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THE GEOLOGY OF THE BENJAMIN RIVER INTRUSIVE COMPLEX,
RESTIGOUCHE COUNTY, NEW BRUNSWICK

by

ROBERT DONALD STEWART

B.Sc. (Hons.), Mount Allison University, 1975

A thesis submitted to the Faculty of
Graduate Studies in partial fulfillment
of the requirements for the degree of
Master of Science

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February 14, 1979

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ABSTRACT

The complex is located in northeastern New Brunswick on the south branch of the Benjamin River at latitude $47^{\circ}49'$ north and longitude $66^{\circ}20'$ west.

The complex is exposed as a composite plug flanked to the southwest by smaller simple and composite intrusions which intruded Silurian subaerial volcanic rocks during the Devonian. Four phases make up the complex; a gabbroic phase, a granodioritic phase, a quartz monzonitic phase and a late felsic phase. Each phase is composed of a variety of rock types which differ slightly from each other in composition and/or texture. The oldest and youngest phases of the complex are the gabbroic and late intrusive phases respectively. The relative intrusive relationship between the granodioritic and the quartz monzonitic phases is not known.

Porphyritic rock types of each phase contain similar, strongly zoned plagioclase phenocrysts which suggests a common genetic relationship between phases. Differentiation of the complex followed a calc-alkaline trend from gabbroic to granodioritic to quartz monzonitic compositions. The gabbroic, granodioritic and quartz monzonitic phases may be distinguished on the basis of their major element chemistry but the late intrusive phase is chemically similar to the granodioritic and quartz monzonitic phases. A whole-rock Rb/Sr isochron determination indicates a Devonian age (370 ± 30 m.y.) and a mantle-like source ($^{87}\text{Sr}/^{86}\text{Sr}_i = 0.7046$) for the complex.

Structural geology shows that deformation increases to the southeast in the region. The volcanic rocks intruded by the complex

are flat-lying to gently-dipping and are lacking cleavage. A satellite photograph, regional geology, aeromagnetic and gravity maps suggest that the Benjamin River Intrusive Complex may be an exposed portion of a felsic batholith that is largely mantled by Silurian volcanic rocks.

The Benjamin River porphyry copper deposit is spatially and possibly genetically related to the granodioritic phase of the complex. Pyrite and chalcopyrite occur in quartz veins and along fractures in biotite granodiorite and Silurian volcanic rocks. Visible molybdenite is generally restricted to milky quartz veins. Weak propylitic alteration is pervasive whereas phyllic and minor potassic alteration occur in narrow alteration envelopes about veins and fractures in the volcanic and intrusive rocks.

TABLE OF CONTENTS

Chapter		Page
1	Introduction	1
	Accessibility	1
	Methods of Study	3
	Previous Work	5
	Acknowledgements	6
2	Geology	7
	Regional Geology - Northeastern New Brunswick	7
	Local Geology	11
	- Chaleur Group	13
	Mafic Volcanic Rocks	13
	Felsic Volcanic Rocks	14
	Tuff or Sedimentary Rock	15
	- The Benjamin River Intrusive Complex	15
	Setting	15
	Petrology	19
	- Gabbroic Phase	19
	- Granodioritic Phase	21
	- Quartz Monzonitic Phase	24
	- Late Intrusive Phase	25
	Discussion	27
3	Chemistry of the Benjamin River Intrusive Complex	30
	Analytical Techniques	30
	Discussion	32
	Chemical Comparison of the Benjamin River Intrusive Complex to Granitic Rocks South of the Complex	38
	Conclusions	42
4	Rubidium-Strontium Isochron Study of the Benjamin River Intrusive Complex	43
	Previous Geochronological Work	43
	The Rubidium-Strontium Isochron Method	46
	Analytical Results	48
	Discussion	48
5	Structural Geology	52
	Regional Structural Geology	52
	Structural Geology Within the Thesis Area	60
	Discussion	62
6	Alteration and Economic Geology	63
	Alteration	65
	Nature and Distribution of the Opaque Minerals	70
	Discussion and Summary	72
7	Geologic History	78

Chapter		Page
8	Summary of Conclusions	81
	References	84
Appendix I	Methods	92
Appendix II	Thin Section Descriptions	97
Appendix III	Locations and descriptions of specimens selected for whole-rock chemistry study	103
Appendix IV	Whole-Rock Data	106
Appendix V	Supplementary Variation Diagrams	111
Appendix VI	References to age determinations illustrated on figures 14 and 15	115
Appendix VII	Attitudes of Planar Features to the Core Axis	118
Appendix VIII	Summary of Assay Results	121
Appendix IX	Method of Estimation of the Grade and Tonnage of the Benjamin River Deposit	124

LIST OF FIGURES

Figure		Page
1	Location map	2
2	Geology map	in pocket
3	Station location map	in pocket
4	Tectonostratigraphic zones of northern New Brunswick	8
5	Intrusive phases in the northeastern part of the thesis area	20
6	Sketch of the geology of the southwestern part of the thesis area	22
7	Sample locations used in the whole-rock geochemical study	31
8	Larsen variation diagrams for the Benjamin River Intrusive Complex	34
9	AFM plot for the Benjamin River Intrusive Complex	35
10	CaO-Na ₂ O-K ₂ O plot for the Benjamin River Intrusive Complex	36
11	Larsen variation diagrams comparing the complex to Devonian intrusions from northern New Brunswick	39
12	AFM plot comparing the complex to Devonian intrusions from northern New Brunswick	40
13	CaO-Na ₂ O-K ₂ O plot comparing the complex to Devonian intrusions from northern New Brunswick	41
14	Isotopic age map of New Brunswick and Gaspé	44
15	Histogram of K/Ar and Rb/Sr ages from granitic rocks of New Brunswick and Gaspé	45
16	Whole-rock isochron plot	50
17	Structural subzones of northeastern New Brunswick	53
18	Poles to bedding in northeastern New Brunswick	55
19	Poles to cleavage in northeastern New Brunswick	56
20	Satellite photograph of northeastern New Brunswick	58
21	Gravity map of northeastern New Brunswick	59
22	The Benjamin River Deposit	64

LIST OF TABLES

Table		Page
1	Stratigraphic table for northeastern New Brunswick	9
2	Stratigraphic table for the thesis area	12
3	Relative proportions of rock types in the thesis area	18
4	Modal analyses of granodiorite and quartz monzonite	23
5	Rubidium and strontium analytical data	33
6	Analytical results for the whole-rock Rb/Sr isochron study	49
7	Variation in alteration assemblages between different rock types and styles of alteration	66
8	Comparison of the Benjamin River porphyry copper deposit with other porphyry copper deposits	75

CHAPTER I

Introduction

The Benjamin River Intrusive Complex, (hereafter referred to as the complex), consists of Devonian plugs, dikes and sills that are intrusive to Silurian subaerial volcanic rocks. A variety of rock types, defined on compositional and textural grounds, are simplified into four major phases with gabbroic, granodioritic and quartz monzonitic compositions. A sub-economic porphyry copper deposit is spatially related to granodioritic rocks in the southwestern portion of the thesis area.

The main objectives of this study are to describe the petrology, chemistry and age of the complex. Other topics that have been studied in less detail are the petrography of the volcanic rocks intruded by the complex, the regional and local structural geology and the alteration and sulphide mineralization that occurs within the porphyry copper deposit related to the complex.

Accessibility and Physiography

The thesis area is 19 km south of Chaleur Bay (figure 1) in northeastern New Brunswick. It is reached by road from Highway 11 at Benjamin River or from Selwood. Clearcut lumbering operations have provided an excellent system of roads for study of the main plug of the complex. However, to the southwest the terrain is low-lying and outcrop is rare. Geological interpretations in this low-lying area are based on diamond drill core.

Figure 1. Location map.

Overburden blankets most of the bedrock in northeastern New Brunswick. Exposures are generally limited to river valleys and recent road cuts. Pleistocene glacial erosion and deposition has only slightly altered the former landscape (King, 1972). River valleys generally follow fault traces (Greiner and Potter, 1966).

Methods of Study

The 1976 field season was divided between studying drill core and traversing the thesis area. Some 17,000 feet of AX-size diamond drill core was examined and relogged to establish the intrusive phases and their inter-relationships within the complex.

The northeastern portion of the thesis area was traversed and mapped at a scale of 1:15,000. Interpretation of the surface geology for the southwestern portion is largely based on drill holes because outcrop exposures are rare. The predominant lithology of outcrops and boulder fields was plotted on the surface geology map (figure 2; in pocket). Surface exposures were located on airphotos (New Brunswick, 1972) or surveyed by pace and compass methods (figure 3, in pocket).

Selected samples from surface locations and drill core were further studied petrographically and chemically at the university. Petrographic methods included staining for potassium feldspar (Chayes, 1952), modal analysis of hand specimens and thin sections, thin section observation and confirmation of mineral identification by X-ray diffraction. The whole-rock chemistry of 17 samples was determined using X-ray fluorescence techniques by Bondar-Clegg Ltd. and the Geological Survey of Canada. The estimated reliability of analyses by the Geological Survey of Canada is $\pm 2\%$ of the reported value (G. Lachance, personal communication). The precision and

4

accuracy of the analyses by Bondar Clegg Ltd. is not known. CIPW normative minerals and the differentiation index for each sample were calculated using the "Irvine" program (Irvine and Baragar, 1971). The Larsen differentiation index was calculated separately. Sixteen samples were analysed for Rb and Sr by X-ray fluorescence and five of these samples were prepared for isotopic analysis. Dr. J. Blenkinsop determined the strontium isotopic compositions of these five samples. Operation of the mass spectrometer and reduction of the isotopic data was controlled by a PDP-11 computer.

Data used in the regional structural study was taken from the regional geology map (Irrinki, 1976) and plotted on an equal area Schmidt net. An aeromagnetic map (Geological Survey of Canada, 1954), a gravity map (Energy, Mines and Resources, 1977) and a satellite photo (NASA, 1973) were also used in studying the regional structure.

The limits of the cupriferous zone were defined using estimates of chalcopyrite content as determined by Soquem geologists (Richard, 1970, 1972; Chev, 1971; Gagnon, 1971). These limits are supported by assay data given in drill logs submitted for assessment by Soquem.

The nature of sulphide mineralization and alteration were studied in hand specimen, thin section and polished thin section. Alteration was only studied mineralogically and not chemically.

Included in the appendices are a discussion of sampling and analytical methods, thin section descriptions, descriptions of specimens chemically analysed, whole-rock analyses, variation diagrams, structural measurements, a summary of assay results and the method used in calculating the grade and tonnage of the porphyry copper deposit.

~
A data file has also been compiled to store information that was used in the thesis study. Included are drill hole logs and sections and detailed descriptions of sample preparation and analytical techniques. This data file is on deposit with the Carleton University geology department and the Bathurst office of the New Brunswick Department of Natural Resources, Mineral Resources Branch.

Previous Work

The regional geology has been mapped by Alcock (1935, 1941), Greiner (1960, 1965, 1970) and Irrinki (1976). The stratigraphic succession has been revised by each of the above and by Noble (1976). The nature of the regional structure, volcanism and tectonism have been described by Stringer (1975), Pajari and others (1976), and Ruitenberg and others (1977) respectively.

The complex was first referred to as "the upper granite mass on the South Benjamin River" (Alcock, 1941, p. 23). Publication of the aeromagnetic map for the Charlo region in 1953 precipitated a staking rush which included the magnetically high areas surrounding the complex. Stratmat Ltd. made the first reference to quartz-sulphide veins within the intrusion (Mowat, 1954).

A stream water and sediment geochemical survey (Boyle and others, 1966) led to the discovery and investigation of a low-grade copper and molybdenum occurrence by Soquem and Umex. Geological mapping, geochemical and geophysical surveys and diamond drilling were used to assess the occurrence (Tauchid, 1970, 1973; Tauchid and Blouin, 1972). The mineralogy and geology of the occurrence were briefly described by Nutter (1971).

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The New Brunswick Department of Natural Resources generously allowed the author use of office facilities for logging core, preparation of maps, etc. and also the use of a tent trailer for field work. They also provided seven whole-rock analyses with monies from the Department of Regional Economic Expansion. The Geological Survey of Canada provided whole-rock and trace element analyses of 10 samples. Strontium isotope analysis was carried out by Dr. J. Blenkinsop.

I am indebted to Rao Irrinki and family for allowing me to stay in their home during the summer of 1976.

CHAPTER 2

Geology

The Benjamin River Intrusive Complex consists of Devonian gabbroic to quartz monzonitic phases that intruded Silurian volcanic rocks. Phases of the complex are similar to those found in other Devonian intrusions in the area.

Regional Geology - Northeastern New Brunswick

Northern New Brunswick is divided into four tectonostratigraphic zones (after Ruitenberg and others, 1977; figure 4) which serve to facilitate discussion of the regional geology.

The oldest rocks in the region are the severely deformed Cambro-Ordovician sedimentary and volcanic rocks of the Tetagouche Group (zone 3, figure 4, table 1) (Poole, 1967). Metamorphism ranges from low grade (prehnite-pumpellyite) in the southwest (Venugopal, in preparation) to high grade (migmatites, sillimanite) along the western margin of the zone (Ruitenberg and others, 1977). Deformation, metamorphism and emplacement of mafic and felsic intrusions occurred during the Taconian and Acadian orogenies (Fyffe and others, 1977; Ruitenberg and others, 1977). The economically important volcanogenic massive sulphide deposits of the Bathurst area occur within volcanic rocks of the upper Tetagouche Group (Davies and others, 1973).

The Fournier and Elmtree Groups occur north of the Tetagouche Group in tectonostratigraphic zone 2 (figure 4, table 1). The Fournier Group is an ophiolitic complex of pillowed mafic volcanic rocks and chert cut by gabbro, sheeted diabase dikes and trondjhemite

Figure 4. Tectonostratigraphic zones of northern New Brunswick (after Ruitenberg and others, 1977).

Table 1. Stratigraphic table for northeastern New Brunswick (after Ruitenberg et al., 1977).

PLEISTOCENE (or older?)	unconsolidated debris
	angular unconformity
PENNSYLVANIAN	Bonaventure Formation; conglomerate, sandstone, shale
	angular unconformity
MIDDLE DEVONIAN	Acadian Intrusives; gabbro, granodiorite, granite
	intrusive contact
LOWER DEVONIAN	Campbellton Formation; con- glomerate, sandstone, shale
	unconformity
	Delhouse Group; basaltic flows and tuffs, siltstone, sandstone, shale, limestone
	disconformity in the northwest - conformity in the east
SILURIAN	Chaleur Group; sandstone, siltstone, mudstone, shale, limestone, basalt, andesite, volcanic conglomerate, rhyolite
	gradational contact
SILURIAN and/or UPPER ORDOVICIAN	Matapedia Group; thinly bedded limestone and shale
	conformable
UPPER ORDOVICIAN	Grog Brook Group; argillite, greywacke, conglomerate, mafic volcanics (sub-zone 1b only)
LOWER to UPPER ORDOVICIAN	Elmtree Group; slate, phyllite, conglomerate (sub-zone 2 only)
	Tetagouche Group; upper Tetagouche Group, mafic volcanics, greywacke, slate, chert, limestone (sub-zone 3 only)
CAMBRIAN to LOWER ORDOVICIAN	Fournier Group; gabbro, diabase, amphibolite, iron hematite, mafic volcanics, chert
	Tetagouche Group; lower Tetagouche Group, slate, limestone, quartzite, phyllite, migmatitic complex (sub-zone 3 only)

(Fyffe, 1974; Pajari and others, 1976). It is conformably overlain by the Elmtree Group (Ruitenberg and others, 1977).

The Elmtree Group (zone 2, figure 4) is composed of quartzose greywacke and interbedded grey slate (Fyffe, 1974). It is a time-stratigraphic equivalent of the upper Tetagouche Group (zone 3, figure 4) and laminated argillite and limestone (Grog Brook and Matapedia Groups) in tectonostratigraphic zone 1B (figure 4) (Ruitenberg and others, 1977). The Matapedia Group is conformably overlain by a turbidic sequence (Siegas Formation) to the northwest (zone 1A, figure 4) and by the Silurian Chaleur Group (table 1) to the east (zone 1C, figure 4) (Alcock, 1935; Ruitenberg and others, 1977). The Chaleur Group is composed of limestone and clastic sedimentary rocks overlain by mafic (Bryant Point Formation) and felsic (Benjamin Formation) volcanic rocks (Greiner, 1970; Irrinki, 1976).

These volcanic rocks are the country rock to the Benjamin River Intrusive Complex.

The Bryant Point Formation is composed of 80% basaltic, 15% andesitic and 5% rhyolitic volcanic rocks near the type section at Bryant Point (Irrinki, 1976). The mafic volcanic flows are commonly amygdaloidal and porphyritic (Irrinki, 1976). Phenocrysts are invariably plagioclase and amygdules consist of calcite, chlorite, epidote, zeolites and/or chalcedony (Irrinki, 1976).

The Benjamin Formation is comprised of felsic volcanic rocks with less than 5% mafic volcanic rocks (Irrinki, 1976). The felsic volcanic rocks consist of grey, orange, pink and maroon aphanitic rhyolite, porphyritic rhyolite and pyroclastic rocks.

The Chaleur Group is conformably overlain (Alcock, 1935) by limestone, calcareous siltstone, sandstone and mafic volcanic rocks of the Lower Devonian Dalhousie Group (zone 1C, figure 4). These in turn are unconformably overlain by lacustrine and fluviatile sandstones of the Campbellton Formation (Alcock, 1935).

Devonian mafic and felsic intrusions were emplaced in tectonostratigraphic zones 1 and 2 during the Acadian Orogeny (Ruitenberg and others, 1977).

The complex is an example of this intrusive activity. The Devonian intrusions in the Chaleur Bay area are gabbro and/or diorite, diabase, biotite granite, hornblende granite, granodiorite, feldspar porphyry and aphanitic felsite (Irrinki, 1976).

Regional metamorphism in tectonostratigraphic zone 1 is sub-greenschist (very low grade), (Mossman and Bachinski, 1972). Open to tight folding locally preceded cleavage development (Stringer, 1975).

The coastal region about Chaleur Bay is underlain by post-orogenic Lower Carboniferous fluviatile sandstones. These sandstones are flat-lying and unconformably overly the pre-Carboniferous basement.

Local Geology

The thesis area is underlain by mafic and felsic volcanic rocks, mafic and felsic intrusive rocks and minor laminated tuff or siltstone (figure 2). Four phases comprise the intrusive complex (table 2). The gabbroic, granodioritic and quartz monzonitic phases differ from one another in modal mineralogy, textures and geochemistry (see chapter 3). The late intrusive phase commonly

Table 2. Stratigraphic table for the thesis area.

PLEISTOCENE (or older?)	unconsolidated debris
	angular unconformity
MIDDLE DEVONIAN	BENJAMIN RIVER INTRUSIVE COMPLEX
	Late Intrusive Phase; quartz monzonite (type B), porphyritic quartz monzonite (type B), quartz diorite (type B), porphyritic quartz diorite (type B), hornblende felsite.
	intrusive contact
	Quartz Monzonitic Phase; quartz monzonite, porphyritic quartz monzonite.
	Granodioritic Phase; biotite granodiorite, quartz diorite, quartz diorite porphyry, porphyritic quartz diorite, porphyritic felsite, porphyritic plagioclase felsite, porphyritic plagioclase aphanite.
	intrusive contact
	Gabbroic Phase; gabbro, leucogabbro
	intrusive contact
UPPER SILURIAN	CHALEUR GROUP
	Benjamin Formation; rhyolite, porphyritic rhyolite, ash flow tuff.
	intercalated relationship
	Bryant Point Formation; massive, amygdaloidal and porphyritic mafic volcanic rocks; tuff, siltstone, red siltstone, rhyolite, rhyolitic ash flow tuff.

occurs as pink fine-grained intrusions cross-cutting the older rocks.

Modal quartz, alkali feldspar and plagioclase contents, determined by point counting or by visual estimation, were used as a basis for the classification of rock types (Streckeisen, 1974). Inequigranular rock types are described as being porphyritic (5 to 50% phenocrysts) or porphyries (> 50% phenocrysts). Porphyritic intrusive rocks with an aphanitic groundmass are called aphanite or felsite to indicate whether the groundmass is intermediate or felsic in composition.

The cross-reference index (data file) lists the locations and contact relationships of each rock type. Thin section and hand sample descriptions are given in appendices II and III respectively. The bulk of the petrography is contained in the drill hole logs (data file).

Chaleur Group

Mafic Volcanic Rocks

Mafic volcanic rocks of the Bryant Point Formation surround the complex (Irrinki, 1976), (map unit 1, figure 2). They are commonly basaltic flows which are massive, dark green, mesocratic and microcrystalline to fine-grained. The basalts are not pillowed and generally have very thin flow top breccias. These rocks are uniformly textured with coarse-grained plagioclase phenocrysts and amygdules occurring locally (see cross-reference index). In thin section (7301-221, -5f2, NT-3a, -10, -13, -30) they have an ophitic texture of plagioclase microlites in a chloritized groundmass. Plagioclase is altered to sericite and carbonate.

Fine-grained basaltic units are commonly "felty"-textured partly due to the original ophitic texture but enhanced immediately adjacent to intrusive contacts. Well-developed hornfelsic zones are relatively narrow. The metamorphic mineral, probably amphibole, has been altered to chlorite and biotite. The role of contact metamorphism in the development of the "felty" texture away from intrusive contacts is not known. Veins in basaltic units are commonly chlorite and calcite.

Andesitic volcanic rocks (colour index < 40) are much less common than basaltic units. They are aphanitic to fine-grained, leucocratic and massive. Some of the "andesitic" units may be altered basalt. Andesitic units have neither a "felty" texture nor an ophitic texture. Quartz veins are common in the andesitic units.

Felsic Volcanic Rocks

Felsic volcanic rocks (Benjamin Formation) are massive rhyolitic (unit 2a, figure 2) or pyroclastic units (unit 2b, figure 2). The massive rhyolitic units may represent subvolcanic intrusions that are related to Silurian volcanism. They are intruded by the gabbroic phase of the complex which suggests they are unrelated to Devonian intrusive activity. Intersections of massive rhyolite in drill core are commonly less than 10 m. The notable exception is drill hole 7229 where the intersection is greater than 60 m.

Felsic pyroclastic units occur throughout the thesis area (unit 2b, figure 2). They commonly contain lapilli and broken phenocrysts of plagioclase and minor quartz. The commonly observed eutaxitic texture was developed when pumice fragments and glass shards were welded. Details in the welded groundmass are defined in thin

section by opaque minerals. Albite, garnet and biotite are developed by contact metamorphism immediately adjacent to intrusive contacts.

Felsic volcanic rocks are intercalated with mafic volcanic rocks (see drill hole sections). As a result, the base of the Benjamin Formation is not easily established. Irrinki (1976) interpreted the formation boundary to be south of the thesis area. More recently, Davies (1978) has chosen the ash flow tuff farthest south in the thesis area as the base of the Benjamin Formation.

Tuff or Sedimentary Rock

Fine-grained, bedded and laminated tuff and/or siltstone are intercalated with the volcanic rocks. They commonly have very short intersections in drill holes. In thin section, they consist of quartz and feldspar with secondary epidote, chlorite, sericite and opaque mineral(s). Intense epidotization and chloritization is common. The secondary minerals may have been developed by contact metamorphism or hydrothermal alteration.

The Benjamin River Intrusive Complex

The complex is made up of four distinct phases which differ in composition and/or age. These phases are the gabbroic phase, the granodioritic phase, the quartz monzonitic phase and the late intrusive phase. Each phase is composed of several rock types that differ from each other in texture or composition.

Setting

A "very high" level of emplacement for the complex is indicated by the estimated thickness of the overlying sedimentary-volcanic

sequence at the time of intrusion. The complex intruded Middle to Upper Silurian volcanic rocks during the Devonian (370 ± 30 m.y.; chapter 4). The maximum thickness of Silurian and Devonian strata that may have been present when the complex was intruded is estimated to be less than 1 km (Irrinki, 1976). Volcanic rocks in the surrounding region are flat-lying to gently dipping (Irrinki, 1976; chapter 5). Therefore the level of emplacement is inferred to be less than 1 km. The regional metamorphism is "very low grade" (Mossman and Bachinski, 1972; Winkler, 1976) which supports this estimate of emplacement depth.

The features of the complex listed below are consistent with characteristics of high level intrusions (Buddington, 1959). The complex is composed of a suite of phases that range from gabbroic to quartz monzonitic composition. Porphyritic and fine-grained rock types of these phases are common. Weak, pervasive alteration is widespread. Chilled contact zones are relatively wide and are locally flow laminated. Xenoliths are common. The volcanic rocks are tilted near the contact of the main plug (chapter 5, Mowat, 1954) but evidence of folding or fabric development due to regional forces was not observed. A genetic relationship between the volcanic rocks intruded by the complex and the complex itself has not been established. Well-developed, equigranular hornfels only occurs immediately adjacent to large intrusions. The maximum distance from an intrusion that contact metamorphism occurred was not determined.

The geological events that occurred in the northeastern and southwestern parts of the thesis area are interpreted to be broadly similar and coeval in each area. Continuity of the Silurian volcanic units between areas is suggested from the geology map

(figure 2). The intrusive complex is defined (page 7) to include all of the Devonian intrusive rocks in the thesis area. However, there are considerable differences in the size and composition of intrusions between the northeastern and southwestern parts of the thesis area. Intrusions are much larger in the northeastern part (figure 2). The granodioritic phase that is the dominant phase in the southwestern part of the thesis area is absent from the main plug of the complex (figure 2, table 3). Similarly the gabbroic and quartz monzonitic phases mainly occur in the main plug of the complex (figure 2, table 3) and not in the southwestern part of the thesis area. The late intrusive phase occurs in each area. Porphyry copper mineralization is spatially related to granodioritic intrusions (chapter 6) therefore it only occurs in the southwestern part of the thesis area. These differences are interpreted to be local variations within the complex. The similar intrusive relationships (i.e. the gabbroic phase as the oldest phase and the late intrusive phase as the youngest phase) between the two areas and their proximity to each other suggest that their geologic history has been both similar and correlative.

The main plug is composed of quartz monzonite of the quartz monzonitic and late intrusive phases discontinuously surrounded by gabbro and leucogabbro of the gabbroic phase (figure 2). Gabbroic rock types are the oldest in the complex (cross-reference index). They are intrusive to the volcanic rocks but are intruded by the younger, more felsic phases. Contact relationships do not conclusively illustrate whether the quartz monzonitic and granodioritic phases are coeval but both phases were intruded by the late intrusive phase.

Table 3. Relative proportions of rock types in the northeastern and southwestern parts of the thesis area. Estimates are based on surface exposures for the northeastern part and on drill core for the southwestern part. Intrusions comprise 5% of the drill core in the southwestern part of the thesis area.

		Northeastern Part of Thesis Area	Southwestern Part of Thesis Area
		(%)	(%)
Late Intrusive Phase	Quartz Diorite (Type B)	-	5
	Porphyritic Quartz Diorite (Type B)	-	2
	Quartz Monzonite and Porphyritic Quartz Monzonite (Type B)	25	1
	Hornblende Felsite	-	0.3
Granodioritic Phase	Biotite Granodiorite	-	30
	Quartz Diorite	-	21
	Quartz Diorite Porphyry	-	7
	Porphyritic Quartz Diorite	-	7
	Porphyritic Felsite	-	2
	Porphyritic Plagioclase Felsite	-	7
	Porphyritic Plagioclase Aphanite	-	2
Quartz Monzon- itic Phase	Quartz Monzonite and Porphyritic Quartz Monzonite	50	13
Gabbroic Phase	Leucogabbro	5	-
	Gabbro	20	2

- phase not observed in this zone

Petrology

Gabbroic Phase

Gabbroic rock types occur about the margin of the main quartz monzonitic plug and as dikes to the southwest (figure 2; areas A, B and C, figure 5). The gabbroic intrusions commonly have wide chilled margins and contain xenoliths of Silurian volcanic rocks.

The gabbroic phase is made up of gabbro and leucogabbro. The gabbro contains more than 60% of unzoned to weakly zoned plagioclase (labradorite, An_{52-60}) that occurs with pyroxene in an ophitic texture. Clinopyroxene (augite) is more abundant than orthopyroxene and accessory minerals include magnetite, ilmenite and olivine. Uncommon gabbroic pegmatite veins contain apatite, plagioclase and pyroxene.

Hydrothermal alteration is common in medium grained gabbro on the eastern margin of the main plug (area A, figure 3). The extent of alteration ranges from narrow envelopes about veins and fractures to complete outcrops. In these zones labradorite is sericitized, biotite and chlorite have replaced pyroxene and hematite has replaced magnetite. Plagioclase varies from blue-green to bluish-grey to white with pink, bronze and green tints. The following assemblages occur in veins and veinlets: chlorite, calcite, calcite-chlorite, epidote, quartz, quartz-epidote, quartz-potassium feldspar and chlorite-amphibole-potassium feldspar.

The gabbro in area B (figure 5) is medium to coarse-grained except along its southern border where it is chilled. Veinlets with alteration envelopes are uncommon.

The southern portion of area C (figure 5) is underlain by fine-grained gabbro and the northern portion is underlain by medium

Figure 5. Intrusive phases in the northeastern part of the thesis area. Intrusions are labelled A, B, C, etc. to aid discussions in the text.

grained leucogabbro. Leucogabbro is leucocratic and inequigranular and does not have an ophitic texture. Hornblende is the only ferromagnesian mineral and accessory quartz and potassium feldspar are common. Some of the plagioclase is strongly zoned and is slightly more sodic (An_{50-52}) than the plagioclase in gabbro.

Granodioritic Phase

The granodioritic phase is made up of rock types that vary in texture and potassium feldspar content. They only occur in drill holes southwest of the main plug of the complex (figures 2 and 6). The granodioritic phase is intrusive to the Silurian volcanic rocks but it is intruded by the late intrusive phase.

Quartz diorite and biotite granodiorite are fine to medium grained and equigranular. Each rock type contains between 5 and 10% fine-grained biotite. They differ only in modal potassium feldspar content, i.e., quartz diorite contains less than 10% alkali feldspar (Streckeisen, 1974). The average modal analysis of biotite granodiorite is 27% quartz, 52% plagioclase, 15% potassium feldspar and 6% biotite (table 4). Weakly zoned andesine (An_{35-40}) and potassium feldspar (microcline and microperthite) are commonly altered to sericite and calcite. Biotite is chloritized, sericitized or recrystallized. Biotite granodiorite and quartz diorite are spatially related to the alteration and sulphides of the porphyry copper occurrences discussed in chapter 6.

The finer grained equivalents of quartz diorite and biotite granodiorite are quartz diorite porphyry, porphyritic quartz diorite, porphyritic felsite, porphyritic plagioclase felsite and porphyritic plagioclase aphanite. Quartz diorite porphyry and porphyritic quartz

Figure 6. Sketch of the geology of the southwestern part of the thesis area based on drill hole data. Abbreviations are the same as those used on drill hole sections (data file).

Table 4. Modal analyses of quartz monzonite and biotite granodiorite from the Benjamin River Intrusive Complex. Values given are percentages.

	<u>Quartz</u>	<u>Plagioclase</u>	<u>Potassium Feldspar</u>	<u>Mafic Minerals</u>
Quartz Monzonite				
RDS-111B	10	40	37	13
RDS-118	20	29	47	4
RDS-120	18	41	22	19
RDS-125	12	38	41	9
RDS-165	14	34	37	16
RDS-172	6	47	37	10
RDS-192	9	49	29	13
RDS-194	18	44	24	14
RDS-194A	7	46	35	12
RDS-197	12	46	37	5
RDS-211	9	38	44	9
RDS-226A	19	45	26	10
RDS-234A	25	47	19	9
RDS-250	11	43	33	13
RDS-263A	7	59	20	14
Mean	13	43	33	11
Biotite Granodiorite				
7008- 48'	21	60	10	9
7008-119'	23	47	22	8
7008-124'	32	62	5	1
7008-273'	25	44	23	9
7020- 78'	28	57	10	5
7020-240'	29	50	16	5
7020-248'	29	43	20	8
Mean	27	52	15	6

diorite occur as plugs and dikes and adjacent to equigranular quartz diorite. They probably formed from the same quartz dioritic magma but they crystallized slightly quicker. Phenocrysts are zoned plagioclase.

Rock types with an aphanitic groundmass are minor components of the complex (table 3) and occur as narrow dikes rather than massive plugs.

The phenocrysts in porphyritic felsite are potassium feldspar rather than plagioclase. Mirolitic cavities partly filled with quartz and minor biotite, are characteristic of porphyritic felsite. Porphyritic plagioclase felsite and porphyritic plagioclase aphanite are compositionally similar to biotite granodiorite and quartz diorite respectively. They probably represent the chilled equivalents.

Alteration of the finer grained granodioritic rock types is similar to that described for quartz diorite and biotite granodiorite.

Quartz Monzonitic Phase

Quartz monzonite and porphyritic quartz monzonite comprise about half of the main plug of the complex (figure 2; table 3; area D, figure 5). They also occur as minor intrusions in eight drill holes southwest of the main plug. Quartz monzonite is fine to medium grained whereas porphyritic quartz monzonite has a fine-grained groundmass and between 5 and 50% plagioclase phenocrysts. Quartz monzonite grain size varies in the main plug from fine-grained along the northern and western margins to medium grained in the centre. The quartz monzonitic phase is intrusive to the Silurian

volcanic rocks and the gabbroic phase. Angular to subhedral mafic xenoliths are common throughout the quartz monzonite in the main plug.

The average modal composition is 13% quartz, 43% plagioclase, 33% potassium feldspar and 11% mafic minerals (table 6). Andesine (An_{32-38}) is weakly zoned in the groundmass and strongly zoned in subhedral phenocrysts. Some subhedral quartz phenocrysts are embayed, due perhaps to resorption or skeletal growth. Potassium feldspar is microperthitic and commonly occurs intergrown with quartz in the groundmass. The mafic minerals are hornblende and/or biotite.

Weak pervasive alteration has resulted in the feldspar being altered to sericite and calcite and the mafic minerals being chloritized. Quartz is weakly strained.

Late Intrusive Phase

The late intrusive phase is composed of quartz diorite (type B), porphyritic quartz diorite (type B), quartz monzonite (type B), porphyritic quartz monzonite (type B) and hornblende felsite.

Contact relationships indicate that these intrusions are the youngest in the complex. Late intrusions are commonly pink or orange and do not contain veins, pyrite, chalcopyrite or molybdenite (Richard, 1970, 1972; Gagnon, 1971; Chevé, 1971; Thériault and Tauchid, 1973). Anomalously low copper and molybdenum assays corroborate the observed lack of sulphides (e.g.; drill hole 7013, 546' to 574', Richard, 1970).

Rock types of the late intrusive phase have a similar modal mineralogy to rock types of the granodioritic and quartz monzonitic

phases. In order to illustrate their different ages, rock types of the late intrusive phase are named "type B". Hornblende felsite is an exception since a similarly named rock type is not included in the granodioritic or quartz monzonitic phases.

The pink coloration of the late intrusive phase is due to pervasive alteration. Feldspars are altered to a very fine-grained mat of sericite and calcite, and ferromagnesian minerals are altered to chlorite. The hydrothermal solutions that developed this pervasive alteration were probably unlike those that developed the alteration and sparse sulphide mineralization in the older phases. Alteration of the older phases is about veins and fractures but strong, pervasive alteration is uncommon. Pyrite and chalcopyrite occur within the weakly to strongly altered sections in the older phases but sulphides are virtually absent in the altered late intrusive phase. This is also true even where the late intrusive phase is cross-cutting altered and 'mineralized' older phases (e.g. drill hole 7022; 92-104', 726-734', 777-788'). The chilled contacts of the late intrusive phase, the different style of alteration and the lack of sulphides all suggest that the phase is the youngest of the complex and that it post-dates the hydrothermal activity that developed the porphyry copper occurrence discussed in chapter 6.

Quartz diorite (type B) and porphyritic quartz diorite (type B) are pink to orange and have chilled contacts with volcanic rocks, gabbro and biotite granodiorite. The equigranular variety is very fine to medium grained. Porphyritic quartz diorite (type B) contains fine to coarse-grained, zoned andesine and biotite phenocrysts in an aphanitic to fine-grained groundmass.

Quartz monzonite (type B) and porphyritic quartz monzonite

(type B) are pink to orange and are intrusive to the volcanic rocks and the gabbroic and quartz monzonitic phases. They occur as three main intrusions within the main plug of the complex (areas E, F and G, figure 5) and as several small intrusions that were intersected in drill holes southwest of the main plug. Areas E and F (figure 5) within the main plug are comprised of orange, medium grained quartz monzonite (type B) that is locally porphyritic. Biotite and hornblende are the chloritized ferromagnesian minerals. The quartz monzonite (type B) at area G (figure 5) is orange, aphanitic to fine-grained and flow laminated near contacts. It contains less than 10% biotite. Apophyses of this composition are common in the quartz monzonite of the main plug. Southwest of the main plug the late quartz monzonite is composed of plagioclase and biotite phenocrysts in a pink, fine-grained groundmass.

Hornblende felsite is composed of hornblende and plagioclase phenocrysts in an orange to pink aphanitic felsic groundmass. It occurs in narrow, flow laminated dikes that are intrusive to gabbro, quartz diorite porphyry and biotite granodiorite. Hornblende felsite is very similar in composition to the porphyritic quartz monzonite at area G (figure 5) in the main plug.

Discussion

The volcanic rocks of the Bryant Point and Benjamin Formations were probably extruded in a subaerial environment in this area. This is suggested by the massive nature of the mafic flows, the welding of pumice and glass shards in ash flow tuff and the lack of interflow material. Fine-grained, non-fossiliferous, laminated

siltstone is locally intercalated with the volcanic rocks. The subaerial and intercalated nature of the mafic and felsic rocks with minor sedimentary units has been previously described by Toong (1963), Stewart (1975) and Irrinki (1976). The complex is comprised of high level plugs, dikes and sills that range from gabbroic to quartz monzonitic compositions. There are four distinct phases that are defined on the basis of composition or age. Rock types within a phase differ in texture or composition.

The four intrusive phases are closely related spatially (figure 2) and temporally (i.e. they are all Devonian in age (chapter 4)). They may have differentiated from a common source because similar strongly zoned plagioclase phenocrysts occur in rock types of each phase (i.e. leucogabbro of the gabbroic phase and in the porphyritic rock types of the granodioritic, quartz monzonitic and late intrusive phases).

The mafic mineral in the intermediate and felsic phases is hornblende and/or biotite. Complete gradation from a hornblende-bearing rock type to a biotite-bearing rock type was not observed within the thesis area. Such a situation does occur within a granodiorite in Soquem drill hole 7226, 1.7 km west of the thesis area.

Classification of rock types on the basis of modal mineralogy, textures and contact relationships permits several observations that may have remained unrecognized had a general classification system been used. These observations are:

- 1) the gabbroic and quartz monzonitic phases of the main plug are mineralogically quite unlike the granodioritic phase that is associated with porphyry copper mineralization (chapter 6);

- ii) the porphyry copper mineralization is younger than the gabbroic, granodioritic and quartz monzonitic phases but it is probably older than the late intrusive phase; and
- iii) the intrusions are not always symmetrical with respect to composition or grain size changes; rock types of similar composition but with different proportions of phenocrysts cross-cut one another.

Observations (i) and (ii) indicate the economic importance of a detailed petrographic classification but observation (iii) suggests that use of this system in the regional mapping of Devonian intrusions may not be effective because of difficulties in correlating rock types due to poor outcrop exposure. Diversity of textures and compositions are common features of the Devonian intrusions in the region (Irrinki, 1976). Therefore the definition of rock types and their relationships to major intrusive phases may only be possible by detailed studies of limited areas.

CHAPTER 3

Chemistry of the Benjamin River Intrusive Complex

The complex is composed of gabbroic, granodioritic and quartz monzonitic phases. These phases are chemically distinct and follow a calc-alkaline differentiation trend that progressed from gabbro to quartz monzonite. The intrusive complex is more sodic and less potassic than some granitic rocks 100 km to the south.

Analytical Techniques

Samples of the gabbroic, granodioritic, quartz monzonitic and late intrusive phases were selected from outcrop and drill core (figure 7) for whole-rock and rubidium and strontium trace element analysis. Analytical procedures and sample descriptions are discussed in appendices I and III respectively. Whole-rock data, CIPW normative minerals and differentiation indices are tabulated in appendix IV.

The CIPW normative minerals and the differentiation index (DI) were computed using Irvine and Baragar (1971) program. CIPW normative minerals provide a rapid method of comparing a variety of oxide ratios and establishing which oxides are in "excess". DI is the sum of the CIPW silic minerals; quartz (Q), albite (ab), orthoclase (or), nepheline (ne), leucite (lc) and kaliphyllite (kp) (Thornton and Tuttle, 1960). The Larsen differentiation index (LDI) is defined as:

$$LDI = (1/3SiO_2 + K_2O) - (CaO + MgO + FeO')$$

where oxides are given in weight per cent and total iron (FeO') is calculated as FeO (Larsen, 1938). The two differentiation indices

Figure 7. Locations of samples used in the whole-rock geochemical study of the Benjamin River Intrusive Complex.

(DI and LDI) and the variation diagrams (AFM, $\text{CaO} - \text{Na}_2\text{O} - \text{K}_2\text{O}$) are used to illustrate the changes in the chemistry of the parent magma that may have been due to differentiation.

Discussion

Analyses of samples that are chemically altered must be rejected before the chemistry of each phase is discussed.

Four analyses (IR-73-243A, IR-73-701A, 7021-576, RDS-228A) were rejected because their major element content and/or Rb/Sr ratio suggest that significant chemical changes have occurred to the original sample (appendix IV; table 5).

The distinct chemical differences between the gabbroic, granodioritic and quartz monzonitic phases are illustrated on variation diagrams (figures 8, 9 and 10). Differentiation indices (LDI, DI) suggest that differentiation proceeded from gabbro to granodiorite to quartz monzonite. Contact relationships confirm that the gabbroic phase is the oldest in the complex (cross-reference index, data file). Temporal relationships of the granodioritic and quartz monzonitic phases are not as well-established. Rock types intermediate to gabbro and quartz diorite (a rock type of the granodioritic phase) have not been observed. The gap between gabbroic and granodioritic analyses on variation diagrams (figures 8, 9 and 10) may be statistical or it may represent the beginning of quartz and potassium feldspar crystallization in the magma (Hyndmann, 1972). Granodioritic and quartz monzonitic analyses are not separated by a major gap on variation diagrams (figures 8, 9 and 10). Only minor discontinuities in oxide trends (i.e. SiO_2 , K_2O , MgO , TiO_2) occur on Larsen diagrams (figure 8) which suggests that these phases may have been differentiated from a common source.

Table 5. Rb and Sr analytical data. Sample 7021-576 was analysed by the staff of the G.S.C. spectrographic lab. The remainder of the samples were determined by the author.

	Sample	Rb (ppm)	Sr (ppm)	Rb/Sr
Late Intrusive Phase	RDS- 160	120	230	0.54
	RDS- 216	81	78	1.0
	RDS- 257	150	120	1.2
	RDS- 263	130	180	0.73
	7006	51	470	0.11
	7015	40	260	0.16
Quartz Monzonitic Phase	RDS- 125	130	200	0.65
	RDS- 144	110	220	0.51
	RDS- 190	110	230	0.48
	RDS- 228A	58	280	0.21
	RDS- 234A	130	210	0.60
Granodioritic Phase	7005	45	390	0.11
	7301	38	300	0.13
	7008	56	430	0.13
	7021- 576	40	660	0.061
Gabbroic Phase	RDS- 97A	12	410	0.029
	7302	11	550	0.020

Figure 8. Larsen variation diagrams illustrating the chemical differences between the four phases of the complex.

Figure 9. AFM plot comparing samples from the four phases of the complex

Figure 10. $\text{CaO-Na}_2\text{O-K}_2\text{O}$ plot comparing samples from the four phases of the complex.

Gabbroic analyses do not form linear trends on the variation diagrams (figures 8, 9 and 10). This is commonly attributed to crystal settling or crystal accumulation (Hyndman, 1972).

Granodioritic and quartz monzonitic analyses have linear trends on Larsen variation diagrams (figure 8). Granodioritic differentiation trends (figure 8) show SiO_2 and K_2O enrichment with CaO and iron depletion. Quartz monzonite differentiation trends (figure 8) show SiO_2 and Na_2O enrichment accompanying CaO , MgO , TiO_2 and iron depletion.

Normative acmite (ac) does not occur in the norm (appendix IV) therefore the phases of the complex are not peralkaline (Shand, 1951). All the samples from the complex plot in the subalkaline field on the alkalis-silica plot (MacDonald, 1968), the Ne -Q -Ol projection (Irvine and Baragar, 1971) and the Cpx-Ol-Opx ternary plot (Chayes, 1965, 1966), (appendix V). Gabbroic samples have tholeiitic (figure 9) and calc-alkaline affinities (figure 9; wt% Al_2O_3 vs normative plagioclase, appendix V). Granodioritic and quartz monzonitic phases followed a calc-alkaline differentiation trend (figures 9 and 10) (Irvine and Baragar, 1971). The quartz monzonitic phase became slightly enriched in Na_2O but it did not follow the trondhjemitic trend towards Na_2O enrichment (figure 10), (Larsen and Poldervaart, 1961).

Quartz monzonite differs from gabbroic and granodioritic phases in having higher Na_2O , K_2O and Rb contents and lower Ca, MgO, Sr and total iron concentrations (appendix IV; table 5).

Quartz diorite analyses (7006, 7015) from the late intrusive phase are similar to an analysis of quartz diorite (7005) from the granodioritic phase (table 8). Two analyses (RDS-160, RDS-263)

from the late intrusive phase are similar to analyses from the quartz monzonitic phase (appendix IV). The other analyses (RDS-216, RDS-257) of quartz monzonite from the late intrusive phase have the highest differentiation indices from the complex (appendix IV). This agrees with petrographic and field observations. The former quartz monzonite analyses are from intrusions very similar in texture to the quartz monzonitic phase. The latter two analyses are from a finer grained intrusion that has chilled margins and occurs as dikes in the quartz monzonitic phase. Therefore contact relationships and the differentiation indices suggest that the intrusion sampled at RDS-216 and RDS-257 is the youngest in the complex. Samples from this intrusion and from the quartz monzonitic phase were used in the geochronology study (chapter 4) to establish the minimum age of the complex.

Chemical Comparison of the Benjamin River Intrusive Complex to Granitic Rocks South of the Complex.

Analyses of granitic rocks (New Brunswick Department of Natural Resources, 1976) from about 100 km south of the Benjamin River Intrusive Complex are illustrated in figures 11, 12 and 13. Larsen variation diagrams (figure 11) illustrate that the Benjamin River phases are generally less differentiated than the granitic rocks further south. The granitic rocks followed a calc-alkaline differentiation trend but they are enriched in total $\text{Na}_2\text{O} + \text{K}_2\text{O}$ relative to the Benjamin River Intrusive Complex (figure 12).

The $\text{CaO}-\text{Na}_2\text{O}-\text{K}_2\text{O}$ plot (figure 13) and the Larsen variation diagrams (figure 11) illustrate that the Benjamin River phases contain more Na_2O and less K_2O and SiO_2 than the granitic rocks. This may be a

Figure 11. • Larsen variation diagrams illustrating the chemical differences between the Benjamin River Intrusive Complex and Devonian intrusions from 100 km south of the complex.

Figure 12. AFM plot comparing the complex to Devonian intrusions from northern New Brunswick.

Figure 13. CaO-Na₂O-K₂O plot comparing the complex to Devonian intrusions from northern New Brunswick.

function of a regional zonation in granitic compositions or it may be due to a local compositional variation at the complex.

Conclusions

The complex is composed of three chemically distinct groups that correspond to the petrographically determined gabbroic, granodioritic and quartz monzonitic phases (chapter 2). Samples of the felsic late intrusive phase are chemically similar to the granodioritic and quartz monzonitic phases. There is good agreement between the observed petrography, the whole-rock and Rb/Sr chemistry and the differentiation indices. Quartz monzonitic samples are the most enriched in Na_2O and K_2O and the most depleted in CaO (figures 8, 9 and 10). This is to be expected since the petrographic classification of the phases is based on the relative proportions of feldspars and quartz. Similarly the chemistry of the gabbroic and granodioritic phases corresponds to their respective mineral compositions.

This complex and Devonian granitic rocks 100 km south of the complex followed a calc-alkaline differentiation trend. The two suites differ in that this complex is enriched in Na_2O relative to SiO_2 and K_2O . Further study is required to determine the nature of these differences.

CHAPTER 4

Rubidium-Strontium Isochron Study of the
Benjamin River Intrusive Complex

The age and initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of the Benjamin River Intrusive Complex were determined from a rubidium-strontium whole-rock isochron of five quartz monzonite samples. Locations of these samples are shown on figure 3. Analytical techniques used in this study are described in the appendix.

Previous Geochronological Work

Previous age determinations of granitic rocks from New Brunswick and Gaspé are mostly K/Ar determinations of biotite, muscovite or hornblende (figure 14).

At least three periods of granitic activity have been recognized in New Brunswick and Gaspé. The first, at 490 m.y., corresponds to the intrusion of granitoid rocks during the Taconian Orogeny (figure 15). These granites have been dated by K/Ar and Rb/Sr methods in central and southern New Brunswick (figure 14). A second peak period of intrusive activity about 390 m.y. corresponds to the intrusion of granitic rocks during the Acadian Orogeny. These Devonian intrusions are the most common (figure 15) and they occur in Gaspé and northeastern, central and southern New Brunswick. A third period of granitic intrusive activity, about 330 m.y., occurred only in southern New Brunswick (figure 14), (Cormier and Stirling, 1977). This period of intrusive activity has not been as well dated as the other two periods, therefore the lack of a corresponding peak on figure 15 is interpreted to be a statistical

ISOTOPIC AGES OF GRANITIC ROCKS IN GASPE AND NEW BRUNSWICK

Figure 14. Isotopic age map of New Brunswick and Gaspé. References for the age determinations are given in appendix VI.

Figure 15. Histogram of ages from granitic rocks of New Brunswick and Gaspé. Rb/Sr determinations are shaded, K/Ar determinations are unpatterned.

omission. These intrusions are alkaline-peralkaline and are comparable to Hercynian orogenic activity in Newfoundland and Europe (Rast and Grant, 1973; Ruitenberg and others, 1973).

Distinction between Devonian and Carboniferous granitic rocks is commonly not possible using stratigraphic relationships. Therefore if there are Carboniferous granitic rocks that are not alkaline to peralkaline, i.e. unlike the Carboniferous granitic rocks recognized to date, radiometric dating may be the only way to distinguish them.

The Rubidium-Strontium Isochron Method

The rubidium-strontium isochron method may be used to avoid many of the problems of open-system behavior encountered in potassium-argon dating. Loss of radiogenic argon may occur during regional metamorphic activity and as a result single mineral ages could be considerably younger than their true ages. Changes in the rubidium and strontium isotope contents within a whole-rock sample are solely due to decay of ^{87}Rb .

There are four isotopes of strontium and two of rubidium. ^{88}Sr , ^{86}Sr and ^{84}Sr are stable isotopes whereas ^{87}Sr is produced by the decay of Rb. The present ^{87}Sr content of a rock consists of ^{87}Sr that was present when the rock was formed and radiogenic ^{87}Sr . Within an intrusion, Rb and Sr contents may vary but the original $^{87}\text{Sr}/^{86}\text{Sr}$ ratio is constant. Samples with higher Rb/Sr ratios will have higher present day $^{87}\text{Sr}/^{86}\text{Sr}$ ratios because they contain more radiogenic ^{87}Sr . This relationship is illustrated on an isochron plot where present day values of $^{87}\text{Sr}/^{86}\text{Sr}$ are plotted against $^{87}\text{Rb}/^{86}\text{Sr}$. A line is fitted to the data using the least squares

fitting technique (York, 1966). This line is an isochron with the generalized formula:

$$y = m \cdot x + c$$

where y is present day $^{87}\text{Sr}/^{86}\text{Sr}$, x is present day $^{87}\text{Rb}/^{86}\text{Sr}$, c is initial $^{87}\text{Sr}/^{86}\text{Sr}$ and m is the slope of the isochron. The slope is defined as $(e^{\lambda t} - 1)$ where λ is the decay constant for ^{87}Rb and t is the age of the rock.

The following assumptions are made in the isochron model:

(i) the samples are coeval; (ii) all samples at $t = 0$ had the same initial Sr isotopic composition; and (iii) each sample has remained a closed system, at least with respect to Rb and Sr, since $t = 0$. Recent experiments have shown that the decay constant (λ) for ^{87}Rb is $1.42 \times 10^{-11} \text{ yr}^{-1}$ (Neumann and Huster, 1976; Davis and others, 1977).

The initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio is sometimes useful in determining whether a magma was derived from the mantle or from the sialic crust (Hurley and others, 1962; Faure and Hurley, 1963). The rate of change in the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio is very slow in the mantle and in mafic rocks due to their low Rb/Sr ratio. Therefore granitic rocks derived from an ultramafic or mafic source will have similar initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, i.e. the "normal" range of granitic rocks (Faure and Powell, 1972). Contamination of a magma by radiogenic Sr from sialic material that had already experienced a long crustal history would result in that magma having a much higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratio.

For a more comprehensive discussion of strontium isotope geology, the reader is referred to Faure and Powell, (1972).

Analytical Results

The analytical results are given in table 6. A plot of the ratios $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{87}\text{Rb}/^{86}\text{Sr}$ defines a good isochron (figure 16). The age and initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of the complex are 370 ± 30 m.y. and 0.7046 respectively. The goodness-of-fit of the data about the isochron can be assessed by calculating a mean square of the weighted deviates (Brooks and others, 1977). The accuracy of the $^{87}\text{Rb}/^{86}\text{Sr}$ ratios is estimated to be $\pm 2\%$ and for the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios it is estimated to be 0.05% at the two sigma level.

Discussion

This is the first published rubidium-strontium whole-rock isochron for a Devonian granite in northern New Brunswick. The age determined is in agreement with the local stratigraphic relationships. The volcanic rocks intruded by the complex are Silurian in age (Greiner, 1960). The complex and the volcanic rocks both lack cleavage and the relationship of intrusion to folding and faulting is not well established. The age of the complex agrees with a K/Ar determination (392 m.y.) for the nearby Nicholas Denys granite (Tupper and Hart, 1961). Therefore the K/Ar age of the Nicholas Denys stock probably represents a primary age that has not been reset by a younger thermal event.

A sub-economic porphyry copper deposit occurs in volcanic and intrusive rocks southwest of the main plug of the Benjamin River Intrusive Complex (chapter 6). The late intrusive phase of the complex post-dates the hydrothermal activity that developed this deposit (chapter 2). Samples RDS-144 and RDS-234A are from the quartz monzonitic phase which is interpreted to predate the porphyry

Table 6. Analytical results of the whole-rock Rb/Sr isochron study of the Benjamin River Intrusive Complex.

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr (weight)	$^{87}\text{Rb}/^{86}\text{Sr}$ (atomic)	$^{87}\text{Sr}/^{86}\text{Sr}$ *
RDS-144	114	223	0.511	1.478	0.7129
RDS-216	81	78	1.038	3.023	0.7207
RDS-234A	126	210	0.600	1.734	0.7139
RDS-257	148	120	1.233	3.572	0.7236
RDS-263	133	183	0.727	2.105	0.7149

* normalized to a $^{86}\text{Sr}/^{88}\text{Sr}$ ratio of 0.1194.

Note: the mean square of the weighted deviates is 2.86.

: this isochron age and all of the rubidium-strontium whole-rock isochron ages on figure 14 are rounded to the nearest 5 m.y..

Figure 16. Whole-rock isochron plot.

copper mineralization while the other three samples are from quartz monzonite of the late intrusive phase. The good fit of the data points to the isochron shown in figure 16 indicates that the time interval between crystallization of the two phases can be accommodated within the limits set by the analytical uncertainty. Therefore each phase crystallized about 370 m.y.. The porphyry copper mineralization episode took place between the crystallization of these two phases. Therefore its age is about 370 m.y..

The initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7046 suggests that the rocks from the complex were derived from a source region with a low Rb/Sr ratio, perhaps the upper mantle (Fairbairn and others, 1974).

Rb/Sr isotopic data is now available for Ordovician, Devonian and Carboniferous granites from the northern Appalachians. Ordovician and Devonian granitic rocks commonly have initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between 0.701 and 0.711 (Fairbairn and Hurley, 1970). The Carboniferous (Hercynian) granitic rocks are distinctly different from the older granites. The Hercynian intrusions are alkaline to peralkaline "granites" that have initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the range 0.715 to 0.724 (Bell and Blenkinsop, 1977; Cormier and Stirling, 1977). These intrusions locally contain "porphyry deposits" of the granitoid elements (i.e. F, Bi, Sn, W, Mo, etc.), (Strong, 1978).

The age and initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of the Benjamin River Intrusive Complex are similar to those for other Devonian intrusions in the northern Appalachians. Therefore the complex and its associated porphyry copper deposit differ from the Hercynian granites and their associated deposits in both age and origin.

CHAPTER 5

Structural Geology

The two major periods of orogenic activity in northeastern New Brunswick are the Middle Ordovician Taconian Orogeny and the Devonian Acadian Orogeny. The region about the Benjamin River Intrusive Complex (figure 17) was only affected by the Acadian Orogeny (Alcock, 1935; Irrinki, 1976). This region is part of the Chaleur Bay synclinal belt (Poole, 1970) or tectonostratic zone 1c (Ruitenberg and others, 1977), (figure 4). Broad, open folds (Poole, 1970) were developed by décollement-style folding during the Acadian Orogeny (Stringer, 1975). The intensity of folding and cleavage development is in part a function of the competency of the various lithologies (Greiner and Potter, 1966). Another major function is the proximity of the strata to an agent of deformation (i.e.; faults, diapirs, batholiths, plugs).

The data for the regional structural interpretation was gleaned from the regional geology map (Irrinki, 1976). The structural interpretation of the thesis area is based on measurements by the author and by Soquem Ltée. geologists (Richard, 1970, 1972; Chev, 1971; Gagnon, 1971).

Regional Structural Geology

Deformation appears to increase to the southeast on the regional geology map (Irrinki, 1976). This region is divided into five structural subzones (figure 17) based on changes in the structural geology across faults, lithologic boundaries and an unconformity.

Figure 17. Structural subzones of northeastern New Brunswick. Boundaries of structural subzones are geological contacts and faults. These contacts and the structural data for each subzone are from the map by Irvin (1976).

Pi diagrams of bedding features (figure 18) and cleavage (figure 19) illustrate these changes.

Structural subzone 1 is underlain by Silurian and Devonian siltstone, mudstone, argillaceous limestone and minor volcanic rocks (Irrinki, 1976). Major folds have a wave length of about 5 km (Irrinki, 1976) and most of the strata are gently dipping (figure 18). The cleavage is subvertical to steeply dipping to the northwest (figure 19). The boundary between structural subzones 1 and 2 is a conformable contact between sedimentary and volcanic rocks (Irrinki, 1976).

Structural subzone 2 is underlain by Silurian and Devonian volcanic rocks and minor sedimentary rocks (Irrinki, 1976). Conglomerate, sandstone, siltstone and limestone are intercalated with the volcanic rocks and occur in two inliers near the coast (Irrinki, 1976). Most of the bedding plane measurements (figure 18) and all of the cleavage measurements (figure 19) are from the sedimentary rocks. Axial traces of folds are poorly defined (Irrinki, 1976) and there is a fairly random distribution of poles to bedding (figure 18). The cleavage is subvertical to steeply dipping to the southeast (figure 19). Subzone 2 is in fault contact with subzones 3 and 4 to the east (Irrinki, 1976).

Subzone 3 is underlain by Devonian volcanic rocks and siltstone (Irrinki, 1976). Units are flat-lying (figure 18; Clemmer, 1978) and lack cleavage. The boundary between subzones 3 and 4 is the Jacquet River. The Jacquet River valley may be fault-controlled (Greiner and Potter, 1966). The relatively undeformed nature of the strata in subzone 3 is distinctly different from the structural style in subzone 4.

Figure 18. Pi diagrams of poles to bedding from northeastern New Brunswick. Zones refer to areas shown in figure 17. Data from the map by Irrinki (1976).

Figure 19. Pi diagrams of poles to cleavage from north-eastern New Brunswick. Zones refer to areas shown in figure 17. Data from the map by Irrinki (1976).

Subzone 4 is underlain by Silurian and Devonian siltstone, mudstone and minor volcanic rocks (Irrinki, 1976). The wave length of folds is commonly about 0.5 km (Irrinki, 1976) and poles to bedding are uniformly distributed about a diffuse girdle (figure 18). Cleavage is subvertical to steeply dipping to the southeast (figure 19).

Subzone 5 is underlain by Carboniferous siltstone, sandstone and conglomerate (Irrinki, 1976). These beds are flat-lying (figure 18; Alcock, 1935) and post-date the Acadian cleavage development (Alcock, 1935). The subzone 5 boundary is an unconformity (Alcock, 1935).

Subzones 1 to 4 are also underlain by Devonian mafic and felsic intrusive rocks which occur as plugs, dikes and sills (Irrinki, 1976). Country rocks are tilted near some intrusive contacts (Mowat, 1954).

Many of the river and stream valleys in the region follow faults (Greiner and Potter, 1966). These valleys appear as strong lineaments on satellite photos. A circular pattern of lineaments 19 km in diameter dominates the southwestern quarter of the region (figure 20). The drainage pattern indicates that the structure is a topographical dome. Geological contacts and bedding indicate that the structure is not a geological dome. Bedding "within the dome" is relatively flat-lying (figure 18).

Minor deflections of isomagnetic contours occur at the edge of the structure (Geological Survey of Canada, 1954). These deflections favour slightly lower gamma values "within the dome". There is also a major gravity low (Energy, Mines and Resources, 1977) coincident with the circular structure (figure 21). This

Figure 20. Satellite photograph of northeastern New Brunswick. The Chaleur Bay coastline has been sketched in. Note the circular structure that dominates the southwestern half of the photo. Photo by National Aeronautic and Space Administration (1973).

Figure 21. Gravity map of northeastern New Brunswick.

suggests that the circular structure is underlain by a material with a slightly lower density and magnetic attraction than the material that occurs outside the structure. A felsic batholith mantled by volcanic rocks is interpreted to account for these negative geophysical anomalies. Cauldron subsidence may have occurred along faults that presently outline the circular structure. The volcanic rocks within the structure may have been block faulted (Toong, 1963) in response to this subsidence. Emplacement of the complex along faults at the northeastern margin of the structure may also have been related to the subsidence and the complex itself may represent the only major surface exposure of this batholith. The abundance of dikes (Stewart, 1975) along the southwestern margin of the structure could similarly be related to the cauldron subsidence and a buried batholith.

Structural Geology Within the Thesis Area

A detailed structural interpretation of the Silurian volcanic rocks is difficult to establish because of four complicating factors: (i) an irregular distribution of units that was a function of the Silurian volcanic topography; (ii) broad, open folding in the region (Alcock, 1935); (iii) local tilting of strata near intrusive contacts (Mowat, 1954) and (iv) unknown displacement along faults.

The drill hole sections that illustrate the geology have interpretative horizontal volcanic contacts and vertical intrusive contacts. Horizontal bedding planes are suggested from the regional dips within the "dome" (figure 18). Locally it is more difficult to directly measure bedding planes. Laminated sedimentary rocks or contacts between volcanic units were not observed in outcrop.

Columnar jointing in a basaltic unit (location 50A) and the plane of flattening of flammé in an ash flow tuff (location 220B) are the only structural measurements from surface. In both cases these outcrops are near an intrusive contact. The units strike parallel to the contact and dip away from it.

Laminations in tuff and/or sedimentary rock range from 35° to 60° to the core axis in drill holes (Richard, 1970; Chev, 1971; Gagnon, 1971). The most common attitudes are between 40° and 50° to the core axis (appendix VII). All of the drill holes are inclined at 45° therefore laminations at 45° to the core axis could have any strike or dip. Horizontal or subhorizontal laminations would, however, always fall in the range of 35° to 55° .

Intrusive contacts range from 20° to 90° to the core axis (Richard, 1970, 1972; Chev, 1971; Gagnon, 1971), (appendix VII). This indicates that not all of the contacts are vertical. Where data is available, intrusive contacts are not vertical (sections 7008-7022, 7013-7019, in data file). Therefore the interpretation that the intrusive contacts are subvertical must be regarded as an oversimplification imposed by limited data.

Veins and fractures range from 0° to 90° to the core axis (Richard, 1970, 1972; Chev, 1971; Gagnon, 1971). They are commonly 20° and 45° to the core axis in drill holes inclined to an azimuth of 156° (Richard, 1970; Chev, 1971). Veins and fractures are commonly 40° to 60° to the core axis in drill holes inclined to 336° (Richard, 1970, 1972; Gagnon, 1971).

• The strike of veins, veinlets and fractures is also variable as is commonly indicated by cross-cutting relationships (i.e. drill hole 7005). There is no apparent structural control for the orientation of veins.

Discussion

The strata in structural subzones 3 and 5 and "within the dome" are flat-lying to gently dipping and are lacking a cleavage. The strata in structural subzones 1, 2 and 4 are flat-lying to steeply dipping and have a northeasterly trending cleavage. Maximum dips of fold limbs increase to the southeast. Pi diagrams of bedding plane measurements suggest that fold axes are more parallel in subzone 4 than in subzones 1 and 2. Axial traces of folds are much closer together in subzone 4 (Irrinki, 1976). Pi diagrams (figure 19) of cleavage for subzones 1, 2 and 4 suggest a "fanning" of the cleavage from very steeply northwesterly dipping in the northwest to very steeply southeasterly dipping in the southeast. These changes in fold style throughout the region indicate increasing deformation towards the southeast. The underlying cause of this increasing deformation is not readily apparent from the regional geology map (Irrinki, 1976).

Indirect evidence supports a geological origin for the circular structure that is observed on satellite photos (figure 20). The margin of the structure follows valleys which suggests that the structure may be fault-bounded. Bedding planes "within the dome" have gentler dips than those outside the structure. Geophysical surveys indicate that the area "within the dome" is underlain by a less magnetic, lower density material than the rocks at surface and outside the structure.

The Benjamin River Intrusive Complex is on the northeastern margin of the circular structure. It may represent the exposed portion of a felsic batholith that underlies the structure.

CHAPTER 6

Alteration and Economic Geology

The Benjamin River deposit is a low grade porphyry copper deposit that occurs in the southwestern part of the thesis area (figure 22). The property containing the deposit was initially obtained in 1954 by Stratmat Ltd. during a staking rush for massive sulphide deposits (Mowat, 1954). In 1968, Soquem and Umex staked the property as a follow-up to reconnaissance stream sediment surveys (Tauchid, 1970). Geological mapping and geochemical and magnetic surveys were undertaken in 1969 and 1970 (Tauchid, 1970). Coincident geochemical and geophysical anomalies were then used as targets for exploration drilling between 1970 and 1973 (Tauchid, 1973). Several cupriferous zones and related hydrothermal alteration were intersected by the drilling. The largest of these is illustrated in figure 22. There are numerous other occurrences of trace amounts of chalcopyrite in the area (Richard, 1970, 1972; Chevé, 1971; Gagnon, 1971) but these were mostly developed by contact metasomatism.

Volcanic and intrusive rocks are weakly altered throughout the area. Strong alteration occurs only locally about veinlets and fractures. Quartz veins with alteration envelopes are most common within the main cupriferous zone.

Drill hole sections illustrating the geology, altered intersections and estimated sulphide contents are given in the data file.

Figure 22. The Benjamin River deposit. Area shown on the location map is the southwestern part of the thesis area. Solid bars on the drill holes indicate cupriferous intersections. Other minor cupriferous zones in drill holes 7017 and 7023 are also illustrated.

Alteration

Alteration has been studied mineralogically but not chemically. Development of secondary minerals in the thesis area has been by hydrothermal alteration, contact and/or regional metamorphism and weathering. Secondary minerals in weathered rocks were not studied. In some cases, the process or processes that led to the development of secondary minerals in unweathered rocks could not be determined. Therefore "alteration" for the purposes of this study will be defined as changes to the primary mineral assemblages of rocks within the thesis area. The two main processes involved in these changes are hydrothermal alteration and metamorphism. The effects of each of these processes are discussed in the following paragraphs. The terms potassic, phyllic, argillic and propylitic used in discussing hydrothermal alteration have been adapted from Lowell and Guilbert (1970). The alteration discussion is summarized in table 7.

Very weak but pervasive propylitic alteration occurs in all rock types in the area (table 7). Plagioclase is partly altered to sericite, epidote, clay minerals and zeolites. Biotite, amphibole and pyroxene are partly altered to chlorite. Original textures are preserved in weakly altered rocks but they are obscured in more highly altered rocks. Weak to very strong alteration commonly occurs within narrow envelopes about veins and fractures. Some envelopes are zoned but zonation of alteration on a larger scale has not been observed. Veins and fractures with alteration envelopes are commonly cross-cutting but the preferred orientations of the veins and fractures could not be determined.

Sericite is by far the most common alteration product in the felsic intrusive rocks. Sericitization ranges from very weak to

Table 7: Variation in secondary mineral assemblages between different rock types and styles of alteration

Abbreviations used in table

ab	albite	K-spar	potassium feldspar
bio	biotite	mag	magnetite
c.m.	clay minerals	mo	molybdenite
cc	calcite	N.O.	not observed
chl	chlorite	opq	opaque minerals
cp	chalcopyrite	P	pervasive
epi	epidote	py	pyrite
f	fracture and/or vein-controlled	qtz	quartz
gt	garnet	ser	sericite
hm	hematite	zeo	zeolite

Table 7: Variation in secondary mineral assemblages between different rock types and styles of alteration

	*Propylitic Alteration	Argillic Alteration	Phyllic Alteration	Potassic Alteration	*Contact +/- Regional Metamorphism
Late Intrusive Phase	ser, cc, chl, P	N.O.	N.O.	N.O.	N.O.
Quartz Monzonitic Phase	ser, cc, chl, P, f epi	N.O.	ser, qtz, epi, cc, mag, py, chl	N.O.	N.O.
Granodioritic Phase	ser, cc, chl, P, f epi, zoo, py, qtz, cp, mo	c.m., chl	ser, qtz; cc, py, cp, mo	f K-spar, ser, bio, qtz, py, cp	N.O.
Gabbroic Phase	chl, ser, cc, P, f ilm, qtz, opa, bio, epi	N.O.	N.O.	f chl, ser, K-spar	N.O.
Felsic Volcanic Rocks	ser, epi, st, P, f zo, cc, py	N.O.	N.O.	N.O.	gt, ab, ppg, qtz
Mafic Volcanic Rocks	ser, cc, chl, P, f epi, qtz, py, cp	N.O.	N.O.	N.O.	ser, epi, chl, qtz, cc, py, cp
Tuff or Siltstone	chl, epi, py, P, f zo, cp, K-spar	N.O.	N.O.	N.O.	chl, epi, qtz, py, cp, K-spar

*Secondary minerals in these groups may have been developed by either process

very strong. It occurs within alteration envelopes and in continuous intersections several feet in length. Cores of plagioclase phenocrysts are commonly more altered than the margins. Weakly sericitized (propylitized) intrusions are cut by quartz-pyrite and/or calcite-chlorite-pyrite veins. Chalcopyrite and molybdenite are not common in these veins.

Strong sericitization is referred to as phyllic alteration (table 7). In these altered zones plagioclase and biotite are completely altered to sericite. Veins are composed of quartz, epidote, pyrite, chalcopyrite and traces of molybdenite.

Minor potassic alteration is present only locally (table 7). Secondary biotite is common and plagioclase is partly to completely altered to potassium feldspar. Pyrite and chalcopyrite occur in quartz veins and veinlets and as disseminated euhedral grains adjacent to secondary biotite. In some cases the zoning in vein alteration envelopes is from an inner core of potassic alteration to phyllic then propylitic assemblages outward.

Argillic alteration is the least common alteration type (table 7). Individual feldspar phenocrysts within a phyllic alteration zone are commonly altered to a white, clay-like mineral. The species of clay mineral was not determined. Intersections (less than 1 m in length) of complete argillic alteration contain chloritized biotite but lack sulphides. Development of these continuous clay mineral-rich intersections may be unrelated to the hydrothermal activity that developed the propylitic, phyllic and potassic alteration.

In addition to hydrothermal alteration about veins and fractures, the volcanic and sedimentary rocks in the area have secondary minerals that were developed by contact and/or regional metamorphism.

Basaltic volcanic rocks commonly have a "felty-texture" of randomly oriented plagioclase microlites and intercrystalline chloritized pyroxene. This primary ophitic texture is gradational to equigranular hornfels that occurs near intrusive contacts and in mafic xenoliths. Mafic hornfels contain chlorite and biotite which have probably replaced amphibole. Calcite-chlorite-epidote veins with and without very narrow sericitic alteration envelopes are the only common veins in basaltic volcanic rocks and the gabbroic phase.

Andesitic and felsic volcanic rocks are very fine-grained and their secondary minerals were not determined. Narrow alteration envelopes are common about fractures and quartz veins. Garnet porphyroblasts occur locally in felsic volcanic rocks adjacent to the main quartz monzonitic plugs.

The most strongly altered units within the Chaleur Group in the thesis area are fine-grained tuff or siltstone. Laminations commonly alternate from dark green and chloritic to pale green and epidote-rich. Quartz and chloritic veinlets cut the tuff and siltstone. It is not known whether this secondary mineral assemblage was developed by hydrothermal alteration or by metamorphism.

Fault zones and volcanic breccias are commonly carbonatized. The development of calcite along these planes may be unrelated to the hydrothermal activity that is associated with the sulphides. A brecciated zone intersected in drill hole 7009 (420' to 454') is composed of mafic and felsic volcanic rock and quartz diorite porphyry fragments. The matrix is very fine-grained, carbonated and cut by calcite and quartz veins. Pyrite and chalcopyrite occur

only in quartz vein fragments. Visible molybdenite was not noted in drill core examined but molybdenum assays (180 to 510 ppm) (Richard, 1970) from the brecciated zone are among the highest found on the property (appendix VII). This is the only major occurrence of a breccia that was encountered in the diamond drilling program. The poly lithologic character of the fragments and the comminuted ground-mass are features common to breccia pipes (Bryner, 1961). However, the geometry of the zone is not known. It may be tabular or prismatic. The origin of the brecciation was probably related to faulting (Mitcham, 1964).

Rock types of the late intrusive phase lack sulphides (Soquem drill logs) and they are not cut by fractures and veins that have alteration envelopes. These late felsic intrusions have a pervasive, very fine-grained propylitic alteration and are intrusive to felsic intrusions that have alteration envelopes about sulphide-bearing veins and fractures. The intrusive relationship, different style of alteration and lack of sulphides suggest that rock types of the late intrusive phase are younger than the hydrothermal activity that led to the development of the sulphide minerals and the alteration envelopes about veins and fractures.

Nature and Distribution of the Opaque Minerals

Opaque minerals are a common accessory component of all the rock types in the thesis area with the notable exception of the late intrusive phase. They may be primary, fracture-controlled or disseminated. In some cases they are spatially related to zones of hydrothermal alteration.

Pyrite, chalcopyrite and molybdenite are the most common sulphides. They mainly occur in quartz veins and along fractures.

Fine-grained, "disseminated" pyrite and chalcopyrite actually follow hairline fractures. Therefore on a gross scale sulphides appear disseminated but on a small scale they are fracture-controlled.

Pyrite content ranges from trace to 2% in felsic rocks and from 2 to 5% in mafic rocks in the southwestern portion of the thesis area. Pyrite makes up less than 1% of the rocks from the northeastern portion of the thesis area. Local concentrations of greater than 5% pyrite are uncommon. These relatively pyrite-rich zones are composed of quartz-pyrite-chalcopyrite veins in gabbro and in very strongly epidotized or hornfelsic mafic volcanic rocks. In rocks with less than 5% pyrite, anhedral to euhedral pyrite occurs along fractures and in quartz, chlorite and calcite veins with narrow alteration envelopes. Quartz, magnetite and chalcopyrite inclusions in pyrite are common.

Chalcopyrite occurs in trace amounts (less than 0.1%) throughout most rocks of the area. Greater than trace amounts of chalcopyrite are found in two types of occurrences. The most common are narrow zones (less than 3 m) of quartz-pyrite-chalcopyrite veins in hornfelsic volcanic rocks. The other mode of occurrence is restricted to specific zones. Within these zones chalcopyrite mineralization is fairly continuous and similar to porphyry copper deposits in nature. Chalcopyrite occurs in fractures and quartz-pyrite veins with alteration envelopes in volcanic and intrusive rocks. There are three major zones with these characteristics; the Benjamin River deposit (figure 22; intersected by drill holes 7008, 7020, 7021 and 7022) and two other smaller occurrences (drill hole

7017, about 170' to 265'; drill hole 7023, about 530' to 680').

In each occurrence the mineralization has a close spatial relationship to rock types of the granodioritic phase. Cupriferous veins and fractures with alteration envelopes are more closely-spaced in these occurrences than in the areas outside these zones. Chalcopyrite is fine-grained and anhedral and commonly contains pyrite and silicate inclusions. Bornite, covellite and malachite are rare secondary copper-bearing minerals (Nutter, 1971).

Visible molybdenite occurs only in trace amounts over short drill intersections. It is commonly within and immediately adjacent to large, milky quartz veins or along hairline fractures. Quartz-molybdenite veins occur within granodioritic rock types in the main cupriferous zone and within volcanic rocks and porphyritic felsite outside the cupriferous zone.

Primary, anhedral magnetite-ilmenite intergrowths are common in mafic volcanic rocks and gabbro. Magnetite also occurs with chlorite after mafic minerals and in quartz veins throughout the area. Magnetite is locally oxidized to hematite. Hematitic staining is a common feature in the felsic volcanic rocks.

Discussion and Summary

The cupriferous zone (figure 22) that occurs southwest of the main plug of the Benjamin River Intrusive Complex has features common to porphyry copper deposits (Kirkham and Soregaroli, 1975). It is a large tonnage, low grade deposit spatially and possibly genetically related to felsic intrusions. An estimate of the tonnage and grade as 20 million tons of 0.18% Cu and 0.01% Mo (appendix VII). A detailed summary of assays (appendix VIII) illustrates that drill

holes intersecting the cupriferous zones contain the greatest proportion of anomalous copper and molybdenum assays. This is an obvious correlation but it substantiates the definition of the cupriferous zones on the basis of chalcopyrite content. It is noteworthy that the number of anomalous molybdenum assays are greatest within the cupriferous zones.

Fine-grained chalcopyrite occurs in quartz veins and along fractures. Observations of trace amounts of molybdenite are not common. Propylitic alteration is pervasive but phyllic and potassic alteration are generally restricted to alteration envelopes.

Alteration about veins occurs throughout the thesis area but is most concentrated within the cupriferous zone. A preferred orientation of veins and fractures could not be established. They are locally cross-cutting and have overlapping alteration envelopes.

The Benjamin River deposit is spatially related to the granodioritic phase of the complex. Rock types within the deposit are not porphyritic although porphyritic rocks compose about 30% of the intrusions near the deposit. Large scale zoning of sulphide minerals and alteration assemblages has not been recognized within the Benjamin River deposit. Development of the alteration assemblages and the deposition of sulphide minerals appear to be related to veins and fractures. The factors that controlled the localization of the deposit itself have not been established. One factor may be the emplacement and cooling of granodioritic intrusions. Well-developed alteration and copper mineralization are not associated with the gabbroic, quartz monzonitic or late intrusive phases of the complex.

Radiometric dating of the quartz monzonitic and late intrusive phases of the main plug of the complex indicates a Devonian age for

the complex (chapter 4). The good fit of the points from these two phases to the isochron suggests that they both crystallized about 370 m.y.. The quartz monzonitic phase predates hydrothermal alteration and sparse sulphide mineralization about veins and fractures. The late intrusive phase post-dates this episode. Therefore the age of sulphide mineralization is about 370 m.y.. Some other porphyry copper deposits associated with Devonian felsic intrusions occur near Woodstock, New Brunswick and Murdochville, Quebec (Kirkham and Soregaroli, 1975).

The gross characteristics of the Benjamin River deposit are broadly comparable to other porphyry deposits in the Appalachians and the southwestern United States (table 8). The common features of these deposits are: (i) a large tonnage of low to medium grade copper, (ii) a proximity to intermediate or felsic porphyritic intrusions, (iii) pyrite, chalcopyrite and molybdenite in veins, veinlets and fractures and (iv) veins and fractures have alteration envelopes.

Most careful observations are required in order to determine the detailed history of a porphyry copper deposit (Gustafson, 1978). Unfortunately limited data access and the scope of this thesis did not permit studies that could have provided a more detailed history of the development of the deposit. It was observed that veins of different composition and with different associated alteration are cross-cutting. Some aspects that would be desirable to establish are: (i) the number of sets of barren and sulphide-bearing veins and fractures, (ii) the alteration type associated with each vein set, (iii) the orientation of each set of veins and fractures, and (iv) the zonation of types of veins, veinlets, fractures and

Table 8. Comparison of the characteristics of the Benjamin River porphyry copper deposit with other porphyry copper deposits from the Appalachians and the Southwestern United States.

Key to Abbreviations

"Ore Minerals"

py	pyrite
cp	chalcopyrite
mo	molybdenite
bn	bornite
tet	tetrahedrite
sp	sphalerite
po	pyrrhotite

Mode of Occurrence of Ore

dissem.	disseminations
bx pipes	breccia pipes

Alteration Types

K	potassic
phy	phyllic
arg	argillic
prop	propylitic

Canadian
Appalachians
Occurrences -
Summary

Southeastern
United States
Summary

Caspé Copper
Québec

Woodstock
New Brunswick

Cathcart Moun-
tain, Maine

Benjamin River
New Brunswick

Typical Composition of Pluton nearest 'Ore'	Granodiorite	Quartz monzon- ite	Granodiorite or quartz diorite	Quartz-feldspar porphyry	Granodiorite, quartz diorite	Quartz diorite to quartz monzonite
Host to 'Ore'	granodiorite, volcanic rocks	quartz monzon- ite, feldspar- quartz porphyry	metasediments, granodiorite quartz diorite	sediments, skarn	quartz diorite to quartz monzonite, hornfels	quartz monzonite metasediments
Major 'Ore' Minerals	Cu	Cu-Mo	Cu	Cu	Cu	Cu
Minor 'Ore' Minerals	Mo		Mo	Mo	Mo	Mo
'Ore' Minerals	py, cp, mo	py, cp, mo	po, py, cp, mo	py, po, cp, bn, tet, mo	py, po, cp, mo, bn	py, cp, mo
Site of Occurrence	veins fractures in hornfels	disseminations veinlets	fractures disseminations	skarn fractures	veins fractures disseminations	disseminations fractures stockwork bx pipes
Alteration Types	K, phy, (arg), prop	K, phy, arg, prop	propylitic	skarn, K	K, phy, prop	K, phy, arg, prop
Alteration Type	propylitic (phy)	K(phy)	propylitic	skarn	variable	variable
Notes of Occurrence	envelopes about veins and frac- tures, narrow zones, narrow zones	envelopes about veins, major continuous zones	propylitic pervasive	adjacent por- phyry	continuous zones, envelopes about fractures	continuous zones envelopes about fractures
Interval of Time	Massive Devonian 0.7620	Late Ordovician	Devonian	Late Devonian	Paleozoic	Tertiary
						0.706 - 0.710
		Schmidt (1974)	Anderson (1963) Lalonde & Ser- egayrol (1975)	MacIsaac (1963) Allcock (1974)	Kirkham & Ser- egayrol (1975)	Lowell & Guilbert (1970)

alteration in the deposit. Pursuit of these topics could possibly lead to a better understanding of the nature of hydrothermal fluids, the regional and local stresses at the time of sulphide mineralization, the erosional level of the deposit and the relationship of the deposit to nearby Devonian stratiform base metal occurrences in volcanic rocks (Clemmer, 1978).

CHAPTER 7

Geologic History

The geologic history of the region represents the growth of a volcanic chain upon shallow marine siltstones and limestones. High level mafic and felsic intrusions such as the Benjamin River Intrusive Complex intruded the sedimentary volcanic sequence late in its development.

The Chaleur Bay region was part of the Gaspé Trough from the late Ordovician to the Middle Devonian (Poole, 1970). Sedimentation was initially (Late Ordovician) flyshoid throughout the trough then in the Silurian deep water (distal) sedimentation became restricted to the core of the trough while shallow water (proximal) sediments onlapped the landmasses to the northwest and southeast (Poole, 1976; Ruitenberg and others, 1977).

The Chaleur Bay region is underlain by shallow water siltstone and limestone that were deposited along the southeastern margin of the Silurian sea (Ruitenberg and others, 1977). A narrow belt of volcanoes developed in the Upper Silurian parallel to the southwestern margin of the trough (Poole, 1970). The volcanic pile is mainly composed of a basaltic and andesitic base overlain by rhyolitic flows and ignimbrites (Greiner, 1965; Stewart, 1975; Irrinki, 1976). The mafic volcanic rocks are locally pillowed and intercalated with fossiliferous siltstone (Irrinki, 1976). However, massive mafic flows, red siltstones and conglomerates and welded felsic tuffs indicate a subaerial environment for most of the Silurian volcanism (Stewart, 1975; Ruitenberg and others, 1977).

This suggests that volcanism may have begun as volcanic islands in a shallow sea, with the environment changing to one of terrestrial volcanism as the mafic platform built up above sea level.

Regional subsidence during the Lower Devonian is suggested by intercalation of shallow marine and terrestrial sedimentary rocks and mafic and felsic volcanic rocks (Irrinki, 1976). Minor stratiform base metal occurrences are associated with some of the Devonian mafic tuffs (Clemmer, 1978).

Folding, cleavage development, very low grade regional metamorphism and emplacement of high level mafic and felsic intrusions occurred during the Lower-Middle Devonian Acadian Orogeny (Ruitenberg and others, 1977). Locally folds predate the cleavage (Stringer, 1975). Contact metamorphism about Devonian intrusions was syn- to post-cleavage development (Ruitenberg and others, 1977).

The Benjamin River Intrusive Complex is an example of a high level Devonian intrusion. The oldest phase of the complex is gabbroic. It mainly occurs as peripheral intrusions to a younger stock of quartz monzonitic composition. Granodioritic intrusions of similar age to the gabbroic and quartz monzonitic phases occur locally. The granodioritic phase is spatially and possibly genetically related to the sparse Benjamin River porphyry copper deposit. Late barren felsic intrusions that post-date the development of the porphyry copper deposit are the youngest rock types of the intrusive complex. Stopped xenoliths of Silurian volcanic rocks are common in the complex which suggests a passive mode of emplacement. A common genetic relationship between Devonian intrusions and Silurian and Devonian volcanic rocks has not been established. Similarly the relationship of Devonian porphyry

copper mineralization and the base metal occurrences in Devonian mafic tuffs is not known.

Following the Acadian Orogeny the region was subjected to intense weathering during the Upper Devonian and Mississippian (Greiner and Potter, 1965). The youngest consolidated deposits in the region are Pennsylvanian fluvial sandstones that rim Chaleur Bay (Alcock, 1935; Gussow, 1953).

Pleistocene glaciation in the region did not radically change the topography (King, 1972). A thin layer of unconsolidated overburden blankets the region but sand and gravel deposits in kames and eskers are restricted to near Chaleur Bay (Greiner, 1965).

CHAPTER 8

Summary of Conclusions

The Benjamin River Intrusive Complex is composed of four distinct phases. The oldest is a gabbroic phase, and the youngest is a late felsic phase that probably post-dates development of the Benjamin River porphyry copper deposit. Two other phases, intermediate in age, have granodioritic and quartz monzonitic compositions. The intrusive complex was emplaced at a high crustal level by stoping of Silurian subaerial volcanic rocks. The complex is composed of a composite main plug flanked to the southwest by smaller simple and composite intrusions. The main plug is composed of two generations of quartz monzonite discontinuously surrounded by the gabbroic phase. The granodioritic phase only occurs in the smaller intrusions about 2 km southwest of the main plug.

The gabbroic, granodioritic and quartz monzonitic phases of the complex are chemically distinct. Porphyritic rock types of each phase contain similar, strongly zoned plagioclase phenocrysts which suggests a common genetic relationship. Differentiation followed a calc-alkaline trend that probably progressed from gabbroic to granodioritic to quartz monzonitic compositions. The chemistry of the late intrusive phase is similar to that for the granodioritic and quartz monzonitic phases. The complex is depleted in SiO_2 and K_2O relative to Na_2O in comparison to Devonian calc-alkaline granitic rocks 100 km to the south. The reason for this difference is not known.

A whole-rock Rb/Sr isochron determination shows that the complex and the Benjamin River porphyry copper deposit are Devonian in age

(370 ± 30 m.y.). This is comparable to a K/Ar determination of 392 m.y. from the Nicholas Denys stock therefore K/Ar ages have probably not been updated in this region. The Devonian age is in agreement with local stratigraphic relationships. The complex is intrusive to relatively undeformed Silurian volcanic rocks. Temporal relationships of the intrusive age of the complex to subgreenschist regional metamorphism and regional folding are not known. The initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (0.7046) suggests that the complex was derived from a source region with a low Rb/Sr ratio, perhaps the upper mantle.

Intensity of deformation increases towards the southeast in the region. The volcanic rocks near the complex are flat-lying to gently dipping and are lacking cleavage. The complex occurs on the northeastern margin of a circular structure about 19 km in diameter, that is visible on satellite photographs. Geophysical surveys indicate that the material within the circular structure is slightly less magnetic and less dense than the material that occurs outside the structure. The circular structure is possibly related to a buried Devonian felsic batholith mantled by Silurian and Devonian sedimentary and volcanic rocks. The complex may represent an exposed portion of this batholith. The sedimentary and volcanic rocks are more gently dipping within the circular structure than outside it.

Characteristics of the Benjamin River porphyry copper deposit are broadly comparable to characteristics of porphyry copper deposits found elsewhere in the northern Appalachians and the southwestern United States. The deposit is spatially and possibly genetically related to the granodioritic phase of the intrusive

complex. Pyrite and chalcopyrite occur in quartz veins, veinlets and along fractures in biotite granodiorite and Silurian volcanic rocks. Visible molybdenite is generally restricted to milky quartz veins. Weak propylitic alteration is pervasive whereas phyllic and minor potassic alteration occur in narrow alteration envelopes about veins and fractures in the volcanic and intrusive rocks. Intense phyllic alteration also occurs in granodiorite as continuous sections several metres in length.

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APPENDIX I

Methods

APPENDIX I

Methods

Sample Collection

Representative samples from Soquem drill holes were collected and labelled using Liquid Paper and india ink. The sample number refers to the drill hole number and the footage; i.e. 20-248 is from the 248' footage of drill hole 7020.

Surface samples were collected from outcrop and boulder fields and were initially numbered using a felt-tipped marking pen. Permanent labelling was with Liquid Paper and india ink. The sample number is made up of the author's initials and the station location number; i.e. RDS-216 refers to surface location 216 that may be located on figure 2.

Selection and Preparation of Samples for Chemical Analysis

Six samples of drill core and ten hand specimens from outcrop were selected for chemical analysis by the author. These samples were large and free of veinlets. The six drill core samples were commercially prepared for analysis. The ten hand specimens were prepared for analysis by the author using the following method:

- (i) samples were reduced in size using a Hein-Werner core splitter,
- (ii) about 75 cm³ from the core of the sample were reduced to less than 1 cm³ in size using the core splitter, a geology pick and a steel plate,
- (iii) these sample chips were pulverized in a Willy Bleuler tungsten carbide mill and then stored in numbered plastic vials. All the equipment was cleaned between samples using compressed air, distilled water and acetone.

Five other samples from the thesis area were chosen for analysis by other geologists. Four samples were selected and prepared by R. Irrinki of the New Brunswick Department of Natural Resources. These analyses are numbered IR-73-243A, IR-73-695A, IR-73-701A and IR-73-1318. These samples correspond to the outcrop locations RDS-76, RDS-106A, RDS-113 and RDS-80 of this study. Dr. R.V. Kirkham of the Geological Survey of Canada selected a sample for analysis from 576' of drill hole 7021. This sample was prepared by the staff of the Geological Survey of Canada.

Analytical Methods

Whole-Rock Analysis

Major element whole-rock analysis by X-ray fluorescence was carried out at three separate laboratories. The six drill hole samples selected by the author were analysed by the staff of Bondar-Clegg and Company Limited. The ten surface samples selected by the author and the drill core sample selected by Dr. R.V. Kirkham were analysed by the staff of the Geological Survey of Canada supervised by J. Lachance. The four samples selected by R.R. Irrinki were analysed by G.P. Venkateswaren of the New Brunswick Department of Natural Resources.

Rubidium and Strontium Analysis

The sixteen samples selected by the author were analysed by the author using the Siemens X-ray fluorescence unit at the Carleton University Geology Department. The U.S. Geological Survey standard G-2 was used and the Rb/Sr ratios and the mass absorption co-efficients of unknowns were measured directly. Concentrations of Rb and Sr were calculated by computer using the Rb/Sr ratio and the mass absorption

co-efficient (Norrish and Chappell, 1967). Detailed descriptions of the analytical procedures are given in the data file.

Strontium Isotopic Analysis

Five of the surface samples selected by the author for chemical analysis were used to determine a Rb/Sr isochron. These samples were prepared by the author for isotopic analysis by means of a hydrofluoric-perchloric acid dissolution, followed by separation of Rb and Sr using ion-exchange columns. A description of this preparation is given in the data file.

Bell and others (1977) have summarized the isotopic analytical technique used for this study as follows: "The Sr isotopic analyses were carried out on a 15 cm, 90° mass spectrometer, with the Sr loaded as the nitrate on a single rhenium filament. Operation of the mass spectrometer, including data reduction, was controlled by a PDP-11 computer. The ion beam was measured by an electron multiplier in conjunction with a Cary Model 31 vibrating-reed electrometer." The decay constant of $1.42 \times 10^{-11} \text{ yr}^{-1}$ (Neumann and Huster, 1976; Davis and others, 1977) was used for this study.

Staining for K-feldspar in Rocks and Thin Sections

A modified technique to that described by Chayes (1952) was used in this study. Rocks were immersed in an HF (50%) bath for about 30 seconds then removed and immersed in a sodium cobaltinitrite solution for about one minute. The sample was then placed in a water bath to remove excess HF and sodium cobaltinitrite. The staining solution is comprised of 50 gm sodium cobaltinitrite in 100 ml distilled water.

Thin sections were covered front and back with celluloid tape except for the area to be stained. The thin sections were immersed in HF for about 12 seconds then in the staining solution for about 30 seconds. Excess acid and stain were then rinsed off in the water bath.

Slightly longer etching and staining periods are required for fine-grained rocks and/or cold and/or weak solutions. The stain is easily abraded and may be preserved for longer periods by sealing the rock with polyurethane spray.

APPENDIX II

Thin Section Descriptions

APPENDIX II

Abbreviations used in thin section descriptions

ab	albite	hm	hematite
amph	amphibole	K-spar	potassium feldspar
ap	apatite	mag	magnetite
bio	biotite	mg	medium grained
cc	calcite	opq	opaque mineral(s)
cg	coarse-grained	plag	plagioclase
chl	chlorite	px	pyroxene
epi	epidote	py	pyrite
feld	feldspar	qtz	quartz
fg	fine-grained	ser	sericite
gt	garnet	vfg	very fine-grained
hb	hornblende	zeo	zeolite

Polished thin sections are denoted with (P) following the thin section number.

Major (> 10%) minerals are listed before the oblique; minor and accessory minerals are listed after the oblique.

(Continued)

Thin Section	Rock Type	Primary Minerals	Secondary Minerals	Textures
7001-250A	gabbro	plag, amphib/ opq, qtz	chl/ser, bio	mg: inequigranular; strongly zoned plag cores altered to ser; An ₅₀ veg; pegmatitic; euhedral apatite
7001-337	gabbroic pegmatite	plag, px/ap	chl, ser, epi/ cc, qtz	fg: inequigranular; chl veins, An ₅₄ , plag weakly zoned
7001-363	gabbro	plag, px, ol	chl, cc/opq, bio	gabbro-cz, ophitic, strongly altered; felsitic-aph, flow laminated, altered contains a gabbroic inclusion
7001-434	gabbro-porphyrific plagioclase felsite	plag, px-feld, qtz	chl, cc, ser-ser, opq	mg: ophitic; weakly altered, An ₅₈
7002-222	gabbro	plag, py/opq	chl, bio/ser	
Granodioritic				
7002-257	quartz diorite	plag, qtz/ bio	/opq, bio	fg: equigranular, strongly zoned plag, biotite recrystallized
7022-359	quartz diorite	plag, qtz, K-spar/bio	ser/bio	mg: inequigranular, euhedral, zoned plag
7023-132	quartz diorite	plag, qtz/ bio	ser/cc, bio	fg: inequigranular, zoned plag, some biotite recrystallized, cc veins
7023-124	biotite granodiorite	plag, K-spar, qtz/bio	chl, ser, cc/ K-spar, qtz	mg: equigranular, strongly altered, euhedral feldspars
7023-179	biotite granodiorite	plag, K-spar, qtz/bio	chl/ser, cc, epi, bio, opq	mg: equigranular, weakly altered, euhedral feldspars, cc-ser veinlet
7015-52	biotite granodiorite	plag, qtz, K-spar/bio	chl, ser/	mg: plag in vfg groundmass; strongly altered
7020-224	biotite granodiorite	plag, qtz, K-spar/bio	chl, cc/py	mg: inequigranular, zoned plag, strongly altered, An ₅₅
7020-230 (P)	biotite granodiorite	plag, qtz, K-spar/bio	cc, ser, py/ sp, cp	mg: very strongly altered, cc veinlets common
7021-253 (P)	biotite granodiorite	plag, qtz, K-spar/bio	chl/bio, ser, py, cp, mag	mg: py-bio-cp in fracture; cp disseminated, in py and in fractures

(Continued)

Thin Section	Rock Type	Primary Minerals	Secondary Minerals	Textures
7021-40c (P)	biotite grano-diorite	plag, qtz, K-spar/bio	ser/chl, cp, py, mag	mg; bio and opq in fractures and disseminated; chl-cp-py veinlet, zoned; plag
7021-463	biotite grano-diorite	plag, qtz, K-spar/bio	ser, cc/zeo, py	mg; fractured, deformed biotite; strained qtz
7021-563	biotite grano-diorite	plag, qtz, K-spar/bio	/ser, chl	mg; cores of zoned plag sericitized, intergranular K-spar, strained qtz
7022-45b	biotite grano-diorite	plag, qtz, K-spar/bio	ser, chl/qtz, zeo	mg; inequigranular, strongly altered, strained qtz
7022-597	biotite grano-diorite	plag, qtz, K-spar/bio	ser, cc/opq	mg; complete sericitization of feld and bio; cc is intercrystalline, disseminated opq
7022-622	biotite grano-diorite	plag, qtz, K-spar/bio	ser, cc/opq	mg; complete sericitization of feld and bio; cc is intercrystalline, opq-chl veinlet
7022-655	biotite grano-diorite	plag, qtz, K-spar/bio	chl, ser/qtz, opq	mg; inequigranular, strongly zoned plag
7301-394	porphyritic plag felsite	plag, qtz, K-spar	cc/opq	mg; broken plag in vfg qtz-feld groundmass; cc in veinlets and feld
7301-425	porphyritic plag felsite	plag, qtz, K-spar/bio	/cc, chl	mg; broken plag in vfg qtz-feld groundmass
Quartz Monzonitic				
7301-65	quartz monzonite	plag, K-spar, epi, chl, ser/cc, qtz/hb	mt	fg; equigranular; strongly altered; epi veins
R05-71	quartz monzonite	plag, K-spar, epi, ser, epi/qtz, hb, qtz, opq		mg; inequigranular, zoned plag, altered; epi-qtz vein
R05-144	quartz monzonite	plag, K-spar, chl, ser/opq, cc, qtz, bio		mg; inequigranular; zoned plag; altered
R05-146	quartz monzonite	plag, K-spar, chl, bio/opq, epi, hb, qtz		mg; inequigranular; contains a vfg auroilith, weakly zoned plag

(Concluded)

Thin Section	Rock Type	Primary Minerals	Secondary Minerals	Textures
RDS-194	quartz monzonite	plag, K-spar/ hb, qtz	ser, cc, chl/epi, opq	mg; inequigranular, An ₉₂ , pervasive alteration, embayed qtz
RDS-234A	quartz monzonite	plag, K-spar/ hb, bio, qtz	ser, cc, chl/opq	fg; inequigranular, weakly zoned plag, pervasive alteration
7201-717	quartz monzonite	plag, K-spar/ qtz	chl, ser, cc/opq	fg; very strongly altered; mottled; chl and chl-free zones; chl vein
Lac. Intrusive				
RDS-162	quartz monzonite	plag, K-spar/ qtz, hb	ser, chl, cc/opq	mg; inequigranular An ₉₀ , pervasive very fine-grained alteration
RDS-168	quartz monzonite	plag, K-spar/ hb, qtz	ser, cc, chl/ opq	fg; inequigranular, feldspars are strongly altered to very fine-grained ser and cc
RDS-166	quartz monzonite	plag, K-spar, qtz/bio	ser, cc, chl/opq	mg; unzoned, plag phenocrysts in vfg quartz monzonite; pervasive vfg alteration
R.S.-257	quartz monzonite	plag, K-spar, ser, qtz/bio	cc, chl/opq	mg; inequigranular, unzoned plag, pervasive vfg alteration
RDS-263	quartz monzonite	plag, K-spar, ser, qtz/bio	cc, chl/opq	mg; inequigranular, unzoned plag, pervasive vfg alteration
7201-175	quartz monzonite	plag, K-spar, ser, qtz/bio	cc, chl/opq	mg; inequigranular, unzoned plag, pervasive vfg alteration, qtz-epi veinlets
7201-283	quartz diorite	plag, qtz/ bio	ser, chl, cc/epi	mg; strongly zoned plag in vfg qtz dioritic groundmass; pervasive vfg alteration

APPENDIX III

Locations and descriptions of specimens
selected for whole-rock chemistry study

APPENDIX III

Locations and descriptions of specimens
selected for whole-rock chemistry study

7005 (47°48'38" N, 66°19'55" W) Medium grained, equigranular quartz diorite. Strongly zoned plagioclase, slightly strained quartz, red-brown biotite. Samples for geochemical analysis were chosen between the footages 337' and 688'.

7006 (47°48'39" N, 66°19'47" W) Coarse-grained plagioclase and biotite phenocrysts in fine-grained quartz diorite. Plagioclase phenocrysts zoned, partly altered to sericite. Biotite altered to chlorite. Fine-grained groundmass altered to very fine-grained sericite and carbonate. Interpreted as a late intrusive phase. Samples for geochemical analysis were chosen between the footages 240' and 322'.

7008 (47°49'9" N, 66°21'4" W) Fine to medium-grained, equigranular biotite granodiorite. Plagioclase partly altered to sericite and epidote. Strained quartz. Biotite partly altered to chlorite. Some biotite is recrystallized. Samples for geochemical analysis were chosen between the footages 26' and 355'.

7015 (47°48'25" N, 66°19'42" W) Medium grained, equigranular quartz diorite. Contains trace amounts of pyrite. Thin section not available. Interpreted as late intrusive phase. Samples for geochemical analysis were chosen between the footages 387' and 525'.

7301 (47°50'1" N, 66°18'9" W) Broken, unzoned, medium grained plagioclase phenocrysts in a very fine-grained felsic groundmass. Plagioclase phenocrysts altered to very fine-grained carbonate and sericite. Minor fine-grained biotite phenocrysts. Classified as porphyritic plagioclase felsite. Samples for geochemical analysis were chosen between the footages 380' and 414'.

7302 (47°50'7" N, 66°18'10" W) Medium to coarse-grained gabbro. Weakly zoned plagioclase laths in ophitic texture with pyroxene. Plagioclase is partly altered to sericite. Pyroxene is partly altered to chlorite and biotite. Samples for geochemical analysis were chosen between the footages 12' and 234'.

7021-576 (47°49'12" N, 66°21'0" W) Medium grained, equigranular biotite granodiorite. Thin section not available. Sample selected by Dr. R.V. Kirkham.

RDS-97A (47°49'20" N, 66°17'47" W) Coarse-grained gabbro; plagioclase laths in ophitic texture with chloritized pyroxene. Thin section not available.

RDS-125 (47°49'12" N, 66°18'54" W) Medium grained quartz monzonite. Thin section not available.

(Concluded)

RDS-144 (47°49'31" N, 66°18'4" W) Medium grained, inequigranular quartz monzonite. Subhedral feldspars are altered to very fine-grained carbonate and sericite. Plagioclase strongly zoned.

RDS-160 (47°50'30" N, 66°18'27" W) Medium grained, equigranular, pink quartz monzonite. Biotite is chloritized. Thin section not available.

RDS-190 (47°49'49" N, 66°18'57" W) Medium grained quartz monzonite. Thin section not available.

RDS-216 (47°49'35" N, 66°19'12" W) Medium grained, broken, unzoned plagioclase phenocrysts in a very fine-grained groundmass. Feldspars altered to very fine-grained sericite and carbonate. Biotite completely altered to chlorite.

RDS-228A (47°49'31" N, 66°19'44" W) Medium grained quartz monzonite. Thin section not available.

RDS-234A (47°49'14" N, 66°18'55" W) Medium grained, subhedral, weakly zoned plagioclase phenocrysts in fine-grained quartz monzonite. Plagioclase partly altered to very fine-grained sericite and carbonate. Potassium feldspar completely altered to very fine-grained sericite and carbonate. Biotite and amphibole altered to chlorite.

RDS-257 (47°49'18" N, 66°19'17" W) Medium grained, inequigranular quartz monzonite. Subhedral feldspars altered to very fine-grained sericite and carbonate. Biotite altered to chlorite.

RDS-263 (47°49'51" N, 66°18'23" W) Medium grained, inequigranular quartz monzonite. Subhedral, unzoned feldspars altered to very fine-grained sericite and carbonate. Zoned plagioclase is uncommon. Biotite altered to chlorite.

IR-73-243A (47°50'15" N, 66°18'6" W) Gabbro; hand sample and thin section not available. Sample chosen by R.R. Irrinki.

IR-73-695A (47°49'15" N, 66°18'7" W) Gabbro; hand sample and thin section not available. Sample chosen by R.R. Irrinki.

IR-73-701A (47°49'6" N, 66°18'57" W) Gabbro; hand sample and thin section not available. Sample chosen by R.R. Irrinki.

IR-73-1318 (47°50'7" N, 66°18'19" W) Gabbro; hand sample and thin section not available. Sample chosen by R.R. Irrinki.

APPENDIX IV

Whole-Rock Data

APPENDIX IV

Whole-rock data and CIPW norms of samples from the gabbroic phase of the Benjamin River Intrusive Complex. Sample 97A was determined by the Geological Survey of Canada; sample 7302 was determined by Bondar-Clegg and Company Limited and the remaining samples were determined by the New Brunswick Department of Natural Resources (G.P. Venkateswaren, analyst).

	RDS 97A	7302	IR-73- 695A	IR-73- 1318	IR-73- 243A	IR-73- 701A
SiO ₂	47.9	47.20	46.38	49.73	53.07	57.80
Al ₂ O ₃	18.9	20.00	17.86	21.05	16.14	16.21
Fe ₂ O ₃	2.5	6.97	11.42	8.46	11.73	9.37
FeO	5.2	n.a.	n.a.	n.a.	n.a.	n.a.
MgO	9.0	7.10	8.26	4.32	3.48	2.27
CaO	12.1	12.20	10.00	10.70	6.08	4.53
Na ₂ O	2.1	3.09	2.17	2.96	4.64	5.04
K ₂ O	0.31	0.71	0.86	0.41	1.10	1.92
TiO ₂	0.65	0.91	1.60	1.32	1.78	1.31
P ₂ O ₅	0.06	0.01	0.31	0.26	0.64	0.38
MnO	0.13	0.10	0.20	0.14	0.22	0.16
S	0.04	0.12	n.a.	n.a.	n.a.	n.a.
CO ₂	0.1	n.a.	n.a.	n.a.	n.a.	n.a.
H ₂ O	1.9	n.a.	n.a.	n.a.	n.a.	n.a.
Total	100.89	98.41	99.06	99.35	98.88	98.99
Q				1.81	2.79	7.10
c						
or	1.86	4.30	5.14	2.44	6.68	11.55
ab	17.98	17.40	18.50	25.35	40.03	43.26
an	41.73	39.50	39.46	43.47	20.35	16.27
ne		5.06				
di	11.56	13.28	4.99	4.88	2.70	1.66
he	3.38	4.73	1.90	2.03	2.38	1.70
en	6.21		6.61	8.63	7.59	5.00
fs	2.09		2.88	4.12	7.68	5.89
fo	7.79	8.36	8.27			
fa	2.88	3.77	3.97			
ru						
mt	3.16	1.48	4.50	4.13	4.83	4.13
il	1.25	1.77	3.05	2.54	3.45	2.54
ha						
ap	0.14	0.02	0.72	0.61	1.52	0.91
po		0.36				
D.I.	19.84	26.76	23.64	29.60	49.50	61.90
L.D.I.	-12.3	-9.1	-12.3	-5.7	-1.3	6.0

Whole-rock data and CIPW norms of granodioritic samples from the granodioritic and late intrusive phases. Samples 7006 and 7015 are from the late intrusive phase. Sample 7021-576 was determined by the Geological Survey of Canada. The remaining samples were determined by Bondar-Clegg and Company Limited.

	7005	7006	7015	7301	7008	7021-576
SiO ₂	66.60	65.60	65.50	66.65	68.75	68.5
Al ₂ O ₃	16.26	16.28	16.49	17.04	15.30	16.3
Fe ₂ O ₃	5.73	7.29	5.60	4.96	5.09	0.2
FeO	n.a.	n.a.	n.a.	n.a.	n.a.	0.2
MgO	2.85	2.55	1.75	1.75	3.20	1.3
CaO	3.11	3.55	3.55	3.07	2.60	3.2
Na ₂ O	3.87	4.29	4.14	4.75	3.76	4.4
K ₂ O	2.48	1.94	2.13	2.32	2.95	1.6
TiO ₂	0.44	0.37	0.37	0.39	0.44	0.33
P ₂ O ₅	0.01	0.01	0.01	0.01	0.01	0.12
MnO	0.05	0.09	0.08	0.06	0.06	0.02
S	0.43	0.10	0.06	0.08	0.46	0.22
CO ₂	n.a.	n.a.	n.a.	n.a.	n.a.	nfl
H ₂ O	n.a.	n.a.	n.a.	n.a.	n.a.	0.9
Total	101.83	102.07	99.68	101.08	102.62	97.29
Q	22.16	18.58	21.23	19.19	23.82	29.45
c	1.56	0.68	0.95	1.15	1.19	1.87
or	14.49	11.31	12.70	13.63	17.10	9.84
ab	32.35	35.77	35.29	39.91	31.18	38.71
an	15.18	17.29	17.68	15.06	12.58	15.69
ne						
di						
he						
en	7.01	6.26	4.39	4.33	7.81	3.37
fs	2.77	6.46	4.42	3.61	2.06	
fo						
fa						
ru						0.09
mt	2.46	2.67	2.45	2.15	2.17	
il	0.83	0.69	0.71	0.75	0.82	0.48
hm						0.21
ap	0.02	0.02	0.02	0.02	0.02	0.29
po	1.17	0.27	0.17	0.22	1.24	
D.I.	69.00	65.65	69.21	72.73	72.11	78.00
L.D.I.	13.5	11.1	13.6	15.2	15.5	19.5

Whole-rock data and CIPW norms of samples from the quartz monzonitic phase of the Benjamin River Intrusive Complex. All the samples were determined by the Geological Survey of Canada.

	RDS 125	RDS 144	RDS 190	RDS 228A	RDS 232A
SiO ₂	67.1	65.0	66.1	60.7	66.0
Al ₂ O ₃	15.6	15.9	15.8	16.0	15.7
Fe ₂ O ₃	0.6	1.5	1.0	2.5	0.9
FeO	2.7	3.0	3.3	4.4	2.9
MgO	1.0	1.4	1.3	1.8	1.2
CaO	2.1	2.5	2.6	3.9	2.3
Na ₂ O	4.9	4.3	4.7	5.3	5.0
K ₂ O	4.2	3.7	3.6	2.4	3.7
TiO ₂	0.58	0.76	0.80	1.40	0.66
P ₂ O ₅	0.18	0.23	0.21	0.44	0.21
MnO	0.05	0.09	0.08	0.16	0.05
S	nil	nil	nil	nil	0.02
CO ₂	nil	nil	nil	nil	nil
H ₂ O	1.3	1.2	1.2	0.9	1.4
Total	100.31	99.58	100.69	99.90	100.04
Q	15.78	17.86	16.32	9.96	15.32
c		0.84			
or	25.09	22.25	21.40	14.34	22.19
ab	41.87	36.98	39.97	45.29	42.90
an	8.24	11.08	11.43	12.91	9.59
ne					
di	0.41		0.07	1.73	0.24
he	0.51		0.07	1.35	0.25
en	2.33	3.54	3.23	3.73	2.92
fs	3.36	3.24	4.05	3.32	3.50
fo					
fa					
fu					
mt	0.88	2.21	1.46	3.66	1.32
il	1.11	1.47	1.53	2.69	1.27
hse					
ap	0.42	0.54	0.49	1.03	0.49
po					
D.I.	82.74	77.09	77.69	69.59	80.41
L.D.I.	20.2	17.2	17.5	10.3	18.5

Whole-rock data and CIPW norms of quartz monzonite samples from the late intrusive phase of the Benjamin River Intrusive Complex. All the samples were determined by the Geological Survey of Canada.

	RDS 160	RDS 216	RDS 237	RDS 263
SiO ₂	65.5	71.5	70.3	67.5
Al ₂ O ₃	15.6	14.8	15.3	15.6
Fe ₂ O ₃	1.2	1.3	1.3	0.9
FeO	2.6	1.1	1.3	3.0
MgO	1.4	0.50	0.51	1.1
CaO	2.5	0.26	0.96	2.2
Na ₂ O	4.6	5.8	5.5	4.6
K ₂ O	4.1	4.1	4.4	3.8
TiO ₂	0.75	0.27	0.27	0.63
P ₂ O ₅	0.22	0.11	0.10	0.19
MnO	0.08	0.01	0.05	0.07
S	nil	nil	nil	nil
CO ₂	0.1	nil	nil	nil
H ₂ O	1.0	0.9	0.9	1.0
Total	99.65	100.65	100.89	100.59
Q	15.46	20.88	18.49	18.69
c		0.61		0.37
or	24.61	24.31	26.03	22.57
ab	39.49	49.20	46.54	39.08
an	9.94	0.57	4.06	9.71
ne				
di	0.58		0.03	
he	0.39		0.02	
en	3.27	1.25	1.26	2.75
fs	2.53	0.52	0.95	3.87
fo				
fa				
ru				
wt	1.77	1.89	1.89	1.31
il	1.45	0.51	0.51	1.20
hw				
ap	0.52	0.26	0.23	0.44
po				
D.I.	79.56	94.39	91.06	80.34
L.D.I.	16.3	24.9	23.9	19.1

APPENDIX V

Supplementary Variation Diagrams.

Alkali-silica plot illustrating the subalkaline character of the Benjamin River Intrusive Complex. Plots in weight per cent. Dividing line from Irvine and Baragar (1971).

Figure A. Al_2O_3 versus normative plagioclase illustrating the calc-alkaline nature of the Benjamin River Intrusive Complex. Plots in weight per cent. Diagram after Irvine and Baragar (1971).

Figure B. Cpx-Ol-Opx ternary illustrating the subalkaline character of two gabbroic analyses whose sum of normative nepheline and quartz is zero. Plots in weight per cent. Diagram after Chayes (1965, 1966).

Ol'-Ne-Q' projection illustrating the subalkaline nature of the Benjamin River Intrusive Complex. Ne' is $\text{Ne} + 3/5\text{Ab}$; Q' is $\text{Q} + 2/5\text{Ab} + 1/40\text{px}$ and Ol' is $\text{Ol} + 3/40\text{px}$. Plots in per cent cation equivalents. Dividing line from Irvine and Baragar (1971).

APPENDIX VI

References to age determinations
illustrated on figures 14 and 15

APPENDIX VI

Age (m.y.)	Reference
312	Lowden, 1961
320	Ruitenbergh and others, 1970
330	Cormier and Stirling, 1976
339	Lowden, 1963
340	Cormier and Stirling, 1976
342	Wanless and others, 1974
346	de Römer, 1970
346	Lamarche, 1974
348	Wanless and others, 1972
350	" " " 1967
350	" " " 1974
356	de Römer, 1970
356	Wanless and others, 1974
358	" " " 1974
359	" " " 1974
362	" " " 1972
364	Ruitenbergh and others, 1970
364	Tupper and Hart, 1961
364	Wanless and others, 1974
370	This study
370	Wanless and others, 1967
374	" " " 1974
375	" " " 1966
378	" " " 1972
378	" " " 1974
380	Tupper and Hart, 1961
381	" " " 1961
382	Wanless and others, 1972
384	" " " 1974
385	Pajari and others, 1974
386	Wanless and others, 1972
386	" " " 1974
387	Lowden and others, 1963
392	Tupper and Hart, 1961
393	Wanless and others, 1974
395	" " " 1966
395	Tupper and Hart, 1961
395	Cormier, 1972
397	Wanless and others, 1974
398	Tupper and Hart, 1961
399	Wanless, 1969
407	Wanless and others, 1974
415	" " " 1974
423	" " " 1969
424	" " " 1974
442	" " " 1967
445	Wanless, 1969
479	Wanless and others, 1970
480	Fyffe and others, 1977

Age (m.y.)	Reference
482	" Wanless and others, 1974
486	" " " 1974
500	Wanless, 1969
508	Wanless and others, 1974
530	" " " 1969

APPENDIX VII

Attitudes of Planar Features to the Core Axis

These core axis angles were noted by Soquem geologists in their core logs. The drill holes are inclined at 45° and are parallel. Abbreviations of rock types used to illustrate the intrusive relationship are:

aft	ash flow tuff	ppa	porphyritic plagioclase aphanite
bgdt	biotite grano- diorite	pqd	porphyritic quartz diorite
gb	gabbro	pqmb	porphyritic quartz monzonite (type B)
hbf	hornblende felsite	qd	quartz diorite
mv	mafic volcanic rocks	qdb	quartz diorite (type B)
pf	porphyritic felsite	qdp	quartz diorite porphyry
		tf	tuff or siltstone

APPENDIX VII

Intrusive Contacts

<u>Location</u>	<u>Angle to Core Axis</u>	<u>Relationship</u>	<u>Reference</u>
1004 - 101'	80°	pf-pqd	Richard, 1970
- 193'	40-70°	pf-pqd	
- 275'	80°	pf-pqd	
- 276'	70°	pf-pqd	
- 312'	45°	pf-pqd	
- 368'	60°	pqd-mv	
- 396'	45°	pqd-mv	
- 411'	45°	pqd-mv	
- 422'	60°	pqd-mv	
7009 - 101'	30°	qdp-aft	Richard, 1970
- 163'	90°	qdp-mv	
- 361'	90°	qdp-mv	
- 491'	50°	qd-mv	
7010 - 328'	40°	gb-rt	Richard, 1970
7012 - 477'	60°	gb-pqm	Richard, 1970
7013 - 312'	20°	qd-rtf	Richard, 1970
- 344'	45°	qm-rtf	
- 348'	45°	qd-rtf	
- 574'	30°	qd-pqmb	
7015 - 320'	25°	bgdt-mv	Chevé, 1971
- 326'	35°	bgdt-mv	
- 387'	35°	qdb-mv	
7018 - 236'	30°	ppa-mv	Chevé, 1971
- 320'	45°	ppa-mv	
7022 - 278'	40°	qm-mv	Gagnon, 1971
- 311'	38°	qdp-mv	
7229 - 76'	60°	qd-rt	Richard, 1972
- 84'	60°	qd-rt	
- 207'	45°	qd-rt	
7231 - 74'	60°	bgdt-mv	Richard, 1972
7232 - 164'	45°	mv-qd	Richard, 1972
7233 - 237'	60°	bgdt-mv	Richard, 1972
- 240'	60°	bgdt-mv	
- 251'	60°	qd-mv	
7236 - 76'	40°	hbf-bgdt	Richard, 1972

Bedding plane attitudes in drill core

<u>Location</u>	<u>Angle to Core Axis</u>	<u>Reference</u>
7009 - 87'	50°	Richard, 1970
7012 - 29-52'	35°	Richard, 1970
- 52-72'	30-40°	" "
7013 - 109'	45°	Richard, 1970
- 312'	35°	" "
- 326'	10-60°	" "
7019 - 158'	25°	Richard, 1970
- 180'	60°	" "
- 183'	50°	" "
- 185-229'	20-45°	" "
- 229'	45°	" "
7022 - 169'	47°	Gagnon, 1971
- 186'	40°	" "
7024 - 463'	60°	Chev�, 1971

APPENDIX VIII

Summary of Assay Results

These two tables illustrate the drill holes richest in copper and molybdenum. The data is tabulated to facilitate comparison of neighbouring drill holes. The number of assays in each hole is listed under the column entitled "N". The percentage of assays that occur within a given interval are listed for each drill hole under that interval heading. The precision and accuracy of these assay results are not known.

APPENDIX VIII

		Copper in ppm						
	N	0- 500	500- 1000	1000- 1500	1500- 2000	2000- 2500	2500- 3000	>3000
7009	100	50	18	10	6	4	2	10
7023	138	68	17	4	3	1		7
7029	102	53	27	8	8	1	3	1
7022	179	17	30	15	11	11	7	9
7008	142	12	17	12	13	20	9	17
7021	110	13	23	22	23	11	5	4
7020	115	51	27	10	5	3	2	3
7004	47	87	9	4				
7001	43	74	23	3				
7228	47	72	21	4				2
7236	48	90	10					
7229	54	96	4					
7237	49	100						
7230	47	87	13					
7233	78	63	32	4		1		
7232	54	96	4					
7231	54	80	17		2			2
7234	47	57	30	9	1			2
7235	4	100						
7007	120	54	37	7	2			1
7013	144	88	8	1	2	1		
7019	41	95	3	3				
7010	120	84	10	3	1	1		1
7012	121	79	12	5	3			2
7014	126	91	7	1	1			
7018	102	96	4					
7005	136	38	51	10	1			
7006	98	54	19	7	11	5	2	1
7002	60	87	12	1				
7003	30	84	16					
7015	92	68	11	11	7	1	2	
7017	101	75	7	8	7	3		1
7016	78	67	22	4	5	1		1
7301	20	100						
7302	7	100						

		Molybdenum in ppm						
	N	0-50	50-100	100-200	200-300	300-400	400-500	> 500
7009	109	75	11	7	6	1	-	1
7023	138	75	12	7	2	1	2	1
7024	102	72	10	9	4	1	1	3
7022	179	61	17	10	3	6	1	2
7008	142	48	25	21	3	2	-	1
7021	110	67	10	12	5	2	-	4
7020	115	81	14	4	-	1	-	
7004	47	100						
7001	43	91	7	2				
7228	47	100						
7236	48	96	4					
7229	54	98	2					
7237	49	100						
7230	47	96	2	2				
7233	78	93	6	1				
7232	54	100						
7231	54	98	2					
7234	47	98	-	2				
7235	4	100						
7007	120	97	3					
7013	144	99	1					
7019	41	96	2	2				
7010	120	89	5	5	1			
7012	121	98	2					
7014	126	100						
7018	102	100						
7005	136	82	11	6	1			
7006	98	83	11	3	2	1		
7002	60	100						
7003	30	80	17	-	3			
7015	92	91	5	-	1	1	-	2
7017	101	93	3	1	1	1	1	
7016	78	100						
7301	20	100						
7302	7	100						

APPENDIX IX

Method of Estimation of the
Grade and Tonnage of the Benjamin River Deposit

A hand-drawn sketch of a river or deposit boundary, consisting of a single continuous line that starts near the center-right, curves upwards and to the right, then downwards and to the right, ending near the bottom right. There is a small loop or bend in the line near the top right.

APPENDIX IX

Estimation of Grade and Tonnage of the Benjamin River Deposit

An estimate of the grade and tonnage of the zone most enriched in chalcopyrite serves to illustrate the very low grade nature of the occurrence.

The enriched zone (see diagram) was defined using estimates of chalcopyrite content (Richard, 1970; Chev, 1971; Gagnon, 1971). Fairly continuous intersections of trace to 1.5% chalcopyrite occur in drill holes 7008, 7020, 7021, 7022 and 7023 (op. cit.). Drill hole 7023 is separated from the other four drill holes by drill hole 7024. Hole 7024 contains only trace amounts of chalcopyrite (Chev, 1971).

The enriched zone is based on the following drill hole intersections:

7008: 26-600'

7020: 20-320'

7021: 130-595'

7022: 400-960'.

The zone is defined as having vertical walls that are extrapolated 100 feet west of drill holes 7008 and 7022 and 200 feet east of drill holes 7020 and 7021. This defines a quadrilateral with corners at:

Soquem Lte. Grid Reference: line 54+00 W; 51+00 N
 : line 54+00 W; 43+00 N
 : line 61+00 W; 40+00 N
 : line 61+00 W; 44+00 N.

The area of this quadrilateral is about 400,000 ft². The quadrilateral was extrapolated to a depth of 680' which is the maximum depth of the enriched zone encountered in drill hole 7022. The volume of this prism is about 2.7 x 10⁸ ft³.

The mean specific gravity of granodiorite is 2.72 or 170 lb/ft³ (Daly, 1942). The tonnage contained within this prism is thus estimated to be about 23 million tons.

The estimated grades are 0.18% for copper and 0.01% for molybdenum. These were determined using assay values given in the Soquem Lte. drill logs. Assays were prorated with respect to their sample lengths but not with respect to the area of influence of the drill hole. The best assay results occur in drill holes 7008 and 7022 (see table 5) hence the grade estimates may be considered as overestimates.

The Benjamin River deposit is outlined by the dashed lines. Heavy solid lines are vertical extensions of cupriferous sections in drill holes.

KEY

- ALL-WEATHER LOGGING ROADS
- LOGGING ROADS
- IMPASSABLE LOGGING ROADS
- CLEARING
- ALDER SWAMP or MARSH
- INTERMITTANT STREAMS
- DIAMOND DRILL HOLE
- OUTCROP (AREA, LOCATION)
- FLOAT (FIELD, LOCATION)
- LIMITS OF THESIS STUDY AREA
- GEOLOGICAL CONTACT: APPROXIMATE
- 40 S₀ ATTITUDE: VOLCANIC ROCKS

LEGEND

BENJAMIN RIVER IN

- 6 Late Intrusive P
- 5 Quartz Monzoni
- 4 Granodioritic P
- 3 Gabbroic Phase

CHALEUR GROUP

- 2 Felsic Volcanic F
- 1 Mafic Volcanic F

LEGEND

RIVER INTRUSIVE COMPLEX

intrusive Phase

Monzonitic Phase

poritic Phase

c Phase

GROUP

Volcanic Rocks { B: PYROCLASTIC
A: MASSIVE

Volcanic Rocks

LONGITUDE 66° 23' 00"

50F

LONGITUDE 68° 17' 24"

100F

110F

LONGITUDE 66°17' 24"

Figure 2.

120F12

KEY

- ALL-WEATHER LOGGING ROADS
- LOGGING ROADS
- IMPASSABLE LOGGING ROADS
- CLEARING
- ALDER SWAMP or MARSH
- INTERMITTANT STREAMS
- DIAMOND DRILL HOLE
- OUTCROP (AREA, LOCATION)
- FLOAT (FIELD, LOCATION)
- LIMITS OF THESIS STUDY AREA
- 7005 DIAMOND DRILL HOLE NUMBER
- 177 SAMPLE LOCATION NUMBER
- 0, 4-4 TRENCH, NUMBER

2 of

LONGITUDE 66°23'00"

7022
7008
7024
7023

7011

7225

7226

7019

70109

41

7012

50F

LONGITUDE 66° 17' 24"

LONGITUDE 66°23'00"

LATITUDE 47°47'47"

90F

100 F

BENJAMIN

OUTCR

DATE: JANUARY, 1978

1733 Δ
BLUE MOUNTAIN

110F

Figure 3.

120712

END

06 03 80

FIN