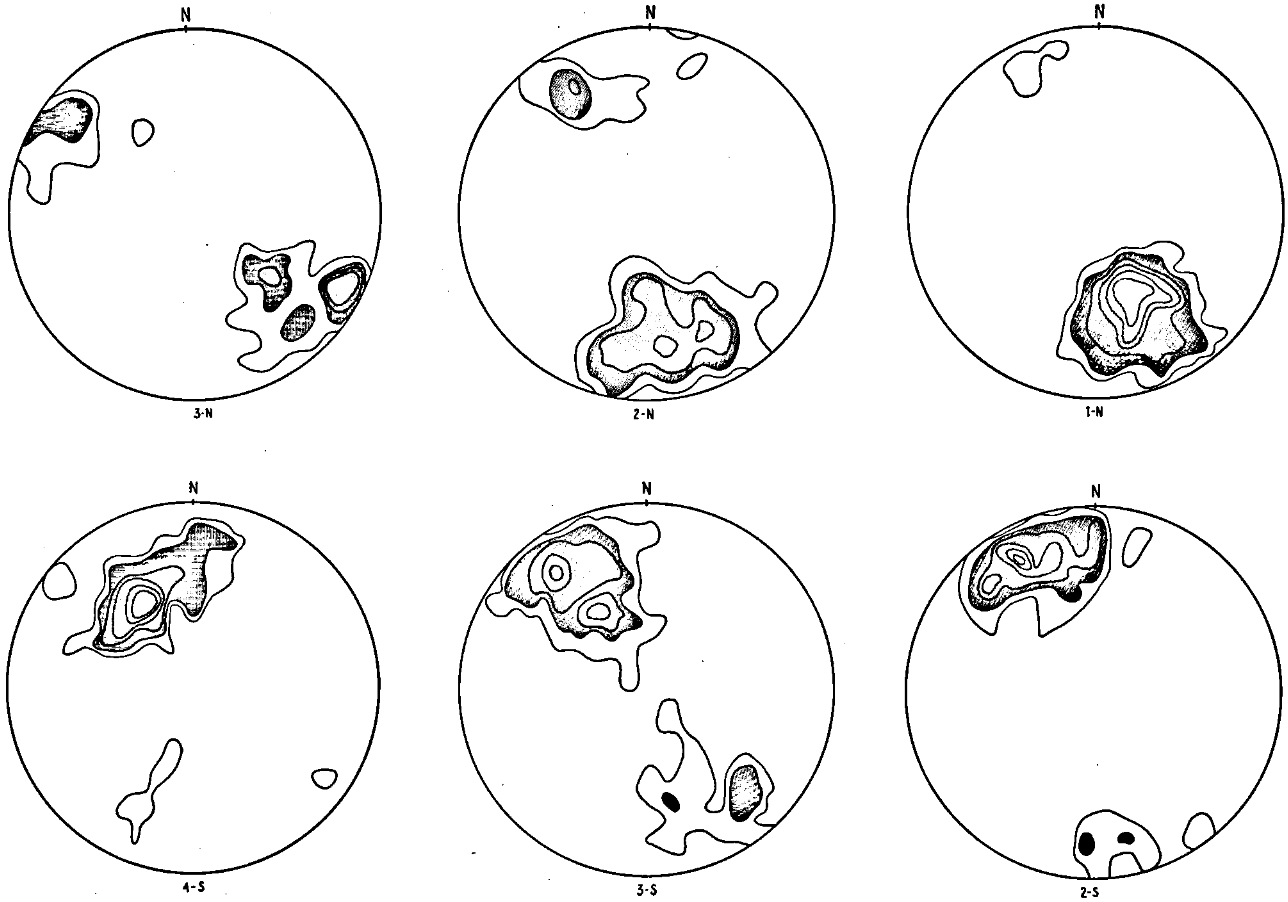


Fig. 3.6. Π–s_1 diagrams. The numbers of the diagrams correspond with the subareas indicated by fig. 3.4.

Diagram	number π-s_1	Contours in % per 1 % area
1—N	92	1.1, 3, 6, 9, 12, 15
2—N	100	1, 3, 6, 9
2—S	66	1.5, 3, 6, 9, 12, 15
3—N	40	2.5, 6, 9, 12
3—S	91	1.1, 3, 6, 9, 12
4—S	51	2, 3, 6, 9, 12, 15

in thick quartzite, greywacke or quartz wacke bands (fig. 3.8).
They occur also in several different shapes. The hinge lines are usually rounded, while the degree of curvature varies with the relative thickness of the competent beds. The angles between the limbs are variable but they are usually greater than 90 degrees. Attenuations along the limbs of some of these open folds (fig. 3.9) are probably related to the F_1 folding.
The axial planes of the F_2 folds, which deform the S_1 planes are roughly parallel to the closely spaced typical strain-slip- or crenulation-cleavage planes (S_2). They are well developed in the exposure shown in figure 3.7. The S_2 planes are deflected by competent

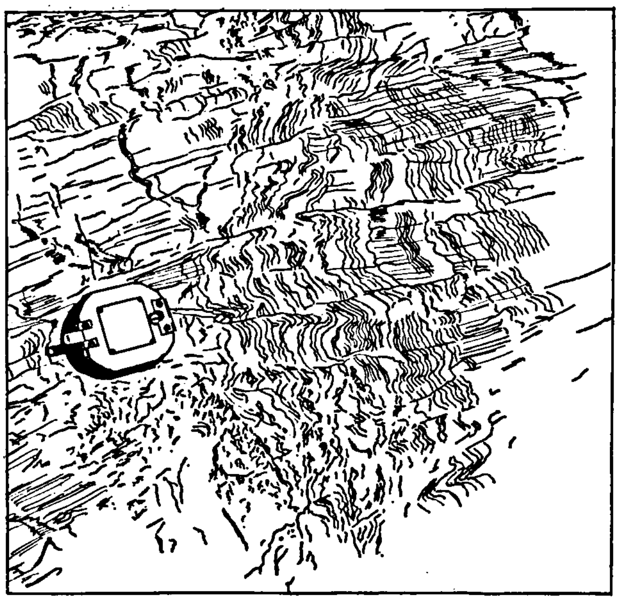


Fig. 3.7. S_2 crenulation cleavage, Cookson Formation Rolling-Dam area (after photo).

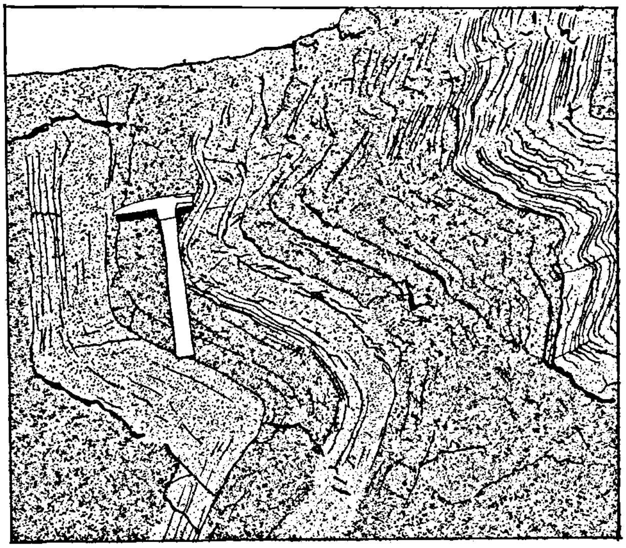


Fig. 3.8. F_2 folds in quartz-wacke-slate sequence, Digdequash Formation, Tryon area (after photo).

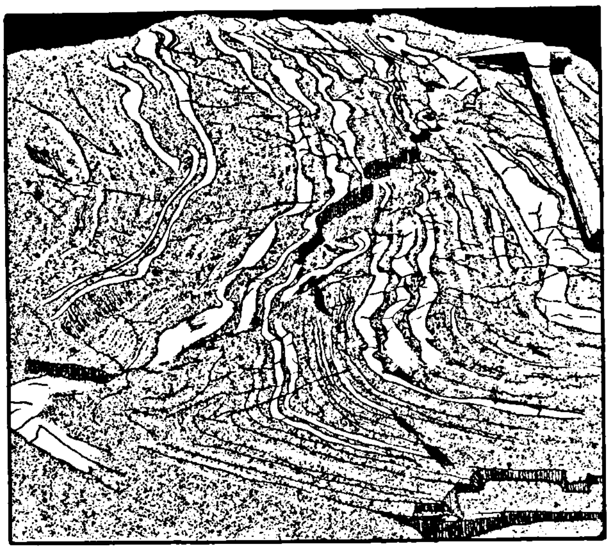


Fig. 3.9. F_2 folds in quartzite, Cookson Formation, Rolling Dam area (after photo).

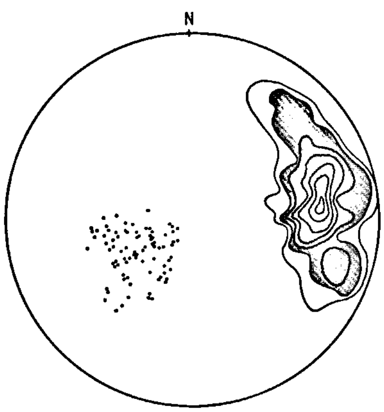


Fig. 3.10. Π-S_2 diagram and attitudes of 94 B_2 axes (contours at 1.1 %, 3 %, 6 %, 9 %, 12 %, 15 % and 18 % per 1 % area), Tryon – and Rolling Dam Station areas.

beds and they are then usually replaced by a widely spaced, irregular fracture cleavage (fig. 3.9).
The F_2 folds plunge for the most part gently to the east or northeast (fig. 3.10), while they are all overturned to the south. The axial planes dip predominantly at a low angle to the east or northeast, but a few dip gently to the north. The variation in attitude of the F_2 fold axes (B_2), in the Tryon-and Rolling Dam Station areas where they are best exposed, is mainly due to the variation in attitude of the S_1 planes, since F_3 folds are poorly developed in this area.
The intensity of F_2 folding varies markedly. In most of the Rolling Dam area, crenulations are well developed in the slates, but the more competent beds are only slightly deformed. However, competent beds of similar thickness in the Tryon area, which is further to the north, are intensely deformed. Moreover, they appear to die out rapidly in the overlying phyllites. A few well developed F_2 folds are preserved in quartzite bands in biotite-staurolite-andalusite schists along the eastern contact of the Tower Hill adamellite stock (fig. 3.11). The S_2 cleavage is here defined by coarse biotite crystals. Staurolite-and andalusite crystals are also well developed in several outcrops in these rocks and they are roughly parallel with the biotite crystals. Locally, they have been rotated after their formation. The relationship between metamorphism and F_2-folding is further discussed in section 3.2.5.

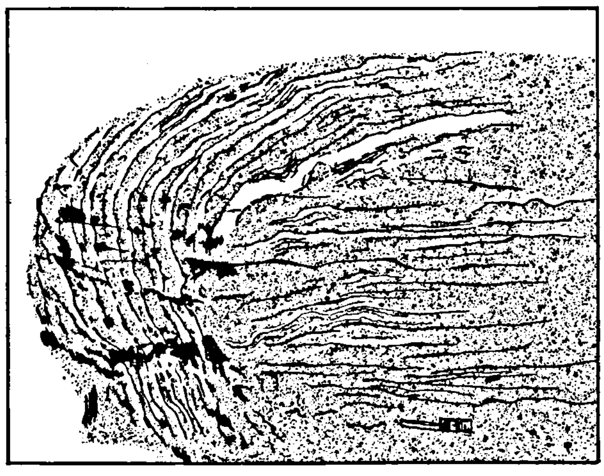


Fig. 3.11. F_2 fold in quartzitic band associated with biotite-staurolite- andalusite-schist, Cookson Formation, east of Tower Hill adamellite intrusion (after photo).

Fyson (1964) describes similar F_2 folds from the Parrsboro area in Nova-Scotia (fig. 1.1) which are also overturned to the south.
This author suggests that the F_2 folds in the Parrsboro area formed possibly in response to the movement of the of upper layers down an average southerly dip towards the main fault in that area.
In northern Charlotte County, the formation of F_2

folds can not be explained with gravity gliding. In the first place there is no suggestion of a south dipping regional slope during the formation of the F_2 folds. In fact, a north dipping regional slope appears to have prevailed during most of the geological history of the area, except in post glacial time. This is shown for the Upper Silurian and Lower Devonian by the increase in maturity of the sediments from south to north (see 2.3.3). Moreover, the younger Flume Formation rocks are only found along the northern flank of the St. David Dome, while fragments of these rocks occur again in the Carboniferous conglomerate further to the north. The F_2 folds also lack the typical characteristics of gravity gliding structures (see De Sitter, 1964, p. 254), while random orientation of the fold axes should also be expected in the case of the latter type of movement.

The F_2 folds deform the F_1 folds, but the axial trends are quite similar. This suggests that they have been formed consecutively, but possibly by the same compressive stress system (see table 3.1). Moreover, the zone where F_2 folds have been found coincides with the upper part of the biotite schist and the lower part of the hornfelsic greywacke and phyllite zone. This might have produced a zone of low shearing resistance, which favoured their development. The same deformation has undoubtedly affected the underlying higher grade metamorphic rocks, but the folds are rarely detected since the original structures have been obliterated.

De Sitter and Zwart (1960) describe similar structures from the Pyrenees. These authors distinguish an upper supra-structure characterized by steep folds, and a lower infra-structure distinguished by flat folds. Both structures are considered to be of a similar age and they developed as a result of a north-south compressive stress. Zwart (1963) believes that the formation of flat lying rather than steep folds in the infrastructure is due to increased temperature, accompanied by greater rock plasticity. Therefore, laminar flow is favoured over simple flattening, as in cleavage folding. Flattening is ascribed, under these conditions, to laminar flow under a load and the component of the compressive stress at right angles to the plane of flattening. Movement along the planes of flattening is demonstrated by the asymmetry of the folds and the consistent sense of rotation of porphyroblasts, which grew during the deformation process.

The F_2 folds, in the map area, developed probably contemporaneously with a vertically rising temperature front. The temperatures in the affected zone became apparently sufficiently high to permit plastic flow. Therefore the simple flattening associated with the F_1 folding (perpendicular to S_1), was replaced by flattening mainly due to laminar flow under a load. Most of the F_2 folds, which are exposed in the map area, occur along the margin rather than in the biotite schist zone. This suggests that they were formed as a result of friction marginal to the zone of plastic flow.

3.2.3. *Third phase folds*

A few F_3 folds of microscopic dimensions have been found but most have limbs ranging in size from about one inch to a few feet. Major F_3 folding appears to have deformed the Oak Bay Formation, northeast of Oak Bay (see main map).

The F_3 folds which deform the S_S and S_1 planes have sharp hinge lines and straight limbs, and they are mostly interfolial (fig. 3.12). The angles between the limbs vary greatly. Many are open (fig. 3.13 and 3.14) and others are close or tight (fig. 3.15). The latter

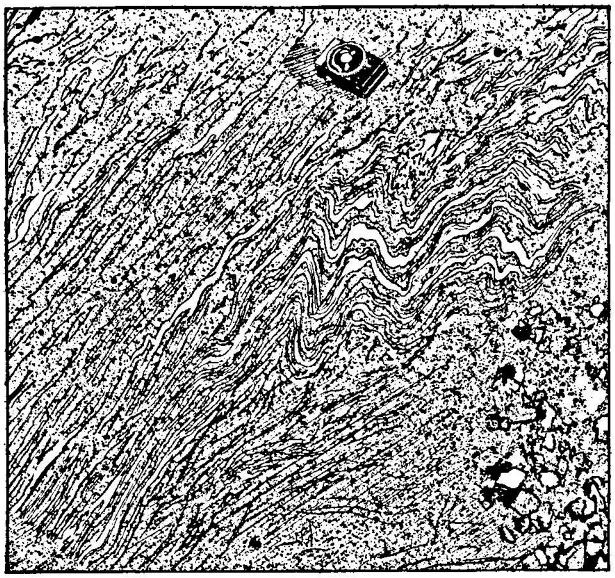


Fig. 3.12. Small E.N.E. trending interfolial F_3 folds in thinly bedded phyllite-quartzite sequence, Cookson Formation, Waweig River area (after photo).

Fig. 3.13. N.W. trending F_3 fold in quartzite, Cookson Formation, Waweig River area.

have sometimes a slightly flattened appearance and they occur in the vicinity of the core of the St. David Dome. The axial planes are always steep (fig. 3.19) and irregularly curved and only fracture cleavage has developed as a result of this deformation. The fold axes are curved in areas affected by F_2 folds. The most primitive F_3 folds are represented by simple kinks in the S_1 planes (fig. 3.16).

F_3 folding produced asymmetric warps in the S_2 planes, where the latter are well developed (fig. 3.17). This is most evident in the schist zone along the Tower Hill adamellite stock.

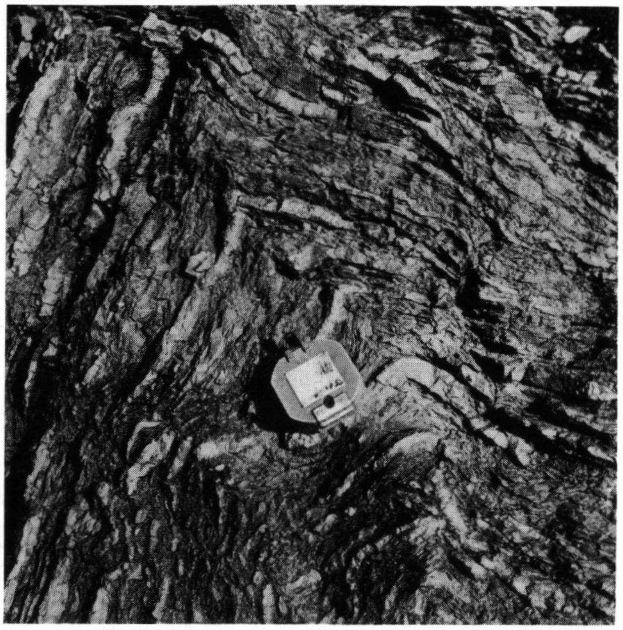


Fig. 3.14. N.W. trending F_3 fold in greywacke-slate sequence, Waweig Formation, Cookson Island.

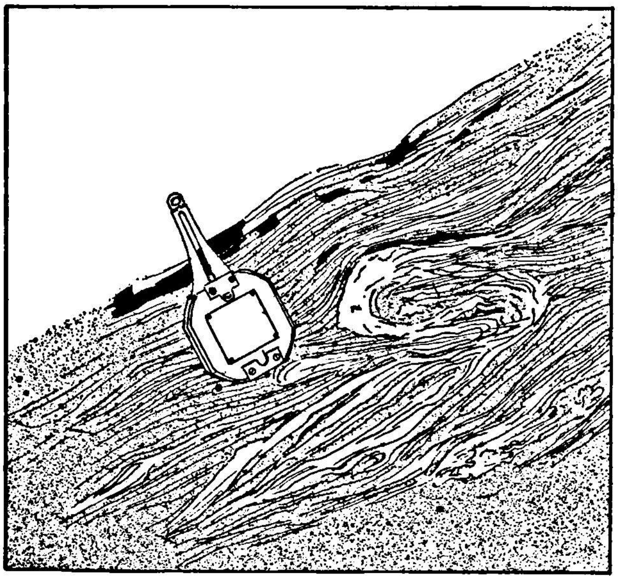


Fig. 3.15. W.S.W. trending F_3 fold in Cookson Formation Dennis stream area (after photo).

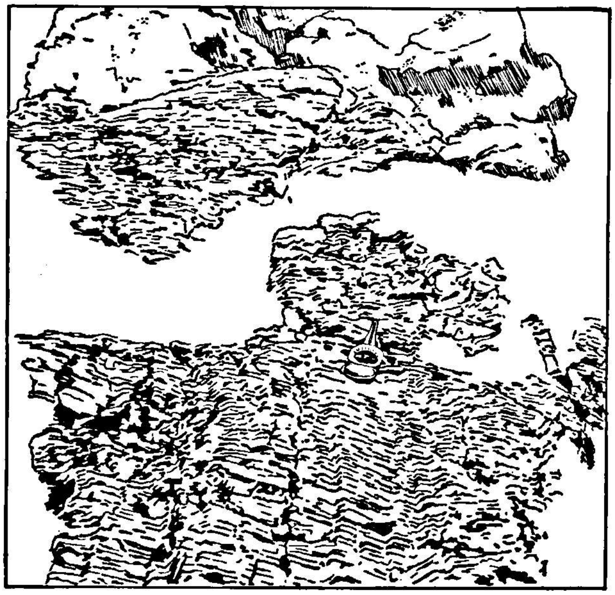


Fig. 3.16. Metasediment inclusion in Tower Hill adamellite stock with kinked S_1 planes (after photo).

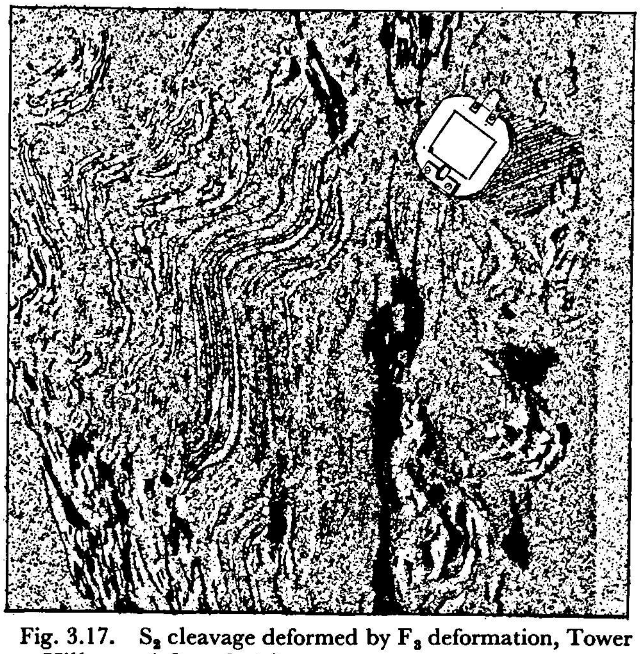


Fig. 3.17. S_2 cleavage deformed by F_3 deformation, Tower Hill area (after photo).

Figure 3.18 shows that the attitudes of the B_3 fold axes fall in two girdles which are oblique to the average trend of the earlier folds. Conjugate pairs of these folds with intersecting axial planes occur locally, but it is more common to find either one set or the other developed in a certain area. The attitudes of the F_3 folds vary with the folded surfaces. For instance, they plunge mostly to the northwest or northeast in the Piskahegan area, where the S_3 and S_1 planes dip north. However, they plunge to the southwest or southeast in the Dennis Stream area, on the southwest side of the St. David Dome.

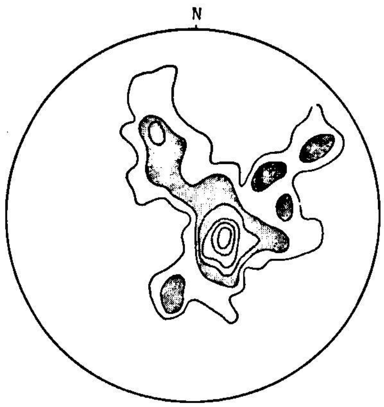


Fig. 3.18. Diagram showing attitudes of 88 B_3 axes (contours at 1.1 %, 3 %, 6 %, 9 %, 12 %, and 15 % per 1 % area).

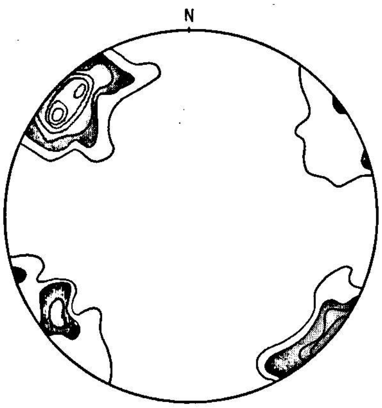


Fig. 3.19. Π–S_3 diagram (88 poles, contours at 1.1 %, 3 %, 6 %, 9 %, 12 %, 15 % and 18 % per 1 % area).

The F_3 folds which occur in partly preserved metasediment inclusions in the Tower Hill adamellite stock, indicate the age relationship of this intrusion to rock deformation (see 3.2.5).

The S_1 planes are forced apart around the interfolial z-shaped F_3 folds. This suggests that these structures have been formed as a result of shortening in the direction of the S_1 planes and dilatation perpendicular to these planes. This effect is consistent with an east-northeasterly trending compressive stress. It has been noted that small F_3 folds trend usually northwest in one area and northeast in another, rather than form conjugate pairs. This is probably due to the relationships of the minor structures to the major folds. Major F_3 folds with limbs of one mile and greater are evident on air photos. This is due to silicification of these structures, which occurred contemporaneously with or after the adamellite intrusions (see 3.2.5).

It appears that the simultaneous effect of the stresses related to the F_3 folding and these intrusions have mainly produced the variation in attitudes of the F_1 folds.

Fyson (1964) describes F_3 folds from the Parrsboro area in Nova Scotia, which show some similarity with these structures in northern Charlotte County. However, they differ in that they are practically all open folds, while those in northern Charlotte County vary from tight-to open folds. This author describes these structures as kink folds. The shapes resemble some of the F_3 folds in the map-area It is interesting to note that a quite similar conjugate cross-fold system occurs in the Pyrenees in Spain (Zwart, 1963, and Oele, 1966).

3.2.4. *Knicking*

Knicking of the S_1 and S_3 planes is well developed in the thinly bedded slates, sandy slates and phyllites of the Flume Formation (fig. 3.20). However, these structures become less pronounced towards the south and they die out in the thick beds of the Digdequash- and Waweig Formations.

The knick zones strike approximately parallel with

Fig. 3.20. Knick zones in sandy slates and phyllites at the Flume.

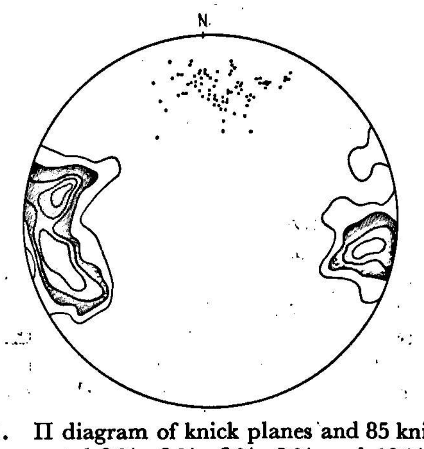


Fig. 3.21. Π diagram of knick planes and 85 knick B-axes (contours, at 1.2 %, 3 %, 6 %, 9 % and 12 % per 1 % area), subareas 1N and 2N.

the S_1 cleavage planes and they dip gently to the south (fig. 3.21). They vary mostly in thickness from one to about six inches and they commonly converge and die out towards the south. The hinge lines are mostly sharp angular in these thinly laminated rocks. Quartz veins fill part of the numerous parallel open fractures in the zones.
The angles between the rotated S_1 planes in the knickzones and the undeformed S_1 planes vary between 20° and 25°. The rotation is always clockwise, which means towards the north. This produces a shortening in the dip direction and a dilatation perpendicular to the S_1 planes. This movement is consistent with a horizontal tensional stress or relative subsidence of the north limb of the St. David Dome. Knicking of S_3 planes has only been observed in one small outcrop, where the Flume Formation is exposed in the Piskahegan River.
The prominence of knickzones in the Flume Formation is due to the thinly laminated character of these rocks, which permits slipping along the cleavage planes in the knickzones. Moreover, it is quite possible that these structures are related to the subsidence of the Carboniferous basin, just north of the map area.

3.2.5. *The relationship between folding, metamorphism and igneous intrusions*

The relationship of the internal cleavages of certain porphyroblasts, such as biotite, staurolite, andalusite or garnet, to the surrounding external schistosity makes it possible to determine the time relationship between folding and metamorphism. Zwart (1960, 1962) describes this procedure in detail for the Pyrenees.
It has been mentioned in the lithological descriptions (2.3.1) that the S_1 planes are chiefly defined by fine white mica and to a lesser extent by flattened quartz grains. However, biotite and staurolite crystals, which developed in higher grade metamorphic rocks cut across the early cleavage planes (fig. 2.2). This means that these minerals have been formed after the main phase folding.
A few well developed F_2 folds which are preserved in quartzite bands in biotite-staurolite-andalusite schists along the eastern contact of the Tower Hill adamellite stock, are described in section 3.2.2. In these folds, the S_2 planes are defined by coarse biotite crystals. This means that these minerals have been formed under the same stress conditions and therefore probably contemporaneously with the F_2 folding.
Small F_3 folds have been found in partly preserved metasediment inclusions in the Tower Hill adamellite stock (fig 3.16), while major deformation of the S_2 planes has been demonstrated by detailed mapping in this area (main map). This suggests that the F_3 folding predated or was contemporaneous with the adamellite intrusions. It is particularly evident from airphotos that well developed major F_3 folds of both main trends are associated with all the adamellite intrusions in the map-area.
It can be concluded that the high grade metamorphism preceded the adamellite intrusions, rather than resulted from it. Moreover, it is definitely later than the main phase (F_1) folding.

3.3. JOINTS

Joints have been measured throughout the mapping program in both the igneous and sedimentary rocks. They have subsequently been plotted on stereograms for various parts of the map area. The distribution patterns are however very complex and it did not seem possible to make a reasonable interpretation. Therefore, most of these diagrams have not been included in this thesis.
The joint pattern of the well exposed Beech Hill adamellite stock is rather unusual (fig. 3.22). A distinct maximum is indicated, which coincides with the trend of typical tension joints in this intrusion. The attitudes of these structures correspond very closely with the average trend of the mineralized tension fractures at Mount Pleasant (see fig. 4.6). This direction showed also in the other diagrams, but it was less pronounced.

Fig. 3.22. Π diagram joints in Beech Hill adamellite intrusion.

It is interesting to note that the trend of these tension joints is symmetrically related to the conjugate F_3 fold trends. Therefore, it is possible that they are the result of the compressional stress, which produced these folds.

3.4. FAULTS

3.4.1. *Honeydale Thrust*

The main known strike fault in the area is the "Honeydale Thrust", which separates the Cookson-and Digdequash Formations (see map and section BB_1). The name has been derived from the small village which is crossed by the fault. Mac Kenzie was aware of this structure, since it was mentioned in his lectures at the University of New Brunswick (pers. comm. R. R. Potter, 1966) but is was never indicated on a published map.

The main fault plane is not exposed in the map area, but it is evident from related structures, such as small faults, slickensides and locally intense silification. These small structures occur in several localities, but they are best exposed just west of the map sheet. It appears in the field that the latest thrust movement is post F_2 folding, but the original thrust is probably related to the formation of the main antiform. The fault continues west of the map area, while it diminishes in importance towards the northeast and it dies out in the Sorrell Ridge area.

The exposure composed of thick quartzite overlain by slate and quartz wacke, in the Digdequash River near Rolling Dam probably represents a window through the "Honeydale Thrust". This indicates an offset of about three and one half miles (section BB_1). The exposure is situated in the belt of adamellite intrusions and it has probably been produced by doming.

It is also interesting that the fault appears to follow, at least in part, the upper zone of well developed F_2 folds (section BB_1).

3.4.2. *Wrench Faults*

Northwesterly trending wrench faults are very prominent in the area. The main fault planes are only exposed in a few localities, but the related smaller structures suggest that the dips are generally steep, while associated drag folds indicate that the movement is chiefly a strike slip. The offsets are mostly left-handed in the central and western part of the area, while they are mostly right-handed in the eastern part.

The major structures consist of several smaller parallel faults, which in some areas produce a total horizontal offset of more than three miles.

Several of the northwesterly trending wrench faults produce offsets in the Devonian granites and therefore the last movements postdate these intrusions. This indicates also that the last movement occurred after or possibly during the final stages of F_3 folding, as a result of north-northwest to south-southeast trending extension (see 3.2.3).

The main northwesterly trending fault system, which is associated with the Mount Pleasant volcanoe, provides particularly good evidence for extension in a north-northwesterly to south-southeasterly direction (main map). It appears that the volcanoe has been formed as a result of stretching of the narrow block between the main faults. This produced voids which made it possible for the volcanic material to reach the surface. The trends of the mineralized tension fractures (fig. 4.6), which were formed during the final stages of volcanic activity are also generally consistent with this stress.

Northeasterly to easterly trending wrench faults are locally important in the area. The offsets are right handed but usually smaller than along the northwesterly faults.

3.5. UNCONFORMITIES

The Ordovician-Silurian and, the Silurian and Upper Devonian — Carboniferous contacts are distinct unconformities in the map area, while a disconformity separates the two main Carboniferous tuff sheets.

The Silurian Oak Bay Formation, which unconformably overlies the Ordovician Cookson Formation, is probably a remobilized conglomerate (see 2.3.2). The pebbles are well rounded and sorted, while the matrix is a poorly sorted greywacke. Moreover, the correlative of the Oak Bay conglomerate on the north side of the St. David Dome is a much finer quartz pebble conglomerate. This suggests that the main conglomerate deposition occurred along the base of a major fault scarp. It has not been possible to find direct evidence for this structure. However, known metallic mineral occurrences and high trace metal in the streams tend to occur in a zone where this contact intersects the belt of adamellite intrusions. This suggests renewed opening of a fundamental fault zone. This relationship is quite common throughout the general region (pers. comm. R. R. Potter, 1966).

The unconformable contact between the Upper Silurian and Lower Devonian Waweig- and the Carboniferous Rothea Formation has been discussed in section 2.3.7. The metasediments are locally intensely brecciated in the contact zone with the volcanics. Moreover the volcanics in the zone contain large blocks and boulders of Silurian metasediments, but this extraneous material decreases rapidly in size and quantity away from the contact.

Van de Poll (pers. comm. 1966) interprets this relationship, by assuming that the entire area underlain by Carboniferous rocks has collapsed along a fault zone, which presently forms the contact with the Waweig Formation. However, the extrusive volcanic rocks are not very thick and it appears equally possible, in the writers opinion, that they have been deposited in a shallow north-northwesterly trending basin, while the volcanic rocks were supplied from more or less linear volcanic rifts, such as Mount Pleasant. Brecciation of the country rocks and abundant coarse extraneous material can be expected near the base of the tuff sheets flanking these rifts. In this case, collapse would be confined to narrow rifts rather than to the entire volcanic belt. It is quite evident from the distribution of volcanic dykes in the area that volcanic activity was indeed quite wide spread during the Carboniferous.

CHAPTER IV

MINERAL DEPOSITS

4.1. INTRODUCTION

Three distinct types of metallic mineralization occur in the map area. They are tin-molybdenum-base metal-, nickel-copper- and arsenopyrite – gold mineralizations.

The Mount Pleasant tin-molybdenum-base metal deposit is probably the most interesting in the area, since this type of mineral occurrence is uncommon in North America. Several low-grade tin-molybdenum and some base metal showings are related also to the adamellite intrusions west of Mount Pleasant (see main map).

The nickel-copper mineralization is associated with the St. Stephen basic intrusion, part of which extends into the southwestern part of the map-area. The main ore bodies are situated west of the map-area and north of the town of St. Stephen.

A number of arsenopyrite-gold showings occur in the area west of Rolling Dam.

4.2. THE MOUNT PLEASANT DEPOSIT AND OTHER TIN PROSPECTS

4.2.1. *Discovery and Development*

Base metal was discovered on Mount Pleasant by a group called "Geochemical Associates", during a regional geochemical survey in 1954. This group staked the property as a base metal prospect for Selco Explorations Limited, who did a geochemical soil survey and limited electromagnetic work. Investigation of the discovered anomalies by four diamond drill holes proved disappointing and subsequently the property was returned to Geochemical Associates.

Later Kennco Explorations (Canada) Limited, became interested in the property, since the deposit appeared to have some characteristics in common with the well known porphyry copper deposits. Six holes were drilled beneath some newly discovered base metal anomalies. However, the results were disappointing and Kennco withdrew, and Geochemical Associates allowed the claims to lapse.

A new group staked the ground in 1959 and formed Mount Pleasant Mines Ltd., to explore the property. Dr. W. L. Young, one of the founders of this company, collected some rock samples which assayed moderate to high in tin and base metals. This caused Kennco to become interested again and they made an agreement with Mount Pleasant to explore the property on a partnership basis. Kennco drilled several northeasterly to southwesterly sections across what was thought to be the strike of the mineralized zones. Ore-grade mineralization was intersected by several drill holes, but the results were considered disappointing since the ore did not appear to extend sufficiently in a northwesterly or southeasterly direction.

The writer started a geological study of Mount Pleasant and the surrounding area during the spring of 1961. As a result of this study, a diamond drilling program was carried out in the northern part of the property, which led to the discovery of the main east-west-trending mineralized zone. An adit was subsequently constructed from the north side of the mountain (see geological map of Mount Pleasant) in order to provide access to the potential ore. A network of drifts was laid out from the adit along the potential ore zones and a number of short raises were put up in order to test the vertical continuity of the mineralization. Closely spaced horizontal diamond drill holes from the drifts across the mineralized zone made it possible to map the geology and mineralization in detail (fig. 4.1).

4.2.2. *Geology of the Mount Pleasant Deposit*

General Statement. – The general geological setting of Mount Pleasant has been discussed in section 2.3.7, while the relationship of the volcanoe to the regional structure is discussed in section 3.4.2. The following description is chiefly concerned with the nature and distribution of mineralized structures in the volcanoe. It was possible to make a detailed study of the deposit from the underground workings and the cleared areas on the surface, moreover about 100.000 feet of diamond drill core is available on the property. The writer prepared maps and sections (at 20 foot intervals) across the mineralized zones at a scale of one inch equals twenty feet, which are deposited in the company office on the property. Generalized smaller scale maps and a few sections are included in this thesis (fig. 4.1 – 4.5).

The rocks have been affected by intense hydrothermal alteration, which made it initially very difficult to determine the original rock units and the structure of the volcanoe. Therefore, the writer made first a detailed study of the hydrothermal rock alteration, which was summarized in a Master of Science thesis at the University of New Brunswick (Ruitenberg, 1963). The entire property was subsequently remapped and all the diamond drill core was relogged. In order to reduce the complexity of the geological representation, two types of maps and sections were then prepared: one type indicating the rocks types (e.g. fig. 4.1) and another representing the various types of rock alteration (e.g. fig. 4.16).

Distribution of Mineralization. – It has been noted in section 2.3.7 that two main periods of volcanism can be distinguished in the area. At Mount Pleasant, rocks belonging to the first period consist of quartz-feldspar porphyry, which is intruded by feldspar porphyry. The second period of volcanism is represented

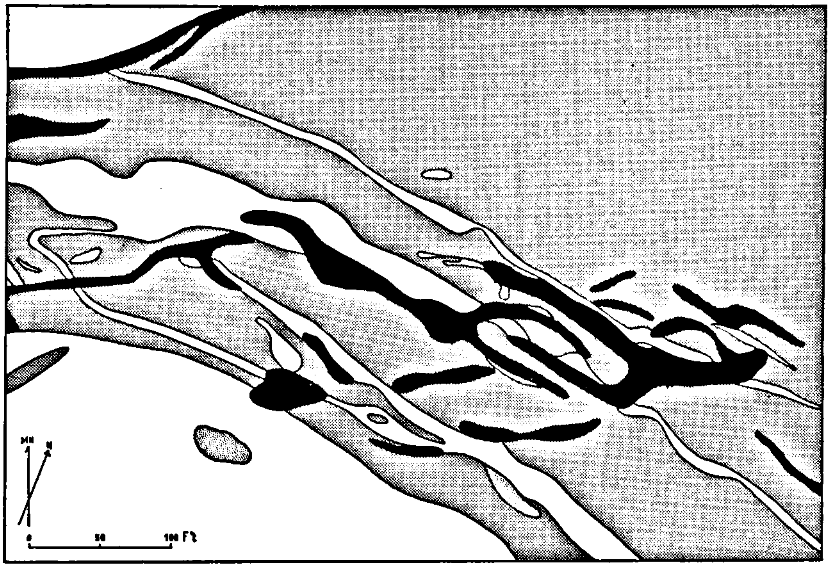


Fig. 4.1. Underground geological map northern main mineralized zone Mount Pleasant.

by intensely brecciated and altered banded quartz-feldspar porphyry which occupies the two vents in the northern- and southern part of the property.

The main mineralized zones are indicated on the geological map and section of Mount Pleasant, which is enclosed in the back of this thesis. It is evident from this map that the mineralization is related to the vents which formed during the second stage of volcanism or along fractures or faults which penetrate into these vents. However, it is quite likely that the mineralized zones of Mount Pleasant are much more extensive than the area that has been explored to date. This is suggested by figure 4.18, which shows the discovered mineralized zones and the anomalous tin zones in the soils on the mountain.

Mineralized Structures. – The mineralized veins at Mount Pleasant are mostly associated with intensely altered light-colored, siliceous fluorite-rich greisen rocks. Single veins vary in width from a few inches to about one foot. The larger veins, which are composed of a number of closely spaced smaller veins, vary in width from a few feet to over 25 feet (see fig. 4.1). However, in the adit and surface exposures the veins tend to pinch and swell, both along the strikes and dips (fig. 4.1–4.4).

The mineralized tension-fractures in the main northern zone trend slightly north or south of west (see fig. 4.6) and they occur in light colored intensely greisenized rocks (fig. 4.16) mostly along the contacts of banded quartz-feldspar porphyry dykes (fig. 4.1). The mineralization is most proliferous where the rocks in the contact zone have been intensely brecciated.

The origin of the breccias, which can have a dyke – or pipe-like shape has been the subject of intense debate among numerous geologists who have visited the property. They have been interpreted as explosion breccias, collapse breccias and hydrothermal breccias. The mineralized breccias are composed of angular to well-rounded and intensely altered fragments of essentially the same composition as the surrounding rocks. The rounded fragments are more abundant near the

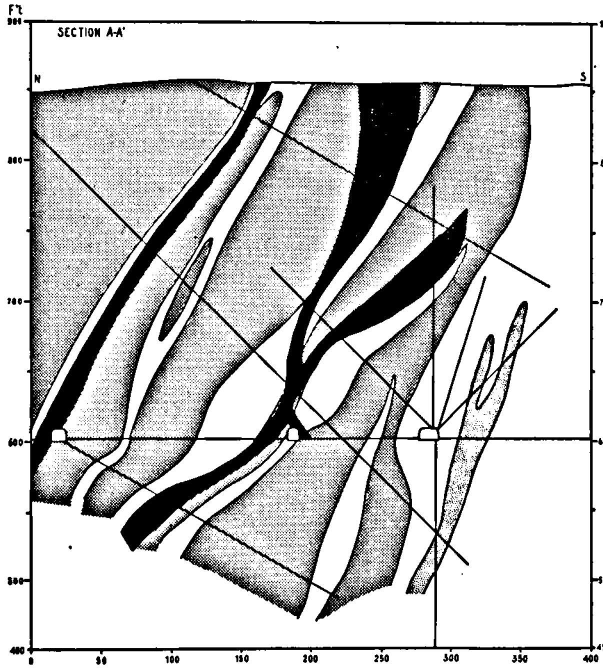


Fig. 4.2. Section AA[1] through main mineralized zone.

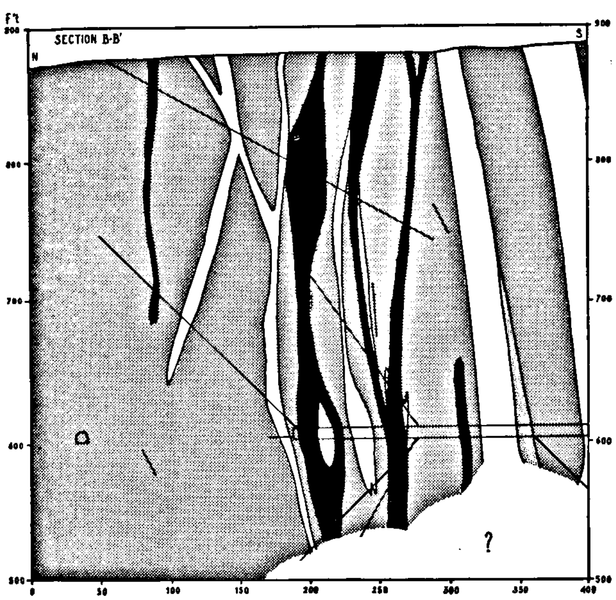


Fig. 4.3. Section BB[1] through main mineralized zone.

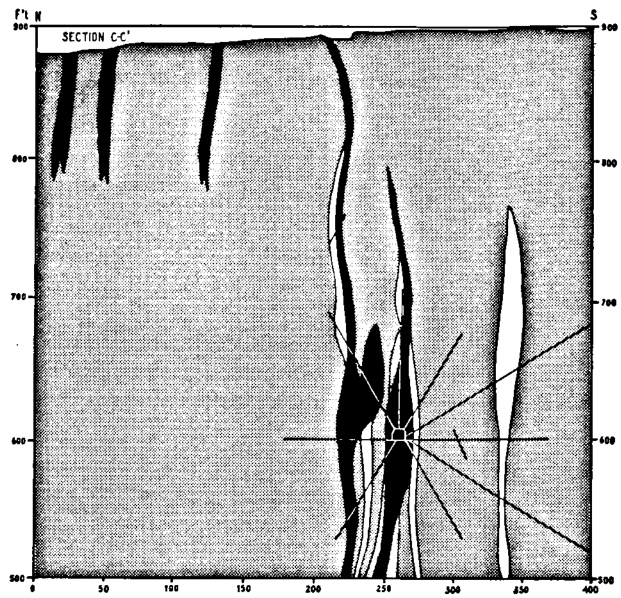


Fig. 4.4. Section CC[1] through main mineralized zone.

core of the pipes and dykes, while their number gradually decreases towards the fractured walls. The rounding appears to be chiefly the result of repeated movement along faults or fractures, while part of the rounding is probably due to solution by volcanic fluids, which produced the alteration and deposited the metallic minerals. The writer therefore believes that they are chiefly tectonic breccias which have been subsequently cr simultaneously affected by hydrothermal activity.

Several narrow quartz-rich veins carrying tin-base metal mineralization follow minor gently south to southwesterly dipping faults, north of the main mineralized zone. A small stockwork zone composed of a fine network of numerous irregular thin tin-base metal veinlets is also intersected by the adit in this area. The mineralization is not always confined to definite veins, but it can also occur as pods, which range in size from a few inches to several feet. These pods predominate in the northwesterly trending mineralized shear zone on the west side of the northern vent (see geological map of Mount Pleasant).

The extent of the metallic mineralization, along the southern vent is incompletely explored. A few well-

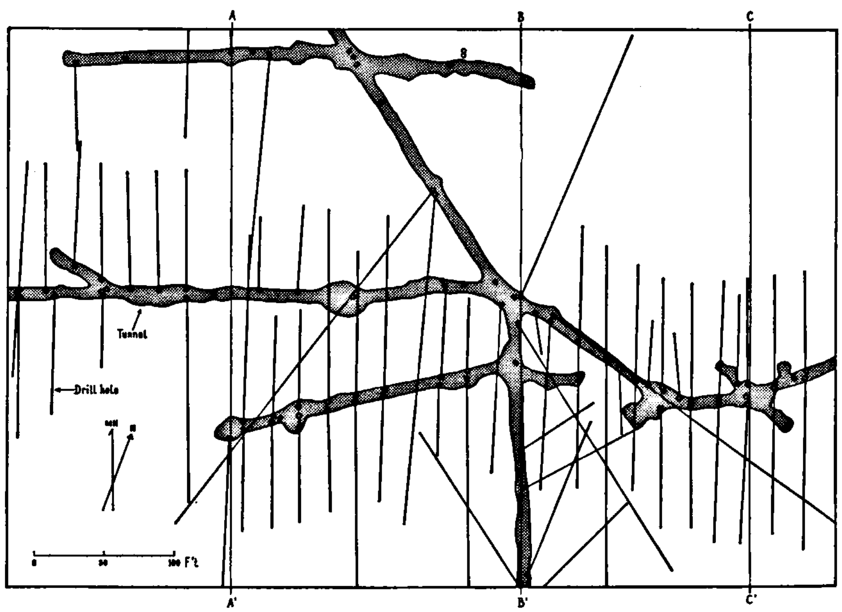


Fig. 4.5. Outline tunnels, flat diamond drill hole locations and section lines for area covered by fig. 4.1.

mineralized breccia pipes have been discovered along the northern contact, while molybdenite occurs disseminated in and along joints in buff to salmon pink silicified rocks in the main vent a little further to the south.

Interesting structures in Mount Pleasant are also the kaolin pipes. These pipes plunge steeply and they vary in diameter from five to twenty feet. They are completely filled with kaolin which contains abundant large pale-green fluorite crystals and large blocks of wall rock. These structures occur locally along major fractures and they are undoubtedly the result of hydrothermal activity.

It has been noted in section 3.4.2 that the formation of the Mount Pleasant volcanoe was probably essentially due to north-northwesterly to south-southeasterly trending extension, which in the final stages also produced tension fractures and thus permitted the introduction of mineralizing fluids. However, it is evident from fig. 4.6 that there is a considerable variation in the attitudes of the mineralized tension fractures. This is probably in part due to the dextral movement along the northeasterly trending faults. This movement is also evident along several of the major fractures in the underground workings.

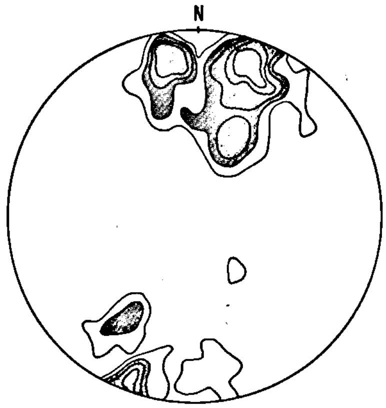


Fig. 4.6. Π diagram mineralized tension fractures northern main mineralized zone.

4.2.3. *Ore Mineralogy*

The Mount Pleasant deposit contains a complex assemblage of mostly fine-grained tin-and base metal minerals. The writer studied numerous polished sections of the ore minerals during his stay at the property.

This work was chiefly carried out in order to provide fundamental information for the concentration of the ore minerals. However, the character of the mineral assemblage provides also interesting information about the nature of the deposit.

The metal content along the mineralized veins is variable. The better parts of the veins and lenses assay usually between one and two percent tin, two to ten percent zinc and greatly varying amounts of copper. The intermediate areas between the better parts of the veins carry usually about .2 to .4 percent tin and varying amounts of base metals.

The mineralogical descriptions given below are a summary of a more complete description given in the writers unpublished Master of Science thesis (Ruitenberg, 1963).

Cassiterite. – Cassiterite, which is the most abundant tin mineral at Mount Pleasant occurs as fine stubby reddish brown crystals which can be identified with a handlens because they protrude from the surrounding softer groundmass. The mineral is medium grey in polished sections and because of its great hardness has a typical pitted appearance (fig. 4.7). In thin sections, the mineral is easily recognized by its reddish brown internal reflection and excellent cleavage.

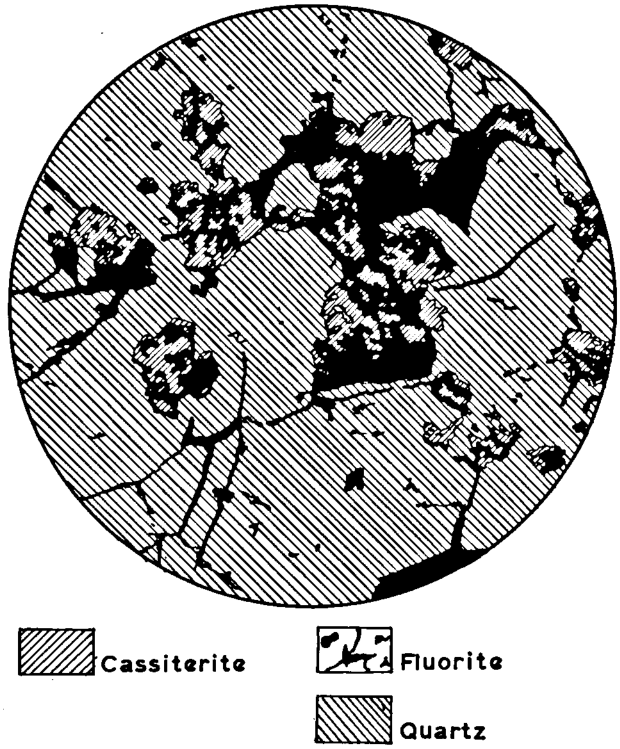


Fig. 4.7. Cassiterite and related alteration minerals in polished section, 48 × (after photo).

Cassiterite occurs as small aggregates of fine-grained crystals disseminated through greisenized rocks and in discontinuous veinlets along fine fractures (fig. 4.7). The disseminated aggregates result from the replacement of altered feldspar phenocrysts in and along their margins, as well as part of the surrounding groundmass. Most cassiterite veinlets and aggregates are accompanied by extremely fine-grained topaz and colorless to pale-brown or sometimes purple fluorite (fig. 4.7, 4.8). The cassiterite is also found in association with fine-grained tourmaline which occurs in the form of disseminated lath-shaped crystals, or

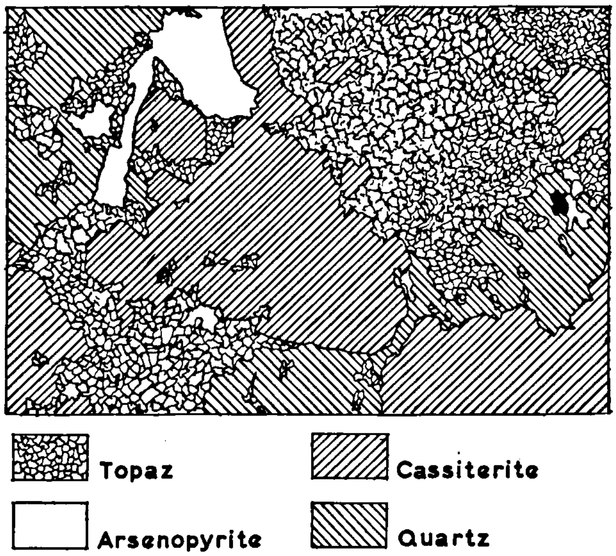


Fig. 4.8. Cassiterite and related alteration minerals in thin section, 50 × (after photo).

clusters composed of fine, pale-green, needle-shaped crystals.

Cassiterite is usually but not always accompanied by arsenopyrite. Locally, patches or veinlets of the latter mineral are corroded by cassiterite (fig. 4.10).

Most of the cassiterite-bearing rocks in the property were later invaded by metallic sulphides, and part of the cassiterite was replaced by stannite, dark brown sphalerite, chalcopyrite or intimately intergrown mixtures of these minerals. It is therefore common to find aggregates of fine corroded cassiterite in these sulphides.

Wolframite, – Wolframite is fine grained in Mount Pleasant and therefore difficult to recognize in hand-specimens. In polished sections, it is easily recognized by its light- to dark-grey polarization colors, good cleavage and great hardness.

It occurs as disseminated patches of fine-grained euhedral crystals, in the western part of the northern mineralized zone. It is here associated with clay minerals, sericite, quartz, fluorite and sometimes topaz. In the southern mineralized zone, it occurs in a similar setting or along fine fractures accompanied by molybdenite. The wolframite is usually corroded where it is in contact with molybdenite.

Molybdenite. – Molybdenite occurs as fine disseminated flakes or joint coatings chiefly in the banded buff silicified rocks in the southern vent (fig. 4.9). It is usually associated with cassiterite and wolframite, while kaolin, fluorite, quartz and fine mica are the common gangue minerals.

Arsenopyrite. – Fine-grained, silvery white arsenopyrite crystals intergrown with stubby cassiterite crystals, are a characteristic association of many tin-bearing veins in Mount Pleasant (fig. 4.10).

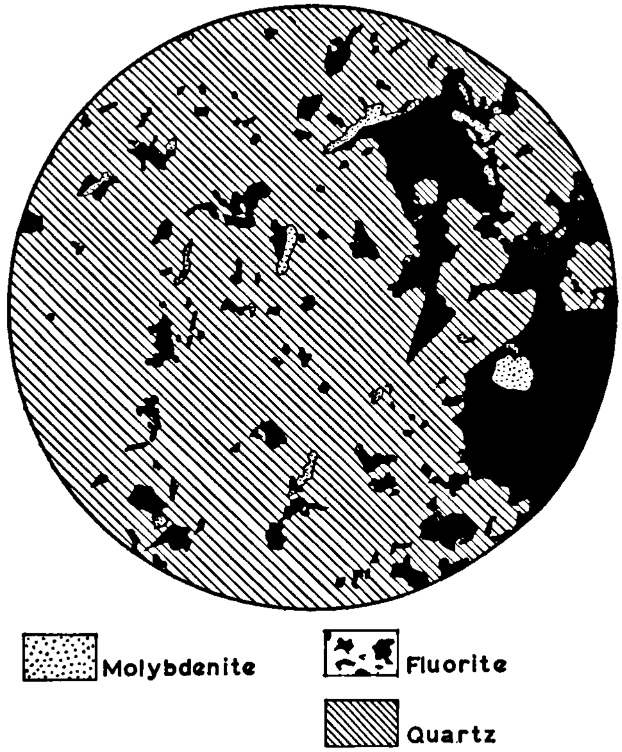


Fig. 4.9. Molybdenite and related alteration minerals in polished section, 48 × (after photo).

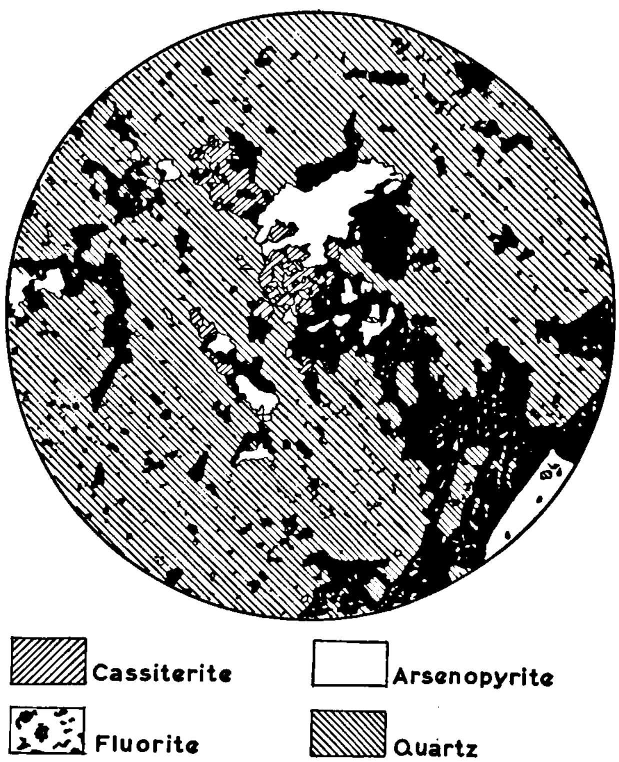


Fig. 4.10. Arsenopyrite corroded by cassiterite in polished section 48 × (after photo).

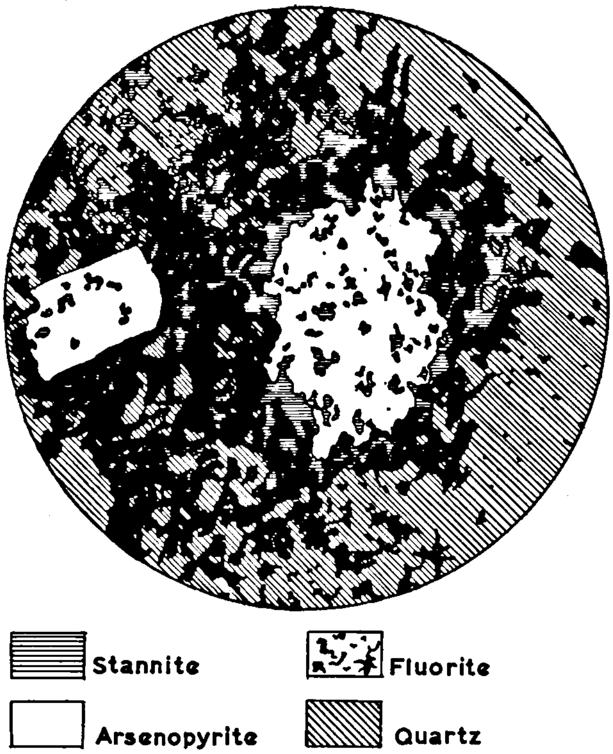


Fig. 4.11. Arsenopyrite partly replaced by stannite in polished section 48 × (after photo).

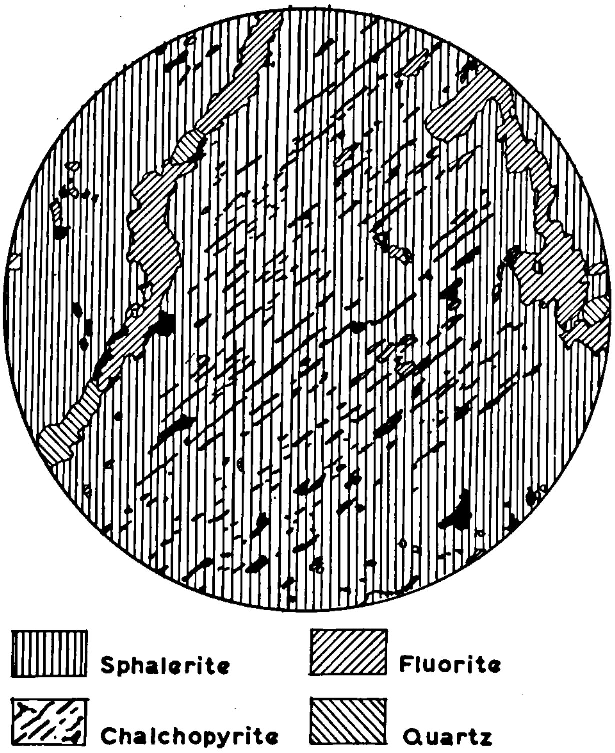


Fig. 4.13. Sphalerite with small blebs and typical blade-shaped inclusions of chalcopyrite in polished section 48 × (after photo).

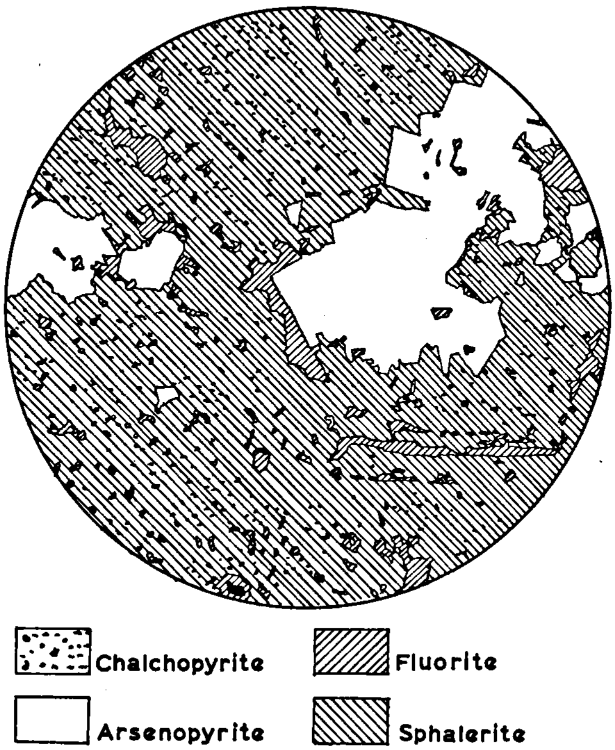


Fig. 4.12. Sphalerite with chalcopyrite inclusions replacing arsenopyrite in polished section 48 × (after photo).

Arsenopyrite is one of the most common minerals found in the property. It occurs as disseminated grains in fractured siliceous rocks or as massive veins or pods up to one foot in diameter. It is commonly associated with cassiterite, however if the arsenopyrite content of the rocks is very high, the tin values are invariably low.

In areas where arsenopyrite is associated with stannite, arsenopyrite is corroded (fig. 4.11), in extreme cases it is almost completely replaced, and only a few relict fragments remain in the stannite.

Dark brown sphalerite replaces arsenopyrite (fig. 4.12) and pseudomorphs have been found in some localities.

Pyrite. – Fine grained pyrite is a common constituent of most of the mineralized rocks, but it is far less abundant than arsenopyrite. Pyrite is locally replaced by galena and sphalerite.

Sphalerite. – Two varieties of sphalerite are found in the mineralized zones of the property: one is black and rich in iron, while the other is yellowish brown and undoubtedly contains more zinc.

Sphalerite occurs as fine veinlets and patches replacing feldspar phenocrysts. It contains invariably fine blebs or blade-shaped bodies of chalcopyrite (fig. 4.13). The yellowish brown sphalerite occurs as massive sections in some drill cores from the area surrounding the southern vent.

Petruk (1963) analyzed some sphalerite samples from

Mount Pleasant for minor elements. The most interesting result of this work is the high indium content of several sphalerite samples. Moreover, the indium content appears to increase with increased tin content of the sphalerite.

sample	Indium in sphalerite	Tin in sample
	Wt %	Wt %
K	. 30	2.28
G	. 12	1.57
L	. 07	. 27
O	. 03	. 25

Stannite. – Stannite is usually intergrown with chalcopyrite and sphalerite (fig. 4.14). This fine-grained mixture can easily be confused with chalcocite in handspecimens.
In polished sections, stannite has a brownish pink color and is slightly anisotropic. Dr. W. Petruk of the Mines Branch, Dept. of Mines and Technical Surveys in Ottawa, confirmed the identification of this rather unusual stannite by X-ray diffraction analysis.

Stannite is usually accompanied by abundant chalcopyrite (fig. 4.14). This association is evident from polished sections as well as numerous chemical analyses.
Some distinct veins composed of chalcopyrite, which cut across the common tin-base metal mineralization, have been found in some parts of the northern mineralized zone.

Tennantite and Tetrahedrite. – These minerals have only been identified in polished sections.
Tennantite has a peculiar pale-bluish color and it is isotropic between crossed nicols. It occurs in fine veinlets which cut sphalerite, stannite and chalcopyrite, but it also occurs as small blebs in these minerals.
Tennantite is usually accompanied by small blebs of tetrahedrite, which are darker grey in color and may exhibit a brownish orange internal reflection.

Galena. – Galena occurs in small veinlets and pods in most of the mineralized zones. It also occurs as veinlets in or rims around sphalerite (fig. 4.15). Chemical assays by Technical Service Laboratories in Toronto show that the galena is argentiferous.

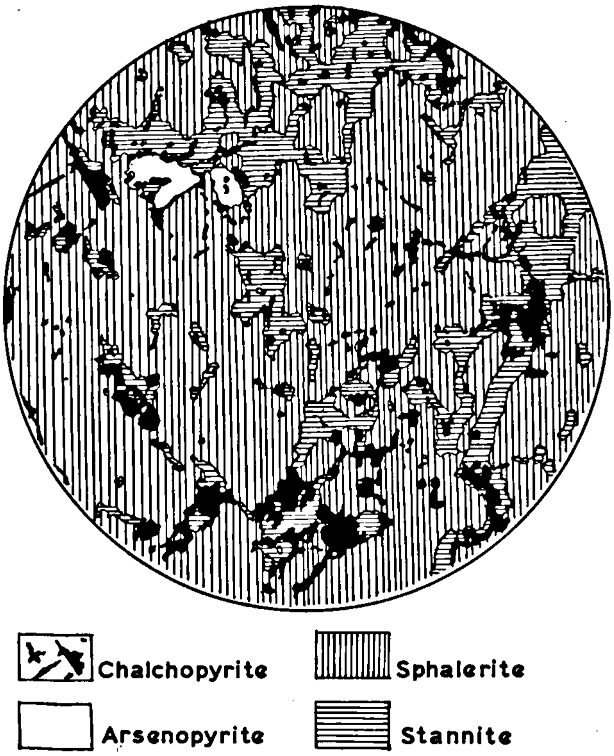


Fig. 4.14. Intergrown sphalerite, stannite and chalcopyrite with a few corroded arsenopyrite crystals in polished section 48 × (after photo).

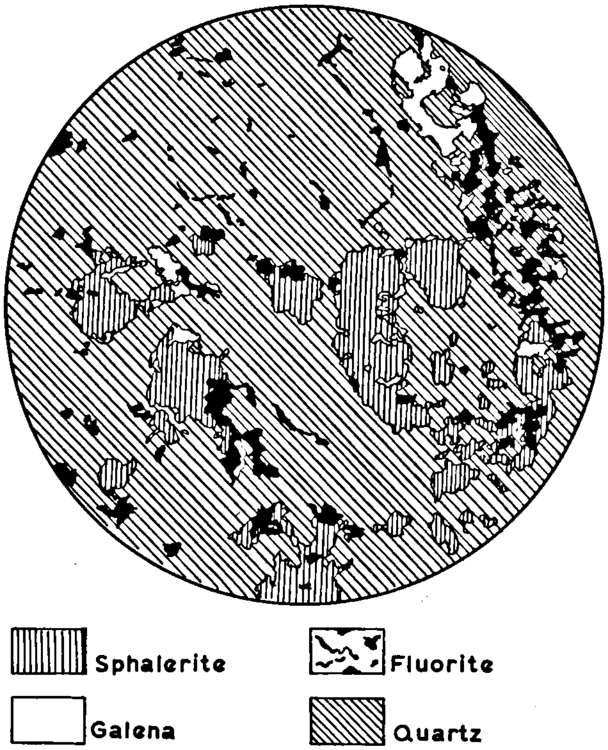


Fig. 4.15. Galena veinlets in and thin rims around sphalerite in polished section 48 × (after photo).

Chalcopyrite. – Chalcopyrite occurs most commonly in small veinlets, or as very fine, rounded, rod-shaped or blade-shaped bodies in sphalerite (fig. 4.12, 4.13). It forms rims around sphalerite patches where the copper-zinc ratio is high.

Marcasite. – Marcasite resembles pyrite in polished sections, but it is slightly lighter in color and it has yellow-green to blue brown polarization colors between crossed nicols. It occurs as fine veinlets cutting sphalerite, stannite, chalcopyrite and tennantite.

Bismuthinite, wittichenite and native bismuth. – Petruk (1963) found these minerals in polished sections from some sphalerite veins. Bismuthinite and wittichenite occur as irregular grains which are frequently intergrown. Native bismuth is present as inclusions in bismuthinite, arsenopyrite, galena and stannite.

Texture. – The metallic minerals in Mount Pleasant occur in desseminated patches and discontinuous veinlets in silicified and greisenized rocks. This type of distribution is chiefly due to deposition in open spaces, such as small fractures and numerous large and small vugs. The latter appear to have formed before or contemporaneously with the deposition of the metallic minerals. The feldspar porphyries with their high percentage of coarse phenocrysts have been most favourable for the formation of numerous vugs, particularly where they are brecciated. They are therefore the best host rocks for the metallic minerals (see fig. 4.1).
Replacement textures are common between various metallic minerals. Some of the most common types are arsenopyrite crystals laced with numerous irregular blebs and veinlets of sphalerite or stannite (fig. 4.11). Occasionally, the latter minerals form pseudomorphs after arsenopyrite. It is also quite common to find galena enclosing or as small veinlets in sphalerite (fig. 4.15). In one polished section, fine cassiterite bearing fractures have been partly invaded by sphalerite, which corrodes the cassiterite in areas where they are in contact. Tennantite and tetrahedrite occur as late veinlets cutting most sulphides other than galena and marcasite.
The most interesting textures are probably the fine intergrowths of sphalerite, chalcopyrite and stannite (fig. 4.14). They have the characteristics of exsolution textures, similar to those described by Edwards (1954). It is evident that it would be difficult to produce separate metal concentrates from the finely intergrown sulphide mixtures. However, it has been shown by mineral concentration tests that most of the tin is in the form of cassiterite rather than stannite, which makes separate recovery of most of this metal possible (pers. comm. J. E. Riddell, 1965).

Paragenetic Sequence. – The different metallic minerals at Mount Pleasant do not occur in distinct separate veins and therefore it is difficult to establish a definite paragenetic sequence. However, it is evident from the mineralogical descriptions that the early mineral assemblage consists essentially of arsenopyrite, cassiterite, wolframite and molybdenite. This is followed by a mixture of sphalerite, stannite and chalcopyrite, and some late chalcopyrite veining. The latest metallic minerals are represented by tennantite, tetrahedrite, galena and marcasite veinlets which cut the earlier sulphide assemblages. Table 4.1 summarizes this sequence.

TABLE 4.1. *Paragenetic Sequence Metallic Minerals*

	Early							Late
Arsenopyrite	····	····						
Cassiterite		····	····					
Wolframite		····	····					
Molybdenite			····	····				
Sphalerite				····	····			
Stannite				····	····			
Chalcopyrite				····	······			
Tennantite					····	····		
Tetrahedrite					····	····		
Galena						····	····	
Marcasite							····	····

4.2.4. *Rock Alteration*

The rocks which comprise Mount Pleasant are all intensely altered, mainly by silification, sericitization and chloritization. This alteration affects the feldspar phenocrysts as well as the matrix. In areas where this type of alteration is very intense, the original feldspar phenocrysts and matrix are completely obliterated, while quite commonly small quartz metacrysts have been formed. This makes initially the distinction of the original rocks rather confusing. However, with some practice, vague dark-green casts, which represent the original feldspar phenocrysts can still be seen, while original quartz eyes and quartz metacrysts can be distinguished by a slight difference in color.
The rocks in and around the vents in the northern and southern part of the property are practically completely replaced by quartz or by a mixture of greisen-type minerals such as quartz, fine mica, fluorite, topaz and kaolin. The former type of alteration has mainly affected the vents, while the greisen type alteration mainly accompanies the potential ore zones surrounding the vents (fig. 4.16). Both these types of alteration are superimposed upon the initial sericitization, silicification and chloritization.
In general the rock alteration is most intense in and around the two vents, while it decreases rapidly towards the margins of the volcanoe. A brief description of the alteration minerals is given in the following sections.

Quartz. – Small veinlets composed of quartz mosaic cut across most of the rocks in Mount Pleasant, but their number increases rapidly towards the two vents, where at least eighty percent of the rocks has been replaced by silica. The quartz in the veinlets usually shows strong conchoidal fracturing and it has a characteristic wavy extinction.
Where feldspar phenocrysts are replaced by these veinlets, the quartz mosaic in the resulting pseudomorphs is usually coarser than in the silicified matrix. This is probably the reason that vague casts of these phenocrysts can still be recognized even after intense silicification, which greatly assists in determining the original rock types.
The banding of the quartz-feldspar porphyries in the two vents is emphasized by the silicification, while

they obtain a typical fawn-brown color. This assists in distinguishing these porphyries from the older intensely silicified white feldspar- and quartz-feldspar porphyries.

Micas and Clay minerals. – Alteration of the feldspar to sericite and fine-grained clay minerals is dominant in the grey-green-altered volcanic rocks, which occupy most of Mount Pleasant.

One of the most common products of feldspar alteration, in the mineralized zones, consists of a fine-grained mixture of hydromica and kaolin. The hydromica occurs as brownish yellow or colorless, very fine, irregular-shaped flakes with moderate birefringince. Pale yellow kaolin which has a slightly higher birefringince is usually intergrown with hydromica, but they can also occur in separate veinlets. Petruk (pers. comm. 1962) checked the identification of these minerals by X-ray diffraction analysis. Dickite, which occurs as white coarse crystals in veinlets associated with the kaolinized zones, has also been identified (Petruk, 1963).

Chlorite. – Dull, grey-green aphanitic chlorite occurs throughout the alteration zone, while a bright green variety is commonly associated with the metallic mineralization. X-ray diffraction analysis of the latter type of chlorite shows that it is a mixture of kaolin and chlorite (Petruk pers. comm. 1962). Petruk (1963) demonstrates that a similar type of chlorite is associated with the cassiterite bearing veins in Cornwall, England.

Fluorite and Topaz. – Fluorite is one of the most characteristic minerals associated with tin and base metal sulphide mineralization on the property. It occurs as veinlets filling fine fractures, as disseminated patches intergrown with the metallic minerals (fig. 4.7–4.15) and as euhedral crystals in mineralized vugs and disseminated through kaolin pipes.

Pale brown fluorite, in places with rims or crosscutting veinlets of purple fluorite, accompanies the tin-base metal mineralization in the main northern mineralized zone. A high percentage of brown fluorite in these rocks, invariably indicates good grade tin mineralization. Purple and colorless fluorite in addition to the brown variety, are abundant in the southern mineralized zone. The pale-green variety has only been found in the kaolin pipes.

Topaz occurs as veinlets of fine-grained aggregates associated with fluorite and cassiterite. Locally, topaz is more abundant than fluorite in the mineralized veins (fig. 4.8).

Tourmaline. – Tourmaline is locally abundant with the cassiterite-base metal mineralization. It occurs as extremely fine-grained, pale-green to almost colorless, needle-shaped crystals in radiating clusters, or as disseminated, short lath-shaped crystals.

Epidote. – Pistachio-green, aphanitic epidote is a common alteration mineral along the margins of the metallized zones. In thin sections, it consists of a dense aggregate of fine-grained lath-shaped crystals, which show greenish-brown to pale-yellow pleochroism.

Apatite. – Apatite is widely distributed in the Mount Pleasant volcanic rocks, but it is most abundant in the intensely silicified varieties.

Rutile. – Rutile is commonly associated with cassiterite in the northern mineralized zone. In thin sections, the yellowish brown color, adamantine luster in reflected light and the charactistic knee-shaped twinning are typical. The dark blue internal reflection is most characteristic in polished sections.

4.2.5. *Relationship of Rock Alteration and Distribution of Metallic Minerals*

The geological map of Mount Pleasant shows that the main mineralized zones occur along the margins rather than in the two vents.

The rocks in the vents are mostly intensely silicified and they contain small amounts of metallic mineralization, but they are for the most part unfavourable host rocks. The mineralized fractures tend to be very thin and irregular in these large brittle silicified masses, while veins of considerable size are very rare. Moreover, the percentage of mineralized vugs is low in these rocks in comparison for instance with the mineralized feldspar porphyry.

The zones marginal to the silicified vents are generally better fractured since both highly competent intensely silicified and less competent grey-green altered porphyries are present (see fig. 4.1, 4.16). The latter rocks are also more favourable for the formation of vugs. It is evident therefore that these are the most favourable host rocks for the metallic mineralization. Moreover, the low permeability of the intensely silicified rocks in the vents undoubtedly assisted in guiding the mineralizing fluids through the well developed fractures along the margins of the vents.

The physical importance of rock alteration for the distribution of the metallic minerals is therefore quite evident, but the chemistry is much more complex. A few of the more obvious phenomena will be discussed here, since they are of practical importance for the development of the Mount Pleasant deposit and for the exploration for tin in the general area.

Fig. 4.16 shows that the major mineralized veins occur all in or along the fluorite-rich greisen zones. In addition some desseminated metallic mineralization is present throughout these zones.

The actual tin content of these rocks appears to be directly related to the intensity of this alteration. The fluorite-rich greisen zones are surrounded by a large zone of dark-green alteration, which is due to sericitization, silicification and chloritization (fig. 4.16). These types of alteration are associated with most known tin deposits in the world.

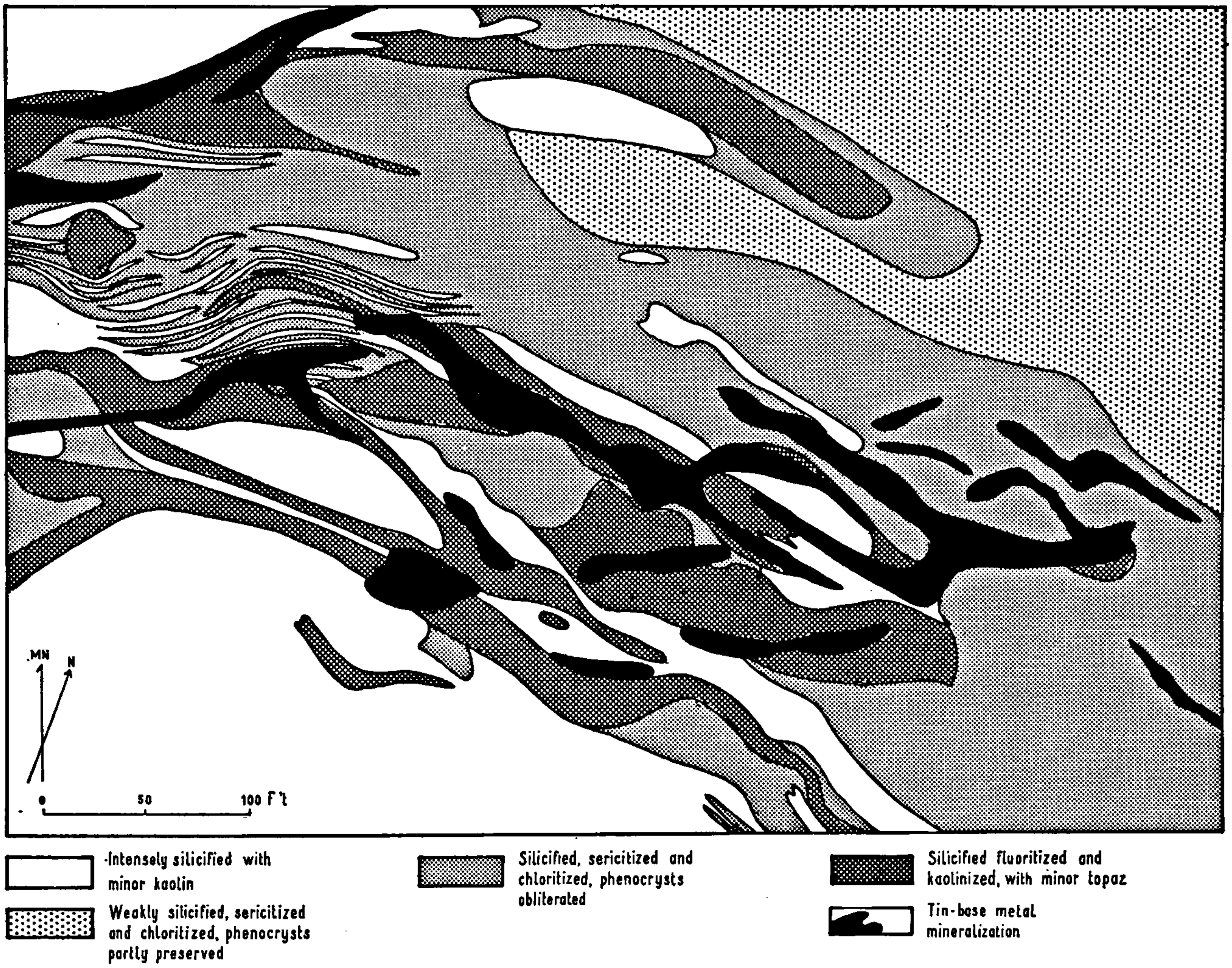


Fig. 4.16. Rock alteration in the main northern mineralized zone of Mount Pleasant.

Barssukov (1957), who made a detailed study of the genesis of tin deposits, gives an explanation for the occurrence of tin deposits and the related alteration. It was found that most of the tin content in tin-rich granites occurs in the lattice of biotite crystals. It is thought that solutions rich in fluorine attack these granites, which results in the albitization of feldspars and the conversion of biotite to muscovite. In the latter process tin is liberated and it is precipitated along the cleavage planes of muscovite crystals as cassiterite. This has been verified in the following manner: tin-rich biotite and muscovite were finely ground, and subsequently the produced powders were placed in a centrifuge. Muscovite lost most of its tin content as a result of this treatment, while biotite retained its original tin content. The fluorine-rich alkaline solutions are thought to dissolve the liberated cassiterite from the muscovite, while the tin is transported in the form of Na_2 Sn (OH,F)6, which is stable in alkaline solutions, into the overlying horizons. As a result of albitization of the feldspars, the solutions become progressively less alkaline until the neutralization point is reached. When this occurs Na_2 Sn (OH, F)6 decomposes into Na OH, H F and Sn O_2. The former two compounds attack feldspars and as a result topaz, fluorite and fluorine-bearing micas may form. Abundant acids are produced in this process which aid in the further precipitation of cassiterite, and at a lower temperature acid attack upon micas and topaz may lead to the formation of kaolin.

This association of tin deposits with igneous rocks containing micas with a high trace content of tin appears to hold true for most tin fields in the world (pers. comm. K. F. G. Hosking, 1962). The source of the tin at Mount Pleasant can only be established from the regional tin distribution pattern. Mount Pleasant is situated on the eastern flank of an adamellite intrusion, similar to those found further to the west, (see section FF_1) and along a major northwesterly trending fault, which penetrates the main granite mass to the south. This posed the question whether the volcanic activity itself should be regarded as the source of the tin, or whether the volcanic activity merely remobilized existing tin mineralization associated with the adamellite intrusions or possibly the main granite mass to the south. The writer examined both possibilities (see 4.2.8) and it was found that the adamellite stocks north of the main St. George granite contained a high trace tin content in several localities where they are intensely fractured or faulted and it was generally extremely low in the unaltered volcanic rocks north and east of Mount Pleasant. Only one small vent was found north of the map area and along the main Mount Pleasant fault which contained intensely altered banded quartz-feldspar porphyry with a high trace tin content. It appears therefore that the source of the tin was situated in the rootzones of the adamellite intrusions, while the volcanic activity produced a remobilization and possibly a further concentration of the tin minerals. Alteration of biotite to muscovite is common in several parts of the adamellite intrusions, which could have liberated the tin from the biotite according to Barssukov's hypothesis.

4.2.6. *Type of Deposit*

The two most important classification systems of mineral deposits are the old depth – temperature classification of Lindgren (1933) and the more modern tectonic classification of Itsikson (1960). The former is based upon general structural features and mineralogy, while the latter is concerned with the tectonic setting. Both classifications generally make it possible to compare mineral deposits, but it is evident that the latter fits best in the type of description used in this thesis.

Depth – Temperature Classification. – Lindgren (1933) gives a number of features which are typical for mineral deposits formed under near surface conditions. Several of these are found at Mount Pleasant: open cavity fillings, short irregular veins, mineralization in stockworks and pipes. However, the metallic minerals cassiterite, molybdenite, arsenopyrite and wolframite are considered to belong to deep seated hypothermal deposits. It is evident therefore that the Mount Pleasant deposit does not fit into this classification.
Turneaure (1960), who made extensive studies of the Bolivian tin deposits, which show many similarities with Mount Pleasant, advocates a separate classification for deposits formed at high temperature and shallow depth. The designation "xenothermal" is proposed.

Tectonic Classification. – The classification of Itsikson (1960) is based on a world wide study of the character and tectonic setting of mineral deposits. It has the advantage that in newly mapped areas, in which it has been possible to determine the tectonic history, certain predictions can be made about the most favourable areas for various metallic mineral deposits. The Mount Pleasant deposit fits quite well into Itsikson's description of deposits formed in the marginal parts of geosynclines, during the late and final stages of geosynclinal development. These stages correspond to conditions of progressive attenuation of tectonic movements, finally resulting in consolidation of the folded region and its transition to a new platform. The following features characterize this stage:

a. Folds are subordinate, but explosive fractures are numerous.
b. Terrestial volcanism is associated with these fractures.
c. In addition to tin, molybdenum is of leading importance and they are accompanied by antimony-, arsenic-, base metal-, silver-, iron-, fluorine- and carbonate minerals.

Itsikson divides deposits formed in marginal parts of geosynclines into two groups:

a. The hypabyssal group.
   This group is associated with intrusions of tin-bearing granitoids ranging in composition from diorites or monzonites to granodiorites, and granites.
b. The subvolcanic group.
   This group consists of deposits formed close to the surface. The intrusions commonly associated with this type are represented by dykes, dyke suites, branched pipes transforming at depth into vein or funnel and mushroom or ax-like bodies. Tin bearing intrusions of this type embrace a wide range of rocks with an acidic to intermediate composition. Breccias along fissures are very common in these rocks, while extensive areas of chloritization, sericitization and silicification, usually disproportionate to the size of the intrusions, are very common.

It is evident from the general geological setting (see 2.3.7), the relationship to the regional structure (see 3.4.2), the mineralogy (see 4.2.3) and the rock alteration (see 4.2.4) that Mount Pleasant fits well into the sub volcanic group (b) of the Itsikson classification.

4.2.7. *Comparison with Bolivian Tin Deposits*

The Mount Pleasant deposit resembles some of the sulphide-tin deposits of the Eastern Bolivian Andes, where tin mineralization is found in a northerly to northwesterly trending, arc-shaped belt (fig. 4.17). This belt is continuous from northern to southern Bolivia, but it can be divided into two parts, having distinctly different characteristics (Ljunggren, 1962). North of Santa Cruz the tin ores are related to a high and narrow granitic batholith of early Jurassic age. Cassiterite and wolframite predominate over sulphides in these deposits.
In the part of the belt south of Santa Cruz, the mineralization is associated with late Tertiary acidic volcanism, which is thought to be derived from deep seated remnants of the Triassic-Jurassic granitic magma. These deposits are characterized by a complex

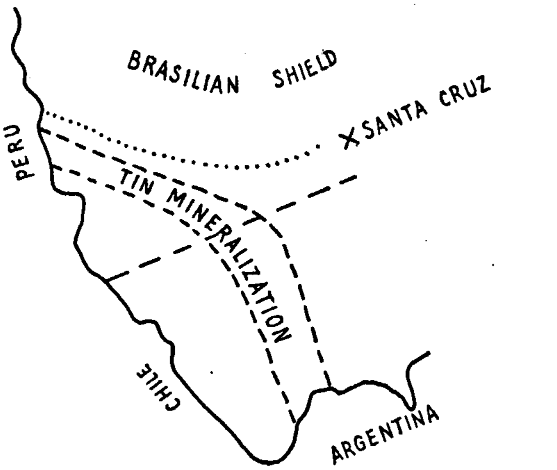


Fig. 4.17. Orogenic zone and Brasilian Craton (after Ljunggren, 1962).

mineral association. They contain abundant base metal sulphides and silver minerals in addition to cassiterite and wolframite. Ljunggren (1962) believes that the formation of sulphides in these deposits was accompanied by a partial remobilization of earlier formed cassiterite-wolframite deposits.

Turneaure (1960) states about these deposits that narrow veins and stringer lodes account for most of the ore, while in some areas stockworks and breccia lenses have been productive. Chlorite, sericite and quartz are characteristic alteration minerals of both the tin-and tin-silver deposits, while tourmaline occurs only with the tin ores. Minerals typical of tin veins are: quartz, cassiterite, bismuthinite, pyrrhotite, stannite, marcasite, siderite and minor tealite or franckeite. The tin-silver ores contain cassiterite, pyrite, stannite, sulphosalts of lead and silver, alunite, kaolin and many other minerals in minor amounts. Lindgren and Greveling (1928) and, Lindgren and Abbott (1931) mention in addition arsenopyrite, sphalerite and chalcopyrite.

It can be concluded that the Mount Pleasant deposit resembles, in geological setting, structure and mineralogy, the sub-volcanic Bolivian deposits south of Santa Cruz. The only significant difference appears to be that tourmaline is prominent in the Bolivian deposits, while it is only present in small amounts at Mount Pleasant. Fluorite, on the other hand, which is prominent in Mount Pleasant, is not mentioned in the literature about Bolivan deposits.

4.2.8. *Exploration for Tin*

Most of the map-area is covered with glacial over burden which makes direct mineral prospecting rather difficult. Therefore, more indirect methods had to be used. A few examples will be given here from areas where tin has been discovered in the region.

The Mount Pleasant deposit has been discovered because abundant base metal sulphides accompanied the tin minerals. This produced highly anomalous base metal concentrations in the streams that drain Mount Pleasant, which were analyzed by "Geochemical Associates" (see 4.2.1). Since no metallic minerals were exposed in the area, it was decided to collect soil samples over the entire property, which would be analyzed for metallic minerals with suitable colorimetric methods. A grid was laid out over the property by "Kennco" (see 4.2.1), which consisted of magnetic east-west lines at 400 foot intervals and one north-south base line. Magnetic rather than true north has been used as reference because claim lines are laid out along magnetic north-south and east-west lines in accordance with the provincial mining act.

Soil samples were collected from the B horizons (Hawkes, 1957), at 100 foot intervals along the cut lines, and they were analyzed for tin, zinc, copper and locally molybdenum. The obtained values were plotted and subsequently contoured. The results are shown in figures 4.18, 4.19 and 4.20.

The discovered tin-base metal zones are also indicated in these figures. It can be seen that the base metal anomalies are displaced by the drainage down the west slope of Mount Pleasant. The tin anomalies, which are due to residual cassiterite in the soil, give a reasonable indication of the metallized zones. However, they appear to be spread out and displaced due to the southeasterly trending glaciation.

It is therefore evident that anomalous metal zones in the soils assist in locating metallic minerals in bedrock,

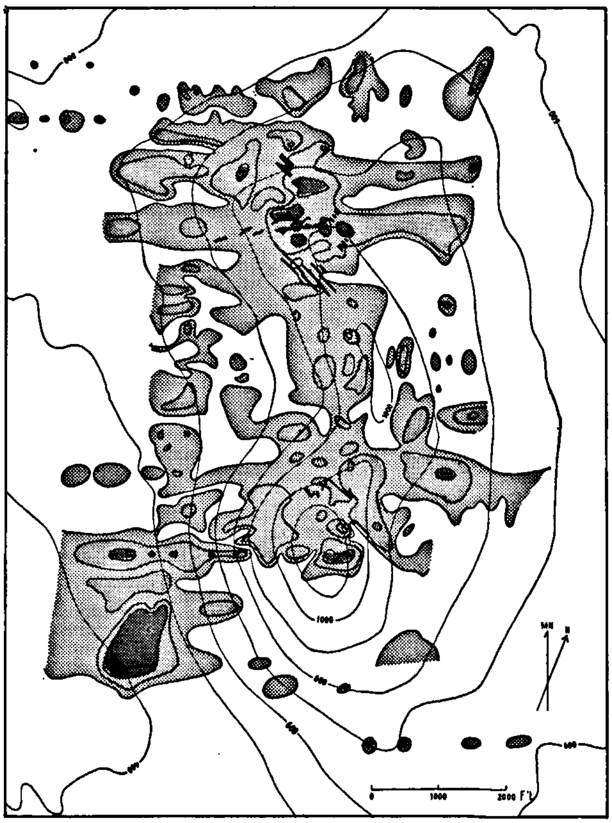


Fig. 4.18. Anomalous tin zones in the soils at Mount Pleasant (contoured at 100-, 200- and 400 p.p.m; ore zones in black).

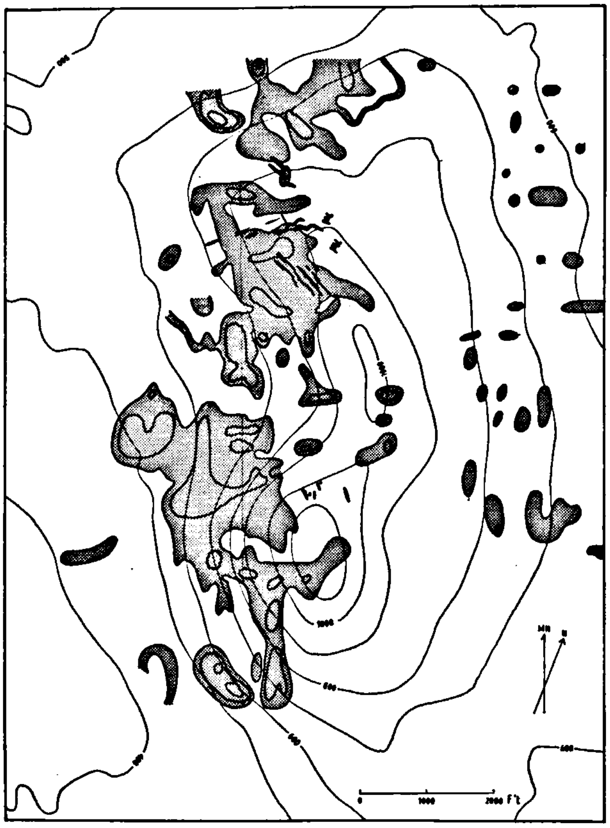


Fig. 4.19. Anomalous zinc zones in the soils at Mount Pleasant (contoured at 500-, 1000- and 2000 p.p.m, ore zones in black).

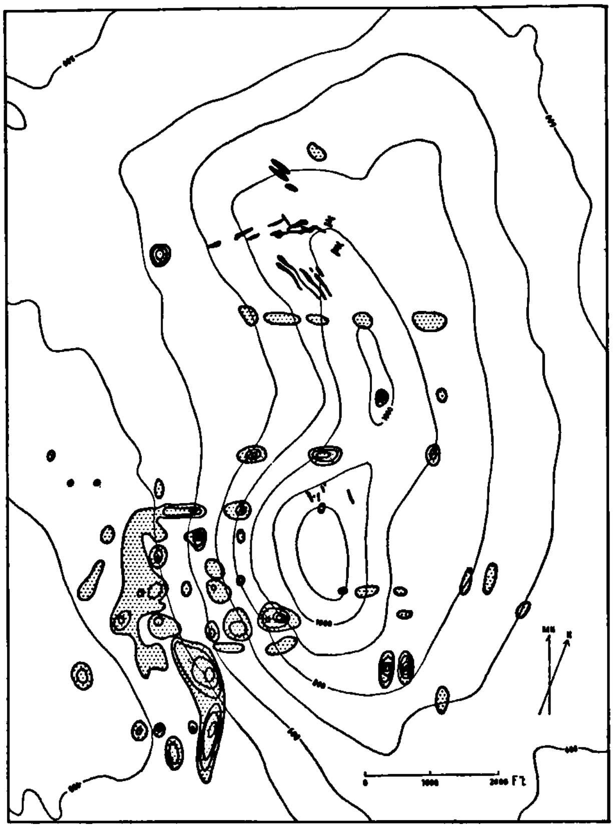


Fig. 4.20. Anomalous copper zones in the soils at Mount Pleasant (contoured at 250-, 500-, 1000- and 2000 p.p.m, ore zones in black).

but they do not provide sufficient information for the planning of diamond drilling work. The writer solved this problem by initially delineating, on air photos, well fractured areas within these anomalous zones. Subsequently, areas with relatively thin overburden, within these selected zones, were cleared in order to locate the metallic minerals in the bedrock. These areas were then mapped and sampled in detail, which provided definite information for the planning of the diamond drilling of the intermediate areas, covered by thicker overburden. In this manner, the entire northern mineralized zone was discovered.

After the discovery of the Mount Pleasant deposit, the surrounding volcanic rocks have been examined by several geologists, including the writer, but the results were generally discouraging. The writer found one small crater, filled with altered banded quartz-feldspar porphyry and breccia, which carried high trace tin, about three miles north of Mount Pleasant (beyond the map area). South of Mount Pleasant some slightly altered volcanic rocks carry locally some weak anomalous tin values.

The possible association of the tin mineralization with the adamellite intrusions was subsequently considered. Some deep diamond drill holes along the west side of Mount Pleasant revealed the presence of a high grade metamorphic zone with some fine adamellite veinlets in the deeper parts. Moreover, an adamellite dyke had been discovered on True Hill, just west of Mount Pleasant (see main map). It became therefore evident that Mount Pleasant was situated on the eastern flank of an adamellite intrusion (see main section FF_1). In order to check the possibility whether or not the source of the tin and possibly the base metals was associated with this intrusion, a few short holes were drilled in the Hatch Brook and True Hill areas just west of Mount Pleasant (see main map). The holes were located along a strong easterly trending fault which penetrated the intrusion. An intensely fractured ten foot wide vein containing cassiterite, quartz and chlorite (assay .4 % Sn) was intersected in the Hatch Brook drill hole, while a complex vein system containing hematite, cassiterite and sphalerite was intersected by the drill holes on True Hill (assay Sn .25 %, Zn 10 %). The cassiterite and sphalerite in the latter case occur in separate veins in contrast to the mixed tin-base metal sulphide veins of Mount Pleasant. This provides another indication that the Mount Pleasant deposit represents a remobilized deposit.

Indications of tin mineralization were also discovered along strong fracture zones which penetrate the adamellite intrusions further to the west. Angular float assaying up to .4 % Sn was found on Beech Hill (see main map). Although this float does not appear to be far displaced, the bedrock source has not yet been discovered.

Highly anomalous tin values have also been discovered in the soils covering the Pleasant Ridge adamellite intrusion (Charlotte County files, Mines Branch, Province of New Brunswick).
A systematic sampling and detailed mapping program has been carried out over an intensely fractured and faulted zone on the west side of the Tower Hill adamellite intrusion (see fig. 4.21). Anomalous tin

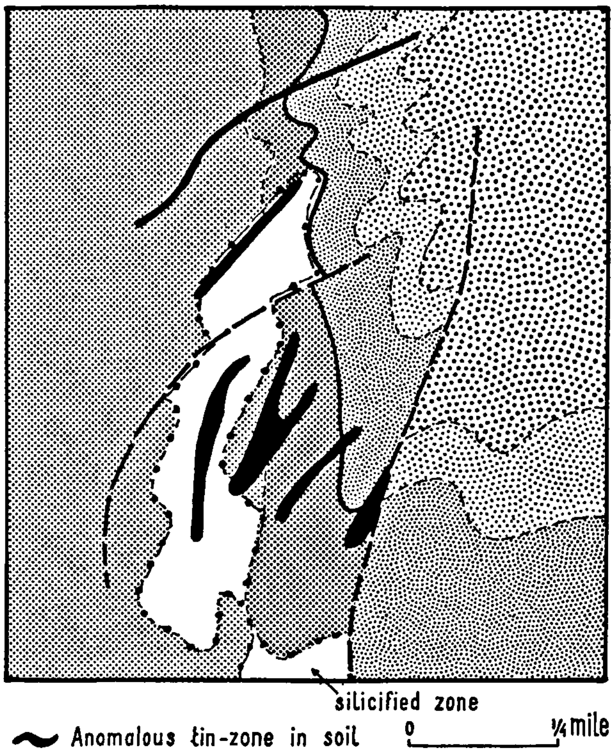


Fig. 4.21. Anomalous tin zones in the soils over faulted block along the west side of the Tower Hill adamellite stock (see main map for lithology).

values have been discovered in bedrock as well as in the soils in this area, but unfortunately this has not been followed up by diamond drilling. The writer selected this area because it is intensely fractured, several small faults penetrate the adamellite stock and it appears to be favourably situated with respect to the major Oak Bay fault system.
It can be concluded that, although no ore grade material has yet been found in the area between Mount Pleasant and St. Stephen, the numerous indications of tin warrant more detailed investigation. Moreover, the occurrences at Hatch Brook and True Hill suggest that tin and base metal sulphides can be expected to occur separately in this area, in contrast to the Mount Pleasant deposit. This would undoubtedly simplify the ore concentration.
For a description of other tin occurrences in the Canadian Appalachians, the reader is referred to Mulligan (1964).

4.3. NICKEL COPPER MINERALIZATION

Several nickel-copper mineral showings are associated with the basic intrusions in the western part of the map area (see main map). They are mostly small mineralized pods in the gabbroic rocks, which consist mainly of nickeliferous pyrrhotite and subordinate intergrown pentlandite, with locally some fine veinlets or blebs of chalcopyrite.
The main nickel ore bodies in the region occur north of St. Stephen and west of the map area. Bailey and Matthew (1870—1871) first mention the presence of nickel mineralization north of St. Stephen. More complete descriptions of various aspects of the deposits are given by Bailey (1897), Ells (1902—1903), Dickson (1906), Campbell and Knight (1907) and Mac Kenzie (1940). More recent petrological studies are by Hale (1950), Dunham (1950) and Clark (1962). The first intensive exploration work was carried out on the St. Stephen nickel deposits between 1928 and 1930 by various mining companies and private individuals. The work consisted of geological mapping, magnetic- and spontaneous polarization surveys, which were followed by trenching and some diamond drilling. Some more geophysical work and diamond drilling was carried out between 1937 and 1938. Interest subsequently declined because the discovered ore bodies were not comparable in size and grade to the extensive nickel-copper ore bodies in the Sudbury area, Ontario. However, in more recent years a shaft has been constructed to provide access to the more promising ore bodies, which have partially been developed, but the property was never put into production. The technical problems which prevented the establishment of an economic mining operation are due to rather small ore bodies, while the nickel is mostly associated with massive pyrrhotite. Concentration of the ores with convential methods is therefore extremely difficult and the size of the ore bodies does not warrant extensive research by private companies in order to develop a new concentration technique.

4.4. ARSENOPYRITE-GOLD MINERALIZATION

Fractured quartz veins carrying small pods and blebs of arsenopyrite accompanied by varying amounts of gold are common in the area between Tower Hill and Rolling Dam. The quartz veins follow mostly easterly to northeasterly trending fractures in the Ordovician metasediments. The most prominent of these gold bearing fractures in this area occur along the flanks of a well developed steeply northeasterly plunging F_3 fold, near the axis of the St. David Dome (see main map). The fold is in part intensely silicified.
Since the F_3 folds were formed approximately contemporaneously with the adamellite intrusions, it is evident that the arsenopyrite-gold mineralization is also associated with these intrusions.
Arsenopyrite-gold veins similar to those in the map area, are also associated with Devonian granitic rocks in Nova-Scotia.

CHAPTER V

SUMMARY AND CONCLUSIONS

1. The main structure in the map area is a northeasterly trending antiform, which is called the "St David Dome" in this thesis.

2. The core of the St David Dome consists of Lower Ordovician graptolite-bearing black slates, minor quartzites and metamorphic equivalents. This indicates quiet water deposition during the Ordovician.

3. The Upper Silurian-Lower Devonian in the map area is characterized by an assemblage of feldspathic greywackes, greywackes, quartz wackes and interbedded slates, which suggests more turbid conditions of deposition.

4. The Upper Silurian-Lower Devonian rocks north of the St David Dome are better sorted and have a much lower feldspar content than those along the southern flank. This suggests a north dipping regional slope, and relative uplift of the region south of the map area, which was probably accompanied by igneous activity.

5. The Oak Bay conglomerate, at the base of the Silurian sequence consists of a well sorted pebble assemblage in a greywacke matrix. This suggests that these rocks represent a remobilized conglomerate, which was deposited along the base of a major fault scarp, below the zone affected by wave action.

6. Three generations of folds have been identified in the area, which are all probably related to the Acadian orogeny (Middle-Late Devonian).

7. The main phase deformation is represented by close to sub-isoclinal cleavage folds. The average trend of these structures is roughly parallel with the St David Dome.

8. The second phase folds are only locally well developed, in zones adjacent to the higher grade metamorphic rocks. These folds deform the bedding and they produce a typical crenulation cleavage, where they affect the main phase slaty cleavage planes. They plunge mostly gently to the east or northeast, roughly parallel to the main phase folds, while they are all overturned to the south or southeast. It is probable that these folds are related to a late stage of the main phase north-northwest to south-southeast trending compressive stress system.

9. Third phase folds occur throughout the map area. They are mostly steeply plunging chevron type folds which deform the bedding and earlier cleavage planes. The attitudes of the fold axes fall into two girdles which are obligue to the trend of the earlier folds. They are consistent with an east-northeasterly to west-southwesterly trending compressive stress.

10. Knick zones are well developed in the thinly laminated slates, sandy slates and phyllites of the Flume Formation. They postdate the compressive folding phases and they appear to be related to a north-northwesterly to south-southeasterly trending tensional stress.

11. The higher grade metamorphic minerals such as biotite and staurolite, cut across the main phase cleavage planes, which are chiefly defined by fine white mica. In a few localities biotite crystals define the second phase cleavage planes. It can therefore be concluded that the higher grades of metamorphism postdate the main phase folding and continued at least into the second phase of folding.

12. F_3 folds occur as ghost structures in partly preserved metasediment inclusions in the adamellite stocks. This indicates that these intrusions are contemporaneous with or postdate the third deformation phase.

13. The adamellite stocks are related to the main St George granite mass. However, they represent a late stage of the Devonian intrusions, since adamellite dykes intrude the main granite mass in several localities.

14. Radio active dating of the St Stephen basic complex indicates an Ordovician age. However, the age of other basic intrusive rocks in the area is uncertain.

15. The Ordovicah rocks in the St David Dome are thrusted over the Upper Silurian-Lower Devonian rocks of the Digdequash Formation. The offset appears to be about 3.5 miles.

16. The latest movements along the northwesterly trending wrench faults, which are very prominent in the map-area, postdate the granitic intrusions.

17. The volcanism in the Mount Pleasant area is related to a narrow block which is delimited by two north-northwesterly trending wrench faults. The offsets along these faults and the trends of the mineralized tension fractures in the volcanoe suggest that the narrow block has been stretched by a north-northwesterly to south-southeasterly trending tensional stress. This made it possible for volcanic material to reach the surface.

18. Two main phases of Carboniferous volcanism can be distinguished in both the Mount Pleasant volcanoe and the extrusive sequence to the east and northeast.

19. The metallic mineralization at Mount Pleasant occurs mostly in tension fractures along the margins of the two vents, which formed during the second phase of volcanism.

20. The concentration of metallized tension fractures along the vent margins is chiefly due to intense silification of the vents prior to the metallic mineral-

ization. Fracture zones formed more easily in this contact zone of the highly competent silicified rocks of the vents and the less competent older feldspar- and quartz-feldspar porphyries. Moreover, the largely impervious, silicified masses in the vents undoubtedly guided the mineralizing fluids along the margins.

21. The intensity of tin-base metal mineralization at Mount Pleasant is closely related to the abundance of fluorite. This suggests that these metals have been transported in a chemical complex containing fluorine.

22. The regional distribution of tin minerals in the map-area suggests that the source of the tin is related to the adamellite intrusions. This indicates that the metallic mineralization at Mount Pleasant represents a remobilized deposit.

23. The copper-nickel deposits in the area are geneticly related to gabbroic rocks. In the main known deposits, the nickel is chiefly associated with pyrrhotite and to a minor extent with pentlandite.

24. The arsenopyrite – gold mineralization in the Rolling Dam area is associated with fractured quartz veins, which are contemporaneous with or postdate the F_3 folds. These fractures occur along the crests or flanks of the St David Dome, which appears to be for the most part intruded by adamellite. Therefore this mineralization appears to be geneticly related to these intrusions.

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