GEOLOGY OF THE PETER STRIDES POND AREA

ASPECTS OF THE GEOLOGY IN THE PETER STRIDES POND AREA, SOUTHWESTERN NEWFOUNDLAND

by

JOHN D. FERGUSON, B.Sc.

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Master of Science

McMaster University

June 1989

MASTER OF SCIENCE (1989)
(Geology)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Aspects of the Geology in the Peter Strides Pond Area, Southwestern Newfoundland

AUTHOR: John D. Ferguson, B.Sc. (University of Western Ontario, London, Ontario)

SUPERVISOR: Professor Paul M. Clifford

NUMBER OF PAGES: xii, 160

ABSTRACT

The Peter Strides Pond study area, approximately 150 km^2, is located in the Southern Long Range Mountains in southwestern Newfoundland. It lies at the southern margin of the Paleozoic Central Mobile Belt in the Dunnage tectonostratigraphic zone. A felsic intrusion, granoblastic gneiss, heterolithic conglomerate and basalt form foliated, linear bodies across the study area parallel to the regional, northeast striking, structural grain; gabbro, diabase and rhyolite have non-linear exposure and no internal fabric. Two parallel mylonite zones traverse the study area. The Victoria River Shear Zone (VRSZ) to the north and the Peter Strides Pond Shear Zone (PSPSZ) to the south are concordant with the regional fabric and separate domains which increase in metamorphic grade from lower greenschist in the northwest to upper amphibolite facies to the southeast. Veins and lenses of variable form and composition are observed in several lithologies but the focussed occurrence of milky white, foliation parallel quartz veins in both the VRSZ and the felsic pluton is significant to these units.

A tentative stratigraphic succession for the study area utilizes regional correlations, radiometric ages and fossil evidence because limited exposure does not reveal contacts between adjacent lithologies. Basalt of the Victoria Lake Group and gneiss of the Bay du Nord Group are the oldest units in the area. Conglomerate unconformably overlies the Victoria Lake Group and contains volcanic and sedimentary clasts derived from the underlying group. Mafic to felsic plutonic igneous rocks intrude volcanic rocks of the Victoria Lake Group. Undated gabbro, diorite and diabase may be coeval with Devonian adamellite-granodiorite. Parallel shear zones are concordant with the regional structural grain and follow lithologic contacts closely. Megacrystic granite cross-cuts PSP mylonite, adamellite and Bay du Nord gneiss. It is the youngest unit in the study area. The study area's tectonic framework represents a compressional environment which dominated during, and continued after Iapetus closure. Mafic volcanic rocks adjacent to ophiolite complexes represent back arc basins preserved via obduction. Continued compression was accomodated by crustal thickening through reverse, northwest directed, thrust faults. The inhomogeneously thickened crust provided a host of potential magma compositions to be intruded locally.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the invaluable assistance provided by Dr. Paul Clifford for his opinions, thoughts and constructive criticism as advisor. Special thanks to Dr. Jean van Berkel for suggesting the topic and for his helpful guidance in Newfoundland. Able field assistance was provided by Glenn Goucher and David Machin. Much appreciation is extended to the Geological Survey of Canada for providing employment, technical data and considerable logistical and financial support.

Independent research became a team effort with the many helpful opinions, advice and technical knowledge of many members of the MacMaster Geology Department to which the author is most grateful. In particular, special thanks go to Franco Marcantonio for his assistance on all things geochemical, Steve Zymela for his help in matters of geochemistry and especially computers and Fereydoun Ghazban for his help in the realm of stable isotopes. Mr. Len Zwicker is thanked for his thin section preparation as is Mr. Jack Whorwood for his excellent photography. Many thanks go to the inhabitants of room 130, Paula Mackinnon, Bill Buhay, Stu Miller and Steve Davies who provided a valuable escape when the institutional environment became too overwhelming.

A last thank you to my wife, Laurie, for her great tolerance and continuous support.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page
17	Composite planar fabrics form reliable kinematic indicators in mylonitic rock.	77
18	Asymmetry of augen tails and pressure shadows provide a reliable sense of shear criterion in deformed rock.	79
19	Rigid materials resist ductile flow and deform by fracture and displacement.	81
20	Sigmoidal extensional veins represent sequential development in a progressively evolving shear zone.	84
21	Boudins form during extensional deformation due to the variable mechanical response of materials.	86
22	Distribution of veins and lenses across the study area.	101
23	Cartoon depicting the possible sequential development of the study area.	116

LIST OF TABLES

LIST OF PLATES

CHAPTER 1: INTRODUCTION

1.1 PURPOSE

The relatively small island of Newfoundland, approximately 130,000 km^2, provides significant exposure of the northern Appalachian Mountains in North America. Difficulty of access to and in southwest Newfoundland, geological complexity and the reconnaissance nature of the majority of previous studies leave us with a poorly understood geological history for the Southern Long Range Mountains. The current investigation arises from a 1:50,000 scale regional mapping and correlation project which began in the summer of 1985 (EMR/GSC Project 850017; van Berkel et al,1986). It deals with the general geology of the study area and then examines two regional scale ductile deformation zones in addition to several occurrences of quartz veins and lenses. The data support an analysis of the kinematics of the deformational processes and of the associated fluid migration. Study of an intervening, foliated, granitoid intrusion bears upon the level of emplacement, age and tectonic setting of felsic plutonism in the study area.

1.2 LOCATION AND ACCESS

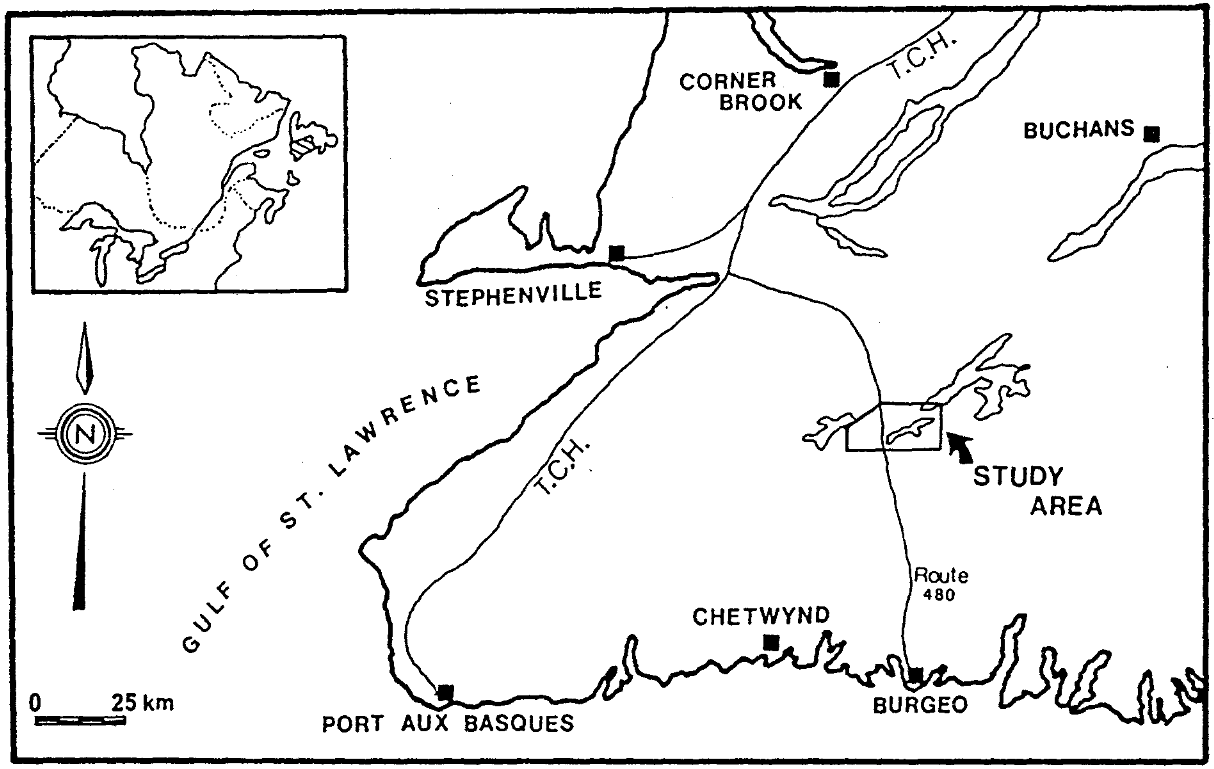
The area of investigation is centered in the north-central portion of the King George IV Lake map sheet (NTS mapsheet 12A/4) at latitude 48° 10' N and longitude 57° 43' W (Figure

1). An all weather gravel road, Highway 480, bisects the study area approximately 81 km south of the Trans Canada Highway and 55 km north of the coastal village of Burgeo. The Victoria River, central to the study area, is navigable by small boat from Peter Strides Pond to within about 2 km of Victoria Lake in late spring to early summer. Fixed wing access to the large ponds and lakes is possible but helicopter travel is more efficient. Private summer recreational camps are maintained near the road at Peter Strides Pond but there are no permanent dwellings in the area.

1.3 PHYSIOGRAPHY

The Peter Strides Pond area is part of the Atlantic Upland of the Canadian Appalachians (Twenhofel & McClintock, 1940; King, 1972). The study area is characterized by hummocky uplands with a local relief of 200 metres. It is bisected by the Victoria River and contains Peter Strides Pond. Regional drainage patterns reflect the northeast-southwest bedrock structure. However, local drainage is greatly influenced by the thick accumulation of glacial debris which blankets and subdues bedrock topography. Stunted spruce is ubiquitous at lower altitudes; grasses and sedge at higher altitudes. Mature spruce, white pine, birch and juniper grow in the deep, sheltered valleys. Generally therefore, outcrop is fair to poor on rounded hilltops but is poor to non-existent in the

Figure 1: Location map of the study area in southwestern Newfoundland.


CORNER
BROOK
T.C.H.
BUCHANS
STEPHENVILLE
GULF OF ST. LAWRENCE
N
T.C.H.
STUDY
AREA
Route
480
CHETWYND
0
25 km
PORT AUX BASQUES
BURGEO

wooded valleys and bogs except for rare stream bed exposures.

1.4 PREVIOUS WORK

The geology of the King George IV Lake area was unknown until mapped by Riley (1957) during a 1:253,000 scale regional mapping project of the Red Indian Lake map sheet (west half). This early reconnaissance work considered most sedimentary and volcanic rocks to be of probable Ordovician age, correlatable, on the basis of similar lithology, with the Buchans Group and Exploits Group (Heyl, 1936) in the northeast, and the Bay du Nord Group (Cooper, 1954) in the south. Riley (1957) considered the intrusive rocks to be of Devonian age based on cross-cutting relations.

DeGrace (1973) mapped at 1:50,000 scale around King George IV Lake, preliminary to more detailed work. He initally regarded the Ordovician volcanic rocks to be potentially favourable for stratabound massive sulphide mineralization. After his investigation, he re-assigned the fluviatile sediments and subaerial volcanic rocks to the Carboniferous period. He also then concluded that the area had low economic potential for base metal deposition.

ASARCO (Swanson, 1952-1960; Smyth, 1979) and the Hudson Bay Oil and Gas Company (Sternenberg, 1973) have mapped parts of the region during the course of base metal exploration programs. BP Selco considered the area around Victoria Lake as favourable for gold exploration and currently holds valid mining leases.

Mapping by Kean (1983) at 1:12,500 and 1:15,840 field scales has provided the most focussed regional study for this area. He gave detailed rock descriptions and erected a preliminary tectonic framework for the units in the Peter Strides Pond area comparable to that for similar exposures in the Lloyds River Valley (Kean, 1977), near Star Lake (Kean, 1979) and Red Indian Lake (Kean and Jayasinghe, 1980; 1982).

Van Berkel et al (1986) are continuing, extending and integrating the work of others (Brown, 1973; 1975; Herd & Dunning, 1979; Chorlton, 1980; 1983; Wilton, 1983; Whalen & Currie, 1984; Keppie, 1986) in remapping the Southern Long Range Mountains with particular emphasis on detailed and regional scale structure (Table 1). This work will contribute to an updated reinterpretation of the tectonic setting of southwest Newfoundland and its role in the large scale Appalachian Orogen.

1.5 METHODOLOGY

During the 1986 summer field season, the author joined a GSC project in its second year of mapping the Southern Long Range Mountains at 1: 100,000 scale. From June to August, 315 rock samples were collected from a 10 km x 15 km study area in the northeast part of the King George IV Lake (12A/4) map sheet. From this representative suite, thin sections, major and trace element analyses, gold assays, rare earth element analyses, catholuminescence petrography and stable isotope geochemistry were completed. A Sm/Nd model age was attempted on one granitic sample.

Thin sections which describe rock fabrics were cut normal to foliation and parallel to lineation. The textural terminology of Barker (1970) was used. Fault nomenclature of Sibson (1977) described deformed rock. Modal compositions for each lithology were estimated visually by point counts with an incremental stage. These data were compared to CIPW norms calculated from major and trace element contents as determined by X-ray fluorescence analyses (Appendix I, Part A). Compositions were classified according to the nomenclature of Streckeisen (1973). Metamorphic grades were named according to Miyashiro (1973) based on observed mineral assemblages.

Gold content was determined by the Direct Current Plasma Fire Assay method (Appendix I, Part B) at X-Ray Assay Laboratories Limited of Don Mills, Ontario.

Rare earth element content was determined by Neutron Activation Analysis (Appendix I, Part C) at Nuclear Activation Services of Hamilton, Ontario.

The melting history, time and level of magma formation for felsic plutonism was inferred from Sm/Nd isotopic examination (Appendix I, Part D).

Relict textures, growth bands and sequential zonations in veins and lenses were investigated via catholuminescence (Appendix I, Part E).

Table 1: The accomplishments of past studies in Newfoundland. Early workers provided lithologic descriptions and suggested a relative timing of events. After the acceptance of plate tectonics, emphasis shifted to integrating known rock units into the tectonic framework and reconstructing the geologic history across the Appalachian Orogen in Newfoundland.

SUMMARY OF PREVIOUS WORK

WORKER(S)	CONTRIBUTION/INTERPRETATION
Heyl (1936) Phair (1946) Cooper (1954) Riley (1957)	- Early reconnaissance mapping from the coast inland during the course of regional studies and mineral exploration programs established local stratigraphic successions, assessed the relative timing of geologic events and proposed correlations of similar lithologies between separated areas of investigation.
Williams (1964) Kay & Colbert (1965) Kay (1967)	- Workers subdivide well described stratigraphic packages and propose relative geologic ages to classify separate geologic provinces across Newfoundland.
Wilson (1966)	- The Appalachian Orogen in Newfoundland is cited as the preserved record of a complete tectonic cycle of ocean formation and closure.
Dewey (1969) Stevens (1970) Bird & Dewey (1971) Church & Stevens (1971) AND OTHERS	- Identified ophiolite complexes across Newfoundland and discussed their tectonic significance with respect to its emplacement history.
Brown (1973-1979) Chorlton (1979-1983) Kean (1978-1983) Kean & Jaysinghe (1981-1983) Williams (1964-1979) AND OTHERS	- Conducted focussed regional mapping which provide concise unit descriptions, basement cover relations and identify and consider the significance of regional scale deformation/fault zones and propose tectonic reconstructions.

PREVIOUS WORKERS SUMMARY CONTINUED

Strong (1974-1980) Dunning (1981-1987) Herd & Dunning (1979) Whalen & Currie (1982-1984) Keppie (1986) AND OTHERS	- Geology/geochemistry/ geochronology of selected rock types particularly granites, ophiolites and economic mineral deposits aid in regional correlations and tectonic reconstructions.
Van Berkel (1986-1987) AND OTHERS	- Continuing and integrating past work in the Southern Long Range Mountains with particular emphasis on structural studies between the Long Range and Cape Ray Faults to provide the next Dunnage Zone tectonic reconstruction and geologic history.

Oxygen isotope determinations on vein material and host rock samples provide comments on fluid source, and suggest the regional extent of fluid migration associated with two vein and lens populations (Appendix I, Part F).

CHAPTER 2 REGIONAL GEOLOGY

2.1 GENERAL STATEMENT

The island of Newfoundland represents the northern extremity of the Appalachian Orogen in North America (Williams, 1964; 1978; Williams et al, 1974). In the 1960's, it was broadly subdivided into three separate geological provinces, the Western Platform (Kay, 1967), the Central Paleozoic Mobile Belt (Williams, 1964) and the Avalon Platform (Kay & Colbert, 1965). After the acceptance of plate tectonics as a working framework, Williams (1978; 1979) divided the island into four tectonostratigraphic zones, named, from west to east, the Humber, Dunnage, Gander and Avalon (Figure 2). Rocks in these divisions are thought to represent the preserved record of the opening and closing of the Iapetus Ocean from the late Precambrian to the middle Paleozoic (Wilson, 1966; Dewey, 1969; Bird & Dewey, 1970; Stevens, 1970; Williams et al, 1972; St Julien & Hubert, 1975; Osberg, 1978;). Rocks in the Humber Zone record the destruction of the Atlantic type, Precambrian continental margin of eastern North America (ie. the western margin of the Iapetus) (Rodgers, 1968; Williams & Stevens, 1974; Williams, 1979). Rocks in the Dunnage Zone represent ocean floor fragments, island arc sequences and mélanges associated with final closure (Horne, 1969; Kean & Strong, 1975; Kay, 1976; Williams & Hibbard, 1976; Williams, 1979;). The Gander Zone

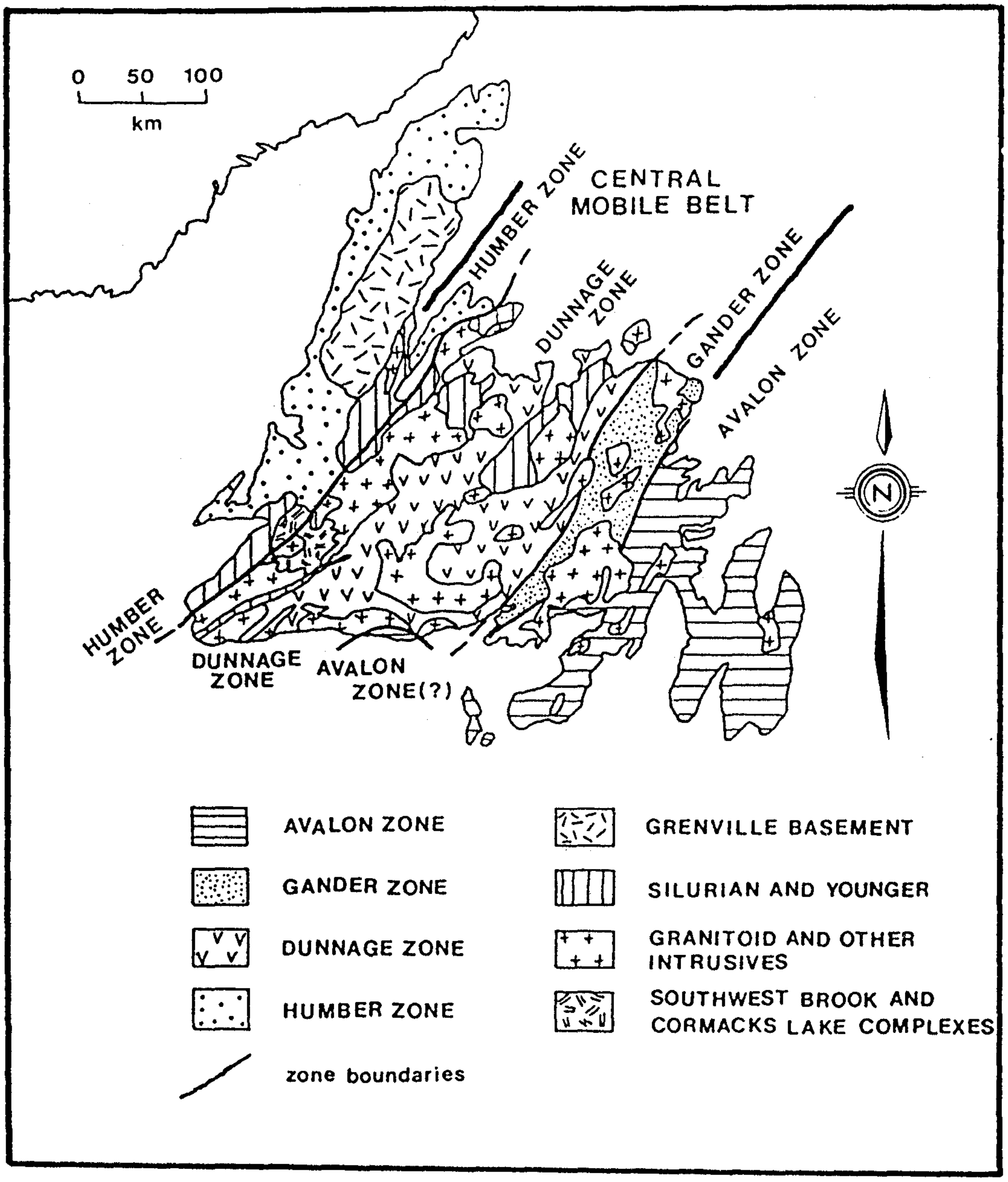


Figure 2: The most recent modification to the positioning of tectonostratigraphic subdivisions in Newfoundland (After Williams, 1978; 1979; Chorlton, 1980; Kean, 1983).

contains continental clastic rocks which may represent the Andean type, eastern margin of the Iapetus (Williams, 1964; 1979; Kennedy, 1976; Blackwood, 1978).

The Avalon Zone is composed of late Precambrian basement and early Paleozoic marine cover. These sequences may relate to initial Iapetus rifting of a stable continental shelf (Papezik, 1972; Strong et al, 1978; Williams, 1979) or a pre-Iapetus subduction cycle (Blackwood & Kennedy, 1975; Rast et al, 1976).

The age and contact relations of rock units in the southern Long Range Mountains associated with this complete tectonic cycle and therefore, the geological mechanisms for their production, and their subsequent history are unclear and much debated (Brown, 1975; Strong, 1977; Dean, 1978; Williams & St Julien, 1978; 1982; Williams, 1979; Kean et al, 1981; Dunning & Krogh, 1985; Dunning et al, 1987).

2.2 TECTONIC SETTING OF THE DUNNAGE ZONE

The King George IV Lake map area is located at the southern margin of the Central Paleozoic Mobile Belt, wholly within the Dunnage Zone. This tectonostratigraphic zone has its maximum width in northeastern Newfoundland but narrows toward the southwest corner of the island (Brown, 1973). Williams (1979) notes that rocks of the Dunnage Zone are less deformed and metamorphosed than those of the adjacent Humber and Gander Zones.

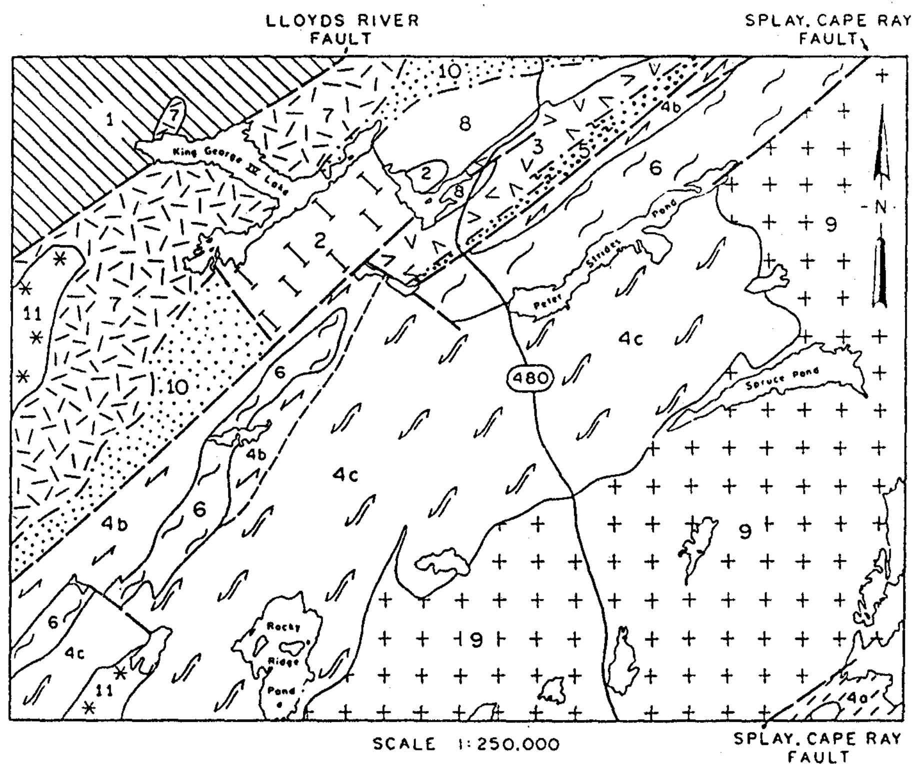
In the Dunnage Zone, rocks having ophiolite stratigraphy, from layered gabbro cumulate (Moho level) through to pillowed lava and chert, are overlain by thick volcanic and volcaniclastic sequences (Brown, 1976; Malpas, 1976; Dunning, 1981; 1984; Dunning and Chorlton, 1985;). The Dunnage Mélange at the eastern margin of the zone contains volcanic and sedimentary blocks up to one km wide in green-black, Ordovician shale (Horne, 1969; Kay, 1976; Williams & Hibbard, 1976; Hibbard et al, 1977). Granitic to dioritic intrusions contain ultramafic inclusions/xenoliths which imply an ophiolitic basement (Pajari & Currie, 1978).

2.3 STRATIGRAPHY

The stratigraphic succession in the King George IV Lake map area may be divided into six primary elements (Figure 3). From the oldest to the youngest, they are: Cormacks Lake Complex, King George IV Lake Complex, Victoria Lake Group, Bay du Nord Group, Rodgerson Lake Conglomerate, Windsor Point Group. There are also several generations of intrusive rocks (Kean, 1983). Each subdivision will be described individually.

The Cormacks Lake Complex contains an assemblage of paragneiss, amphibolite and foliated granite (Herd and Dunning, 1979). It is similarly exposed in both the Puddle Pond (12A/5) and King George IV Lake (12A/4) map sheets. The complex has not been radiometrically dated but Kean (1983)

Figure 3: Generalized geology of the King George IV Lake (12A/4) map area (After Kean, 1983).



11 GRANITE: *Red and pink granite*

10 WINDSOR POINT GROUP: *Red sandstone, siltstone and conglomerate; gray graywacke, black siltstone; mafic and felsic subaerial volcanics*

9 BUCK LAKE GRANITE: *K-feldspar megacrystic granite, minor equigranular granite and granodiorite*

8 BOOGIE LAKE GABBRO: *Gabbro, diorite, granodiorite and granite*

7 LLOYDS RIVER INTRUSIVE SUITE: *Gabbro, quartz diorite, granodiorite, tonalite and granite*

6 GRANITE: *Mylonitized red granite and gray granodiorite*

5 ROGERSON LAKE CONGLOMERATE: *Deformed polymictic conglomerate and minor sandstone*

4 BAY DU NORD GROUP: 4a, *Siltstone, argillite and minor sandstone;* 4b, *mica schist, psammitic paragneiss and amphibolite;* 4c, *granodioritic and tonalitic migmatite*

3 VICTORIA LAKE GROUP: *Interbedded felsic and mafic tuffs, epiclastic rocks, minor pillow lava and agglomerate*

2 KING GEORGE IV LAKE OPHIOLITE COMPLEX: *Gabbro, sheeted dikes and basaltic pillow lava*

1 CORMACKS LAKE COMPLEX: *Paragneiss, amphibolite and deformed granite* considers it to be mid-Proterozoic and the oldest rock exposed in the map area because it is the only unit to display a northwest trending fabric (which pre-dates the northeast, regional fabric). Intrusive contacts with the King George IV Lake Complex and the Victoria Lake Group are common and truncate the Cormacks Lake Complex.

The King George IV Lake Complex consists of gabbro, diabase and basalt forming an incomplete ophiolite suite (Kean, 1983). The complex is subdivided into gabbro with minor diabase, rare sheeted dykes with gabbro screens and pillow lava with minor pillow breccia and pyroclastics. Each division represents a different stratigraphic level of the ocean floor fragment. The King George IV Lake Complex is correlated with the nearby, nearly complete ophiolite of the Annieopsquotch Complex (Dunning & Herd, 1980; Dunning, 1981; 1984; 1987). Both ophiolite sequences are fault bounded against adjacent lithologies (Kean, 1983; Dunning, 1981; 1984; 1987), are presumably incomplete and cannot be traced into each other.

The regionally extensive Victoria Lake Group is a northeast trending belt of mafic to felsic volcanic, volcanoclastic and volcanically derived (epiclastic) sedimentary rocks (Kean, 1977; 1979; 1983; Kean & Jaysinghe, 1980). In the King George IV Lake map area, rocks of the Victoria Lake Group are poorly exposed; but there is an interpreted gradational transition from primarily volcanic in the southwest to volcaniclastic/ sedimentary in the northeast along the Victoria River. Kean and Jaysinghe (1980) interpret the Victoria Lake Group as a product of a pre-Caradocian island arc. The base of the unit is undefined but is considered to be conformable upon the Annieopsquotch Complex. Upper contacts with the overlying Rodgerson Lake Conglomerate are ?erosionally unconformable and fault modified (Kean, 1977; 1983).

Coarse grained, nebulitic to granoblastic gneiss of the Bay du Nord Group (Cooper, 1954; Chorlton, 1980) forms a wide belt in the south central part of the map area. Mafic bands typically contain discontinous, wispy concentrations of biotite termed "mica hairs". Granitic or migmatitic dykes/veinlets are rare. They intrude between or truncate gneissic layers at a low angle. Further south, beyond the study area, Kean (1983) divides the Bay du Nord Group into five subunits, from north to south: unmetamorphosed sedimentary rock, schist, paragneiss, amphibolite and migmatite. He interprets these subdivisions to represent a protolith and the products of progressive metamorphism of that protolith. Granoblastic gneiss in the King George IV Lake area is undated but is correlated with similar rocks to the south, southwest (Chorlton,1978; 1980) and northeast (Kean, 1977; Kean & Jaysinghe, 1980; Dickson & MacLellan, 1981). This correlation implies a middle Ordovician age (Dallmeyer, 1979; Chorlton, 1980). Fault and intrusive contacts bound and truncate this unit to the north but Kean (1977), Kean and Jaysinghe (1980) and Dickson and MacLellan (1981) demonstrate its continuation into central Newfoundland.

Rodgerson Lake Conglomerate forms a poorly exposed, narrow, northeast trending belt across the map area. It is a greyish purple to red, heterolithic, matrix supported conglomerate with minor, intercalated grey sandstone (Kean, 1983). Millimetre to decimetre sized, subround to round, poorly sorted clasts are composed of mafic and felsic volcanic rocks, red chert, white quartz, siltstone, argillite and sandstone. Rodgerson Lake Conglomerate is considered middle Ordovician or younger because it contains clasts derived from volcanic and sedimentary rocks of the underlying Victoria Lake Group (Kean, 1977; 1983; Kean & Jaysinghe, 1980; Kean & Mercer, 1981). No contacts of the Rodgerson Lake Conglomerate are exposed but Kean (1977; 1983) considers the unit to be fault bounded against the Victoria Lake Group to the north. He suggests a fault modified unconformity to the south.

Alluvial sedimentary and mafic to felsic volcanic rocks, all at low metamorphic grade, compose the Windsor Point Group (Brown, 1975; 1977; Chorlton, 1980; Chandler, 1982). It forms a one to two km wide, northeast trending, steeply dipping belt across the northwest corner of the map area. Kean (1983) divides the unit into four elements: alluvial redbed sedimentary rocks, intercalated, terrestrial to shallow water mafic and felsic volcanic rocks, grey litharenite and interbedded conglomerate and argillite. He notes that sedimentary rocks dominate the Windsor Point Group and that felsic volcanic rocks are more common than mafic volcanic rocks. This unit is correlated with metasedimentary and metavolcanic rocks confined to a narrow, linear zone defined by the Cape Ray Fault in the southwest (Brown, 1975; 1977). Plant fossils suggest a Devonian age for deposition (Chorlton, 1980). Intrusive contacts and a fault modified unconformity are exposed to bound the Windsor Point Group against adjacent units (Kean, 1983).

Several generations and compositions of intrusive rocks are exposed in the King George IV Lake map area. Medium to coarse grained, moderately foliated pink granite and grey granodiorite occur in two linear bodies north and west of Peter Strides Pond. Foliation parallel, milky quartz veins are common. Similar granitoid rocks in the Victoria Lake (12A/6) map area yielded a Devonian age (389 ± 20 Ma) by U/Pb methods (Dallmeyer, 1979). Kean (1976) initially considered these granitoid rocks as intrusive into Bay du Nord metasedimentary rocks, but subsequently re-interpreted them as sialic basement migmatized and remobilized during the emplacement of later granitic rocks (Kean, 1977). Intrusive contacts are nowhere exposed but unit boundaries may be approximately located by regional aeromagnetic anomalies (G.S.C., 1968) (Figure 4).

Gabbro, diorite and minor felsic differentiates form a northeast trending body in the northwest and north-central parts of the map area. This gradational mixture of intrusive rocks is medium grained, undeformed and may belong to either the Lloyds River Intrusive Suite or the Boogie Lake Complex (Kean, 1983). Intrusive contacts with Victoria Lake Group or King George IV Lake Complex rocks are not exposed but ophiolitic xenoliths have been described (Kean, 1983). No thermal metamorphic effects are noted in Windsor Point Group rocks and an unconformable contact is interpreted (Kean, 1983).

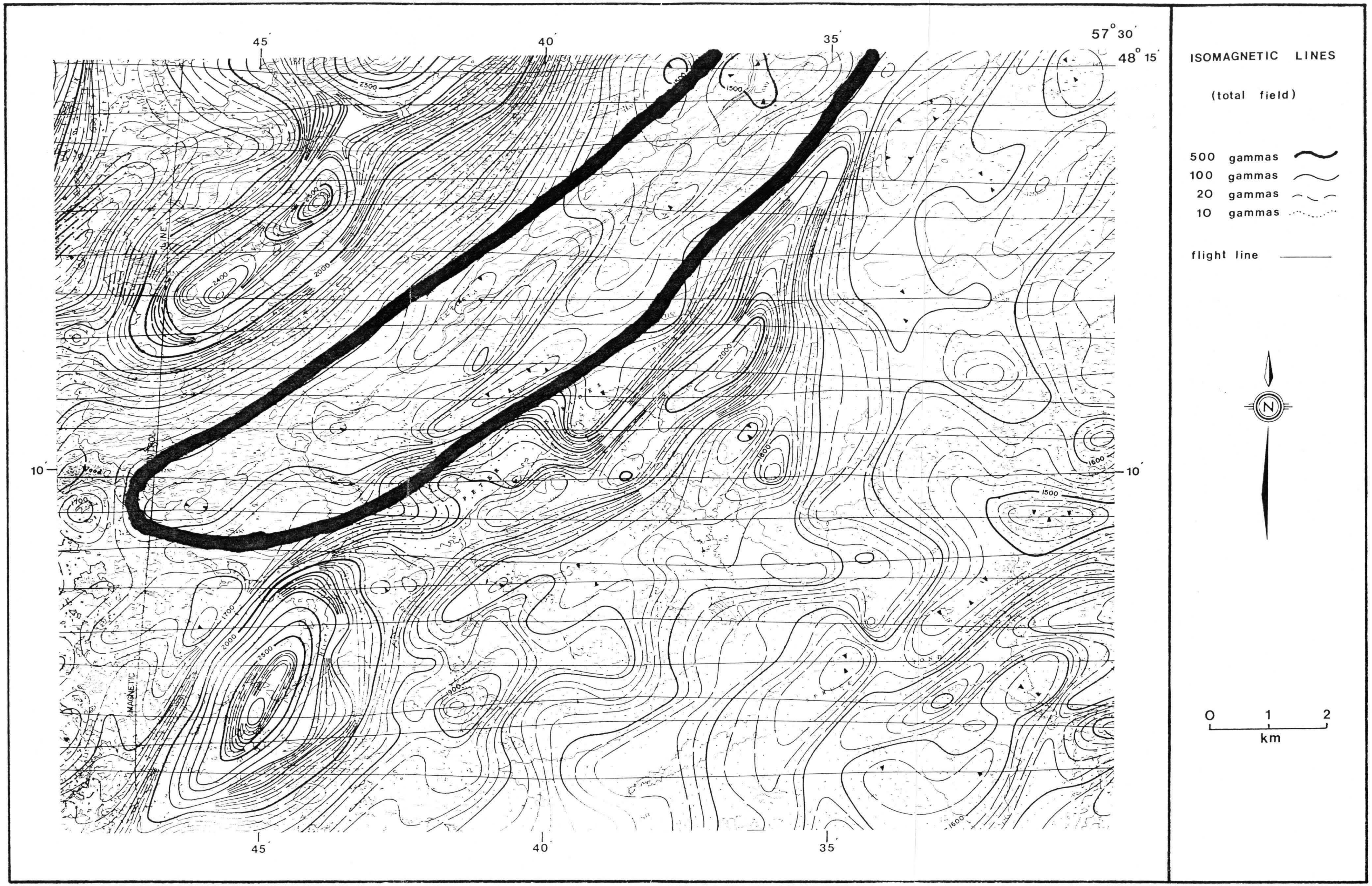
Buck Lake megacrystic granite is typically undeformed but locally displays cataclastic fabric (Kean, 1983; van Berkel et al, 1986). It occurs in the southwest corner of the map area and cross-cuts foliated granite, recrystallized mylonite and Bay du Nord Group gneiss around Peter Strides Pond. The megacrystic granite is undated but Kean (1983) suggested it is Silurian or later in age because it is lithologically similar to Devonian granites which occur throughout central Newfoundland. He proposed an unconformable contact with Windsor Point Group rocks.

Mylonitized country rocks of variable composition form two northeast trending, parallel zones across the centre of the map area. These high strain, ductile zones may be splays of the Cape Ray Fault (Chorlton, 1980; Kean, 1983; van Berkel et al, 1986).

2.4 STRUCTURE

Kean (1983) recognizes two structural packages in the King

Figure 4: Intrusive contacts of the granitoid are not exposed but the heavy line represents the granite boundary inferred from aeromagnetic patterns. The pluton does not significantly extend beyond the southwest corner of the study area (After Geological Survey of Canada, 1968).



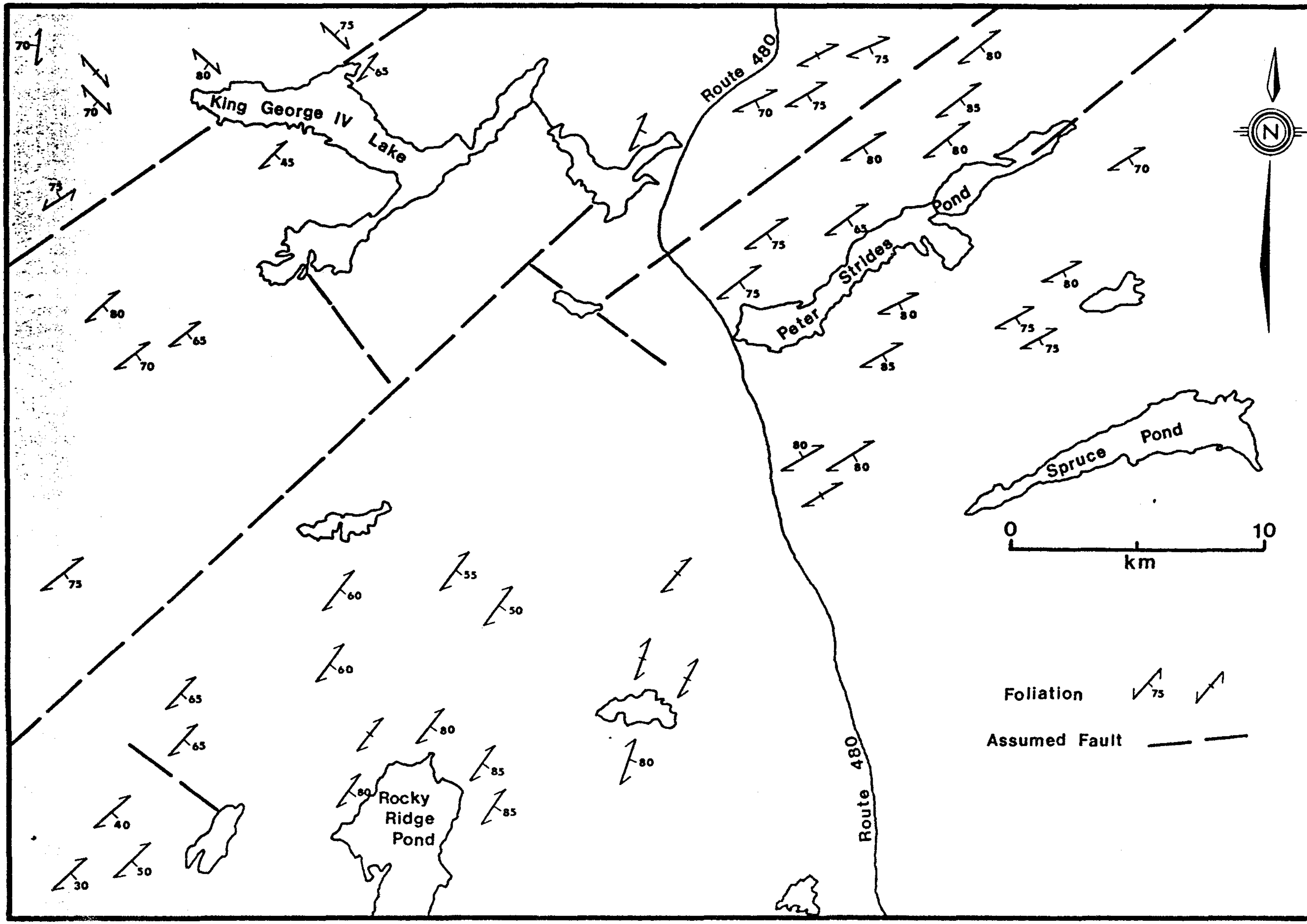
57° 30'
48° 15'
45'
40'
35'
10'
ISOMAGNETIC LINES
(total field)
500 gammas
100 gammas
20 gammas
10 gammas
flight line
N
0
1
2
km

George IV Lake map area and describes each individually (Figure 5).

Complex, polyphase deformation of the Cormacks Lake Complex paragneiss first produced a northwest structural grain defined predominantly by gneissic bands which later have been folded about northeast trending surfaces. Type 1 and type 3 interference fold patterns (Ramsay, 1967) are common. Late, northwest trending folds have been seen locally. Herd and Dunning (1979) recognized these folding phases in the same rock unit in the adjacent Puddle Pond map area. This local northwest structural trend has been attributed to the Grenville Orogeny (Kean, 1983). Remobilization, Appalachian overprinting and the intrusion of younger rocks have occurred subsequently.

Kean (1977; 1983) notes that simple, single phase to complex, polyphase deformational episodes have affected other lithological units in the region and resulted in the northeastern trend typical of the Appalachian structural province. Three separate phases of deformation have been recognized. Localized, late events are also known. The earliest event interpreted from the polydeformed Bay du Nord and Victoria Lake Groups was the variable formation of metamorphic layering/mineral segregation and micaceous foliation. Kean (1983) considers this layering as amplification of pre-existing, planar structures. Chorlton (1980) reports that tight folding and shear zone development

Figure 5: Structural attitudes define two separate packages in the King George IV Lake map area; an early, northwest striking structural grain about Cormacks Lake and the regionally extensive, northeast structural grain typical of the Appalachians in southwestern Newfoundland (Summarized after Kean, 1983).



King George IV Lake
Route 480
Peter Strides Pond
Spruce Pond
Rocky Ridge Pond
N
0
10
km
Foliation
Assumed Fault

accompanied this deformational event in areas south of the King George IV Lake map area. Early structures were overprinted by the main, regional foliation. This inhomogeneously developed fabric is associated with isoclinal, northeast plunging folds (Kean, 1983).

Major faults and shear zones were initiated or re-activated during this episode of deformation. Windsor Point Group deposition is confined to a narrow zone bounded by two such faults. This group rests unconformably against adjacent units to record a major structural and stratigraphic break in the area. Later deformational events formed open folds having northeast striking axial surfaces but no axial planar penetrative fabrics. These effects are of restricted areal extent and may represent movement confined to pre-existing faults (Kean, 1983).

2.5 METAMORPHISM

Metamorphism varies in nature and degree across different parts of the King George IV Lake map area. The metamorphic grade increases toward the south from greenschist, through middle amphibolite, to upper amphibolite facies. Facies boundaries are coincident with narrow, regional scale ductile deformation zones.

2.6 ECONOMIC GEOLOGY

Recent investigations of regional scale faults and adjacent lithologies (Brown, 1973; Chorlton, 1980; 1983; Kean, 1983; van Berkel et al, 1986; and others) suggest a favourable environment for hosting economic concentrations of base metals, PGE and gold in the southern Long Range Mountains of southern Newfoundland.

The study area lies 60 km NNE of Chetwynd and 90 km SW of Buchans (Figure 1). This location, between two established mining camps has been investigated by several mining interests. Ductile shear zones adjacent to felsic volcanic rocks and extensive quartz-carbonate veining with well developed carbonate/epidote alteration are noted across the study area. This initally suggests a positive potential for economic mineralization. However, significant mineralization has not been seen in the study area (Appendix II, Part D). Sulphide minerals are rare, distributed erratically and are not associated with any one specific rock type or structure. Currently, the economic potential of the area is assessed as low.

CHAPTER 3: LOCAL GEOLOGY

3.1 GENERAL STATEMENT

During the current study, mapping was conducted at 1: 12,500 scale with colour, aerial photographs and compiled to 1: 25,000 scale base sheets (Map Pocket). Subsequent to the regional examination, attention was focused on two major shear zones and the form of various populations of quartz veins which occur across the study area. Contrary to Kean (1983), no significant variations between units were noted in the field and therefore, mapping did not distinguish between mafic, volcanic/hypabyssal rocks of the Victoria Lake Group and the King George IV Lake Complex. Field nomenclature is applied to rock descriptions and when applicable, correlated to Kean's (1983) stratigraphic scheme.

3.2 LITHOLOGY

A regional investigation across the study area identified ten lithologic units; granoblastic gneiss, heterolithic conglomerate, basalt with minor intercalated intermediate to felsic tuff, rhyolite, gabbro, diabase, adamellite/granodiorite, megacrystic granite and two mylonitic zones to be discussed later (Appendix II, Parts A & B). Geological contacts between units are typically assumed and approximate but grossly parallel the northeast-southwest structural grain of the area.

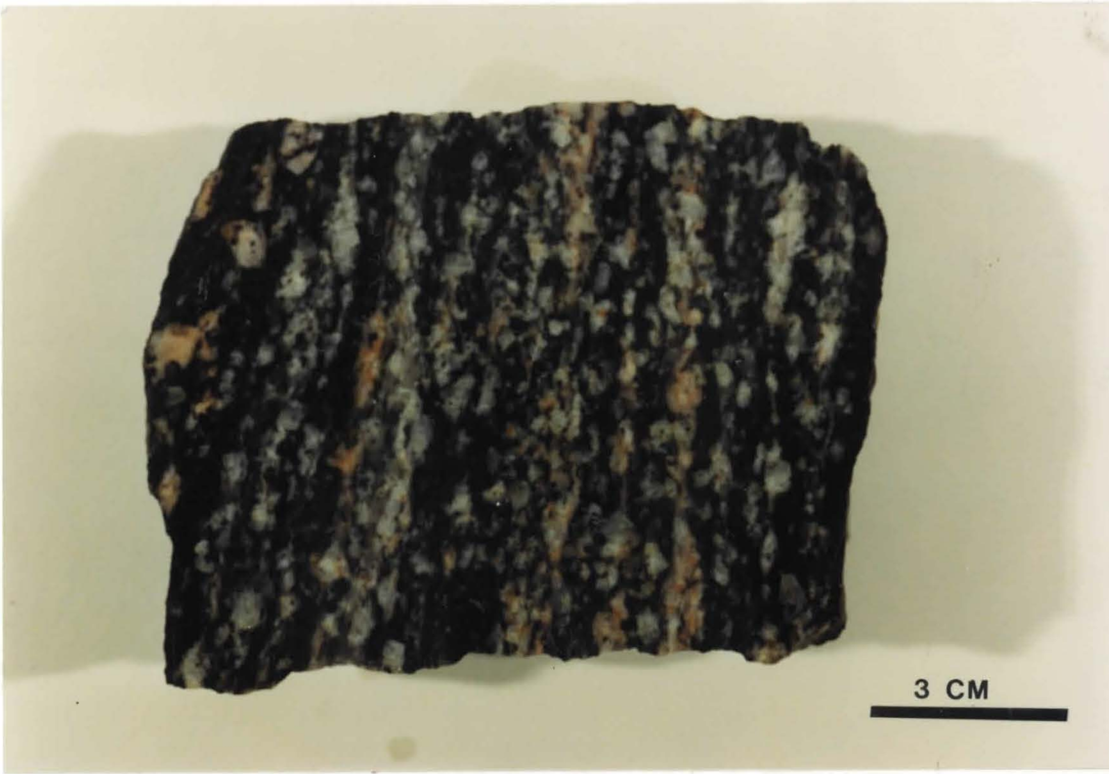
Granoblastic gneiss occurs south of Peter Strides Pond. It extends south and east beyond the study area and is considered by Kean (1983) as part of the metasediments of the Bay du Nord Group. The rock is very hard, resists sampling and is massive to weakly foliated/banded (Plate 1). Weathered surfaces are typically dark grey with minor buff to white mottling. Fresh surfaces are pale grey, medium to coarse grained, with crystals equigranular and interlocked. Colour index is 50. Biotite-rich lenses form discontinuous and diffuse "mica hairs" throughout the unit. Locally, millimeter to centimeter scale compositional layers are noted perhaps mimetic after bedding. Round, red garnet is an accessory mineral. A weak mineral lineation is defined by rare, elongate quartz aggregates. Slickenstriations defined by quartz and feldspar are common. Foliation parallel, milky quartz veins, locally with up to 10% biotite, weather in positive relief and are less than 5% of any exposure. In thin section, (Plate 2) granular, leucocratic bands, 2 to 3 mm wide, are composed of quartz, alkali feldspar and minor biotite. Medium to coarse grained, anhedral quartz shows irregular and sutured grain boundaries with partial subgrain development. Fresh ?orthoclase is subhedral, 0.5 mm in length, may show simple twinning and includes unstrained quartz and subhedral biotite. Locally, inequant quartz and alkali feldspar display preferred shape orientation which defines a weak to moderate foliation parallel to layering.

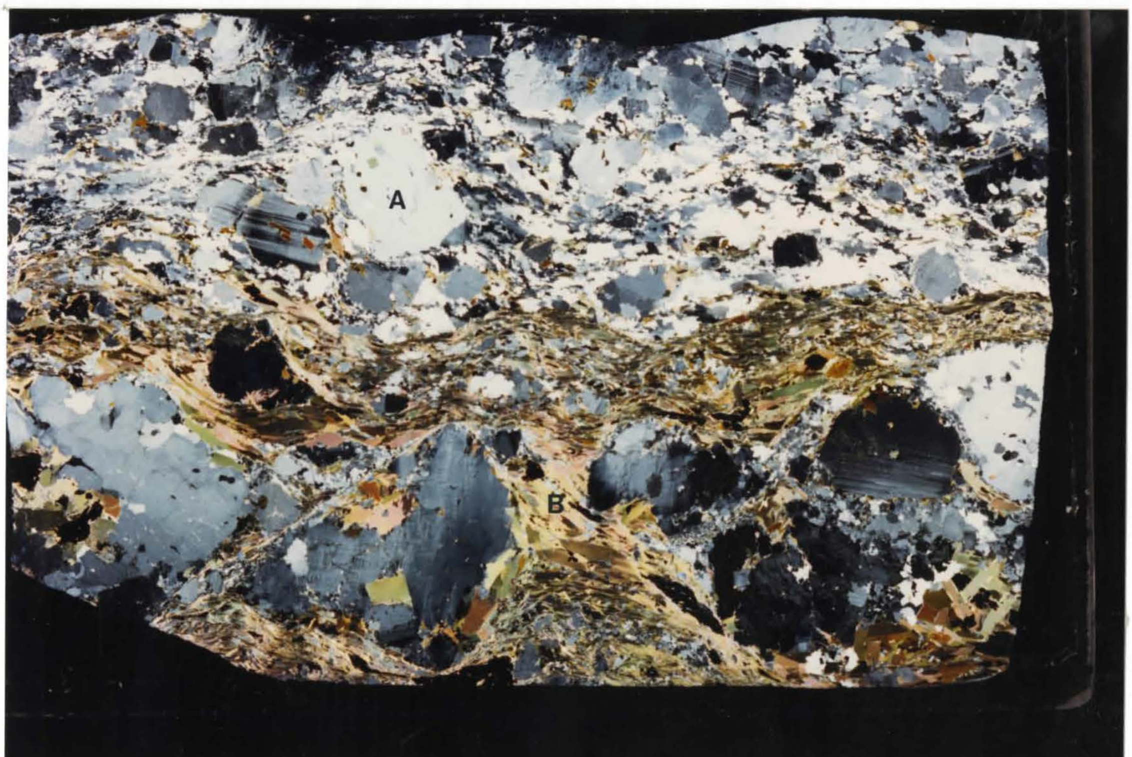
Plate 1: Typical handsample of coarse grained, granoblastic gneiss with (A) discontinuous, wispy biotite concentrations termed "mica hairs".

Plate 2: Photomicrograph of granoblastic gneiss in polarized light.

(A) Granular, leucocratic band of quartz, alkali feldspar and minor biotite shows interlocked and embayed grain boundaries.

(B) Melanocratic band of biotite, plagioclase, muscovite, minor quartz and chlorite displays shredded biotite wrapped about rigid plagioclase grains.





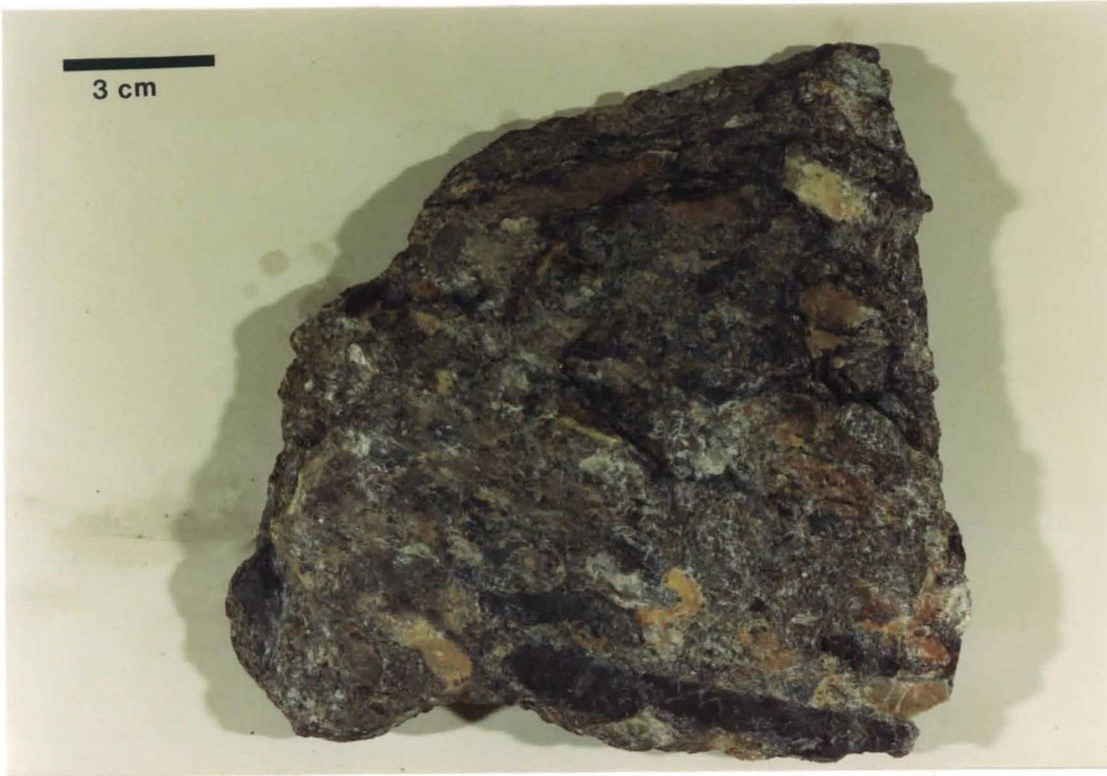
6 MM

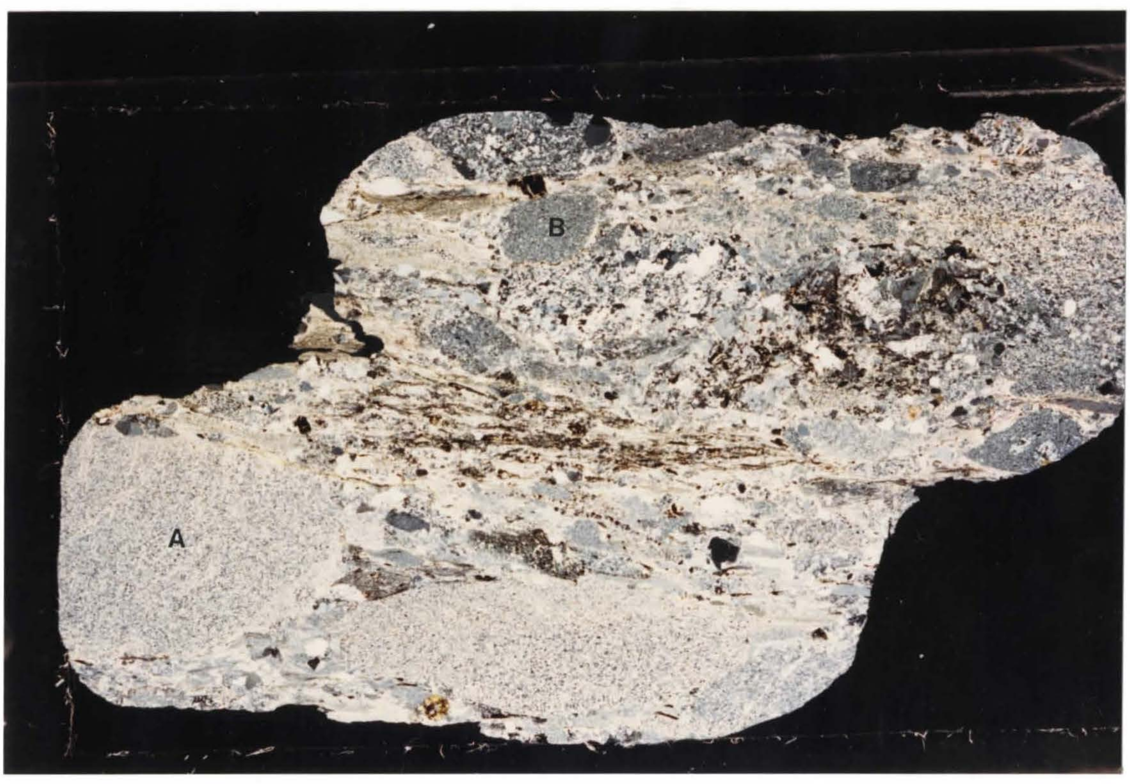
Minor, pleochroic brown biotite, variably altered to chlorite, augments the foliation. Melanocratic bands are 0.5 to 5 mm wide, dominated by biotite with minor quartz, plagioclase, muscovite, chlorite and rare hornblende. Pleochroic brown biotite with grain lengths up to one cm defines a moderate foliation parallel to layering. Green hornblende is randomly oriented and ragged. Quartz is anhedral with sutured/serrated boundaries and undulose extinction. Some individual quartz grains are elongate and augment biotite foliation. Equant garnet is euhedral to 3 mm in diameter and has overgrown biotite and quartz. Coarsest garnet is wrapped by the adjacent foliation. Opaque Fe oxides,in trace quantities, are anhedral and randomly distributed through all compositional bands.

Poorly exposed, fissile heterolithic conglomerate outcrops northwest of the Victoria River. It is a purple to steel grey, unstratified, matrix supported unit containing unsorted, subangular to subround, equant clasts of mafic and felsic volcanic rocks (Plate 3). Clasts may be up to 10 cm in diameter. Regional foliation is defined by a well developed slaty cleavage striking northeast. Milky quartz and quartz-carbonate veins may parallel this fabric. Clasts appear undistorted relative to cleavage. Intercalated with the conglomerate are lenses of fine grained, massive, buff to light grey sandstone. No sedimentary structures have been observed. Kean (1983) correlates this unit with the Rodgerson

Plate 3: Typical unsorted, unstratified, matrix supported heterolithic conglomerate.

Plate 4: Photomicrograph of heterolithic conglomerate in polarized light with the matrix supporting both sedimentary (**A**) and volcanic (**B**) clasts.





6 mm

Lake Conglomerate. Petrographically, (Plate 4) clasts appear evenly divided between sedimentary and mafic, volcanic fragments. Sedimentary clasts are fine grained and show feathery to ragged margins. Volcanic clasts are fine to medium grained and very much altered. Rare, medium grained granite and rounded, unstrained quartz clasts are noted. The supporting matrix is a uniform, very fine grained, felted mass predominately of ?sericite and ?chlorite.

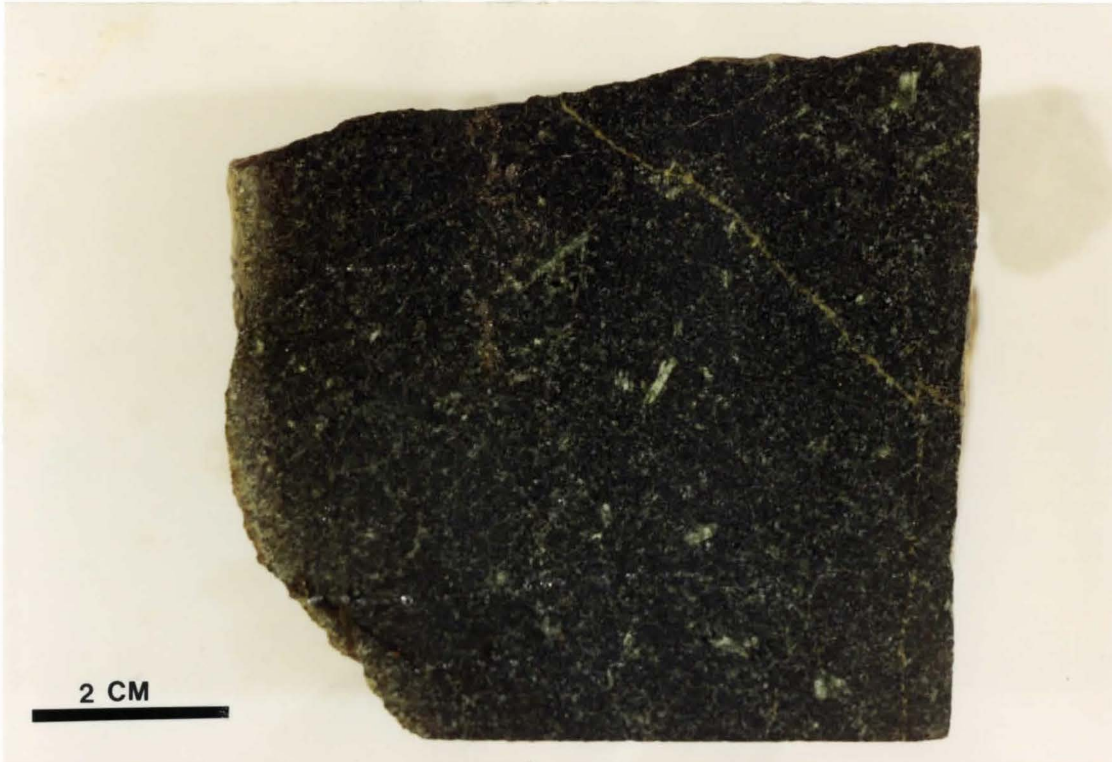
No sandstone thin sections were examined.

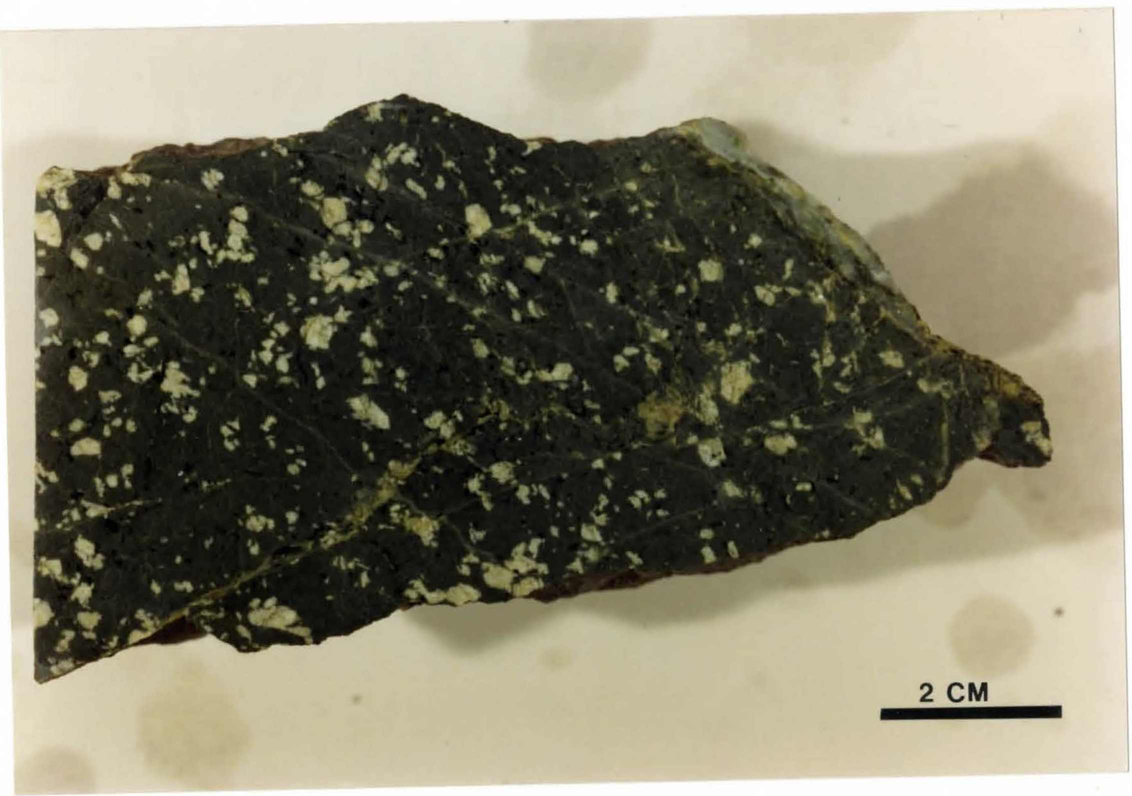
Fine grained, poorly exposed basalt predominates from Twin Ponds to the Victoria River. Weathered surfaces are dark green; fresh surfaces are pale green and may be sugary (Plate 5). It is typically massive but some outcrops display well developed, anastomosing, scaly cleavage in narrow zones which impart a fissile nature to exposures. Homogeneous basalt reacts with dilute HCl due to disseminated carbonate. Local volumes contain 1-2 mm long, equant, subangular phenocrysts randomly oriented in the supporting matrix (?crystal tuff or ?variolitic lava) (Plate 6).

Some portions of this unit are composed of well rounded, non-vesicular pillows, mainly less than 30 cm in diameter. Pillow rims are brown, fissile and 0.5-1 cm thick composed of chlorite which weathers in positive relief (Plate 7). Small fractures are short and radially disposed about pillow margins. Scaly cleavage does not offset/disturb pillows. Minor quartz and quartz-carbonate lenses occur throughout the

Plate 5: Exposures of basalt across the study area are typically massive and homogeneous.

Plate 6: Local intervals of basalt display groundmass supported, equant, angular plagioclase phenocrysts, 1 to 2 mm in diameter.


2 CM


2 CM

unit. Weak, down-dip lineations occur in some fissile exposures. Intercalated with basalt is minor, fine grained, intermediate to felsic tuff. Angular, lithic fragments appear flattened, welded and interlocked. In thin section, (Plate 8) fine grained, basalt is moderately to completely altered and appears as a uniform, dark, felted mass. Plagioclase forms unzoned, twinned laths, is 0.2 mm long and subhedral. Optical determination of plagioclase composition reveals labradorite to bytownite $An_{(50-70)}$. Coarse epidote grains recrystallized after original plagioclase phenocrysts are randomly distributed through the matrix. Epidote, calcite, opaque Fe oxides and chlorite form the structureless groundmass.

No tuffs were examined in thin section.

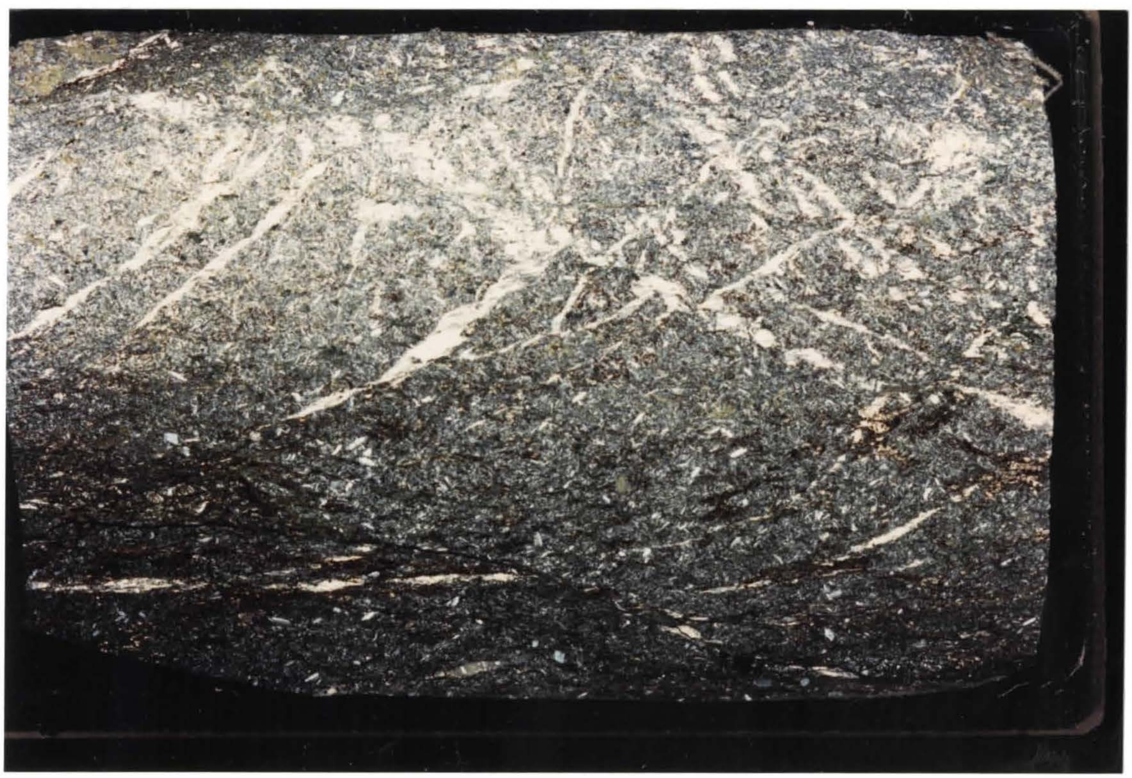
Fine grained, red <u>rhyolite</u> crops out on a small hilltop immediately south of Twin Ponds (Plate 9). Kean (1983) regards this unit as a felsic volcanic component of the Windsor Point Group. It is very competent and resists sampling. No internal variation, quartz veins or cleavage have been seen.

Massive rhyolite was not examined petrographically.

Melanocratic <u>gabbro</u> outcrops as an oblong body north of Boogie Lake and occurs as small, scattered lenses/pods within basalt south of Twin Ponds. The unit is considered part of the King George IV Lake Complex (Kean, 1983). Massive, medium to coarse grained, equigranular gabbro is buff to brown on

Plate 7: Round, non-vesicular pillows have brown, fissile chlorite selvages which weather in positive relief. Inter-pillow material is negligible.

Plate 8: Photomicrograph in polarized light of massive, homogeneous basalt. It is a uniform, dark, felted mass except for variable, pervasive carbonate alteration.



6 MM

weathered surfaces, dark green to black on fresh surfaces (Plate 10). Hornblende up to 3 cm long is common in coarse grained intervals. Narrow, straight, sharp walled dykes of fine grained felsite (?aplite; ?trondhjemite) cut across the gabbro. Milky quartz ($\pm$ carbonate$\pm$sulphide) lenses less than 5 cm long weather in positive relief. No igneous textures (cumulate layering, chilled margins etc.) have been noted. In thin section, (Plate 11) gabbro shows an overall hypidiomorphic, granular texture. Pleochroic green-brown hornblende is anhedral to subhedral up to 2 mm in diameter with simple twins. Largest hornblende grains have irregular grain boundaries and are embayed by green chlorite. Tabular, euhedral plagioclase is typically 2 mm long (up to 4.5 mm long), of labradorite to andesine composition. Minor, unstrained quartz is anhedral and interstitial to other constituents. Accessory clinopyroxene has ragged grain boundaries and is deeply embayed by green fibrous chlorite and granular hornblende. Brown biotite as feathery, serrated grains, is intergrown and embayed with purple-blue chlorite and includes quartz and plagioclase. Carbonate, epidote and sericite occur in trace amounts as secondary minerals.

Felsite dykes were not examined petrographically.

Massive, aphanitic to fine grained diabase occurs as rounded knobs east-southeast of Boogie Lake. Kean (1983) treats this as another component of the King George IV Lake Complex. Weathered surfaces are dark grey-green; fresh

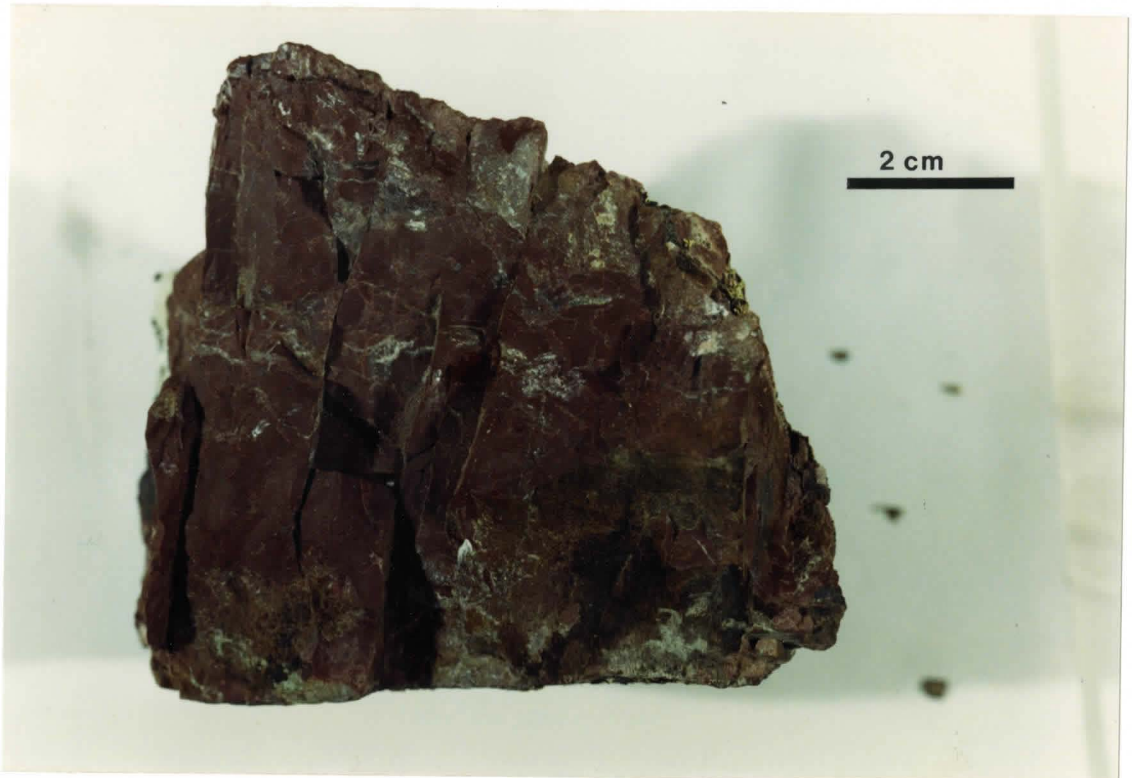
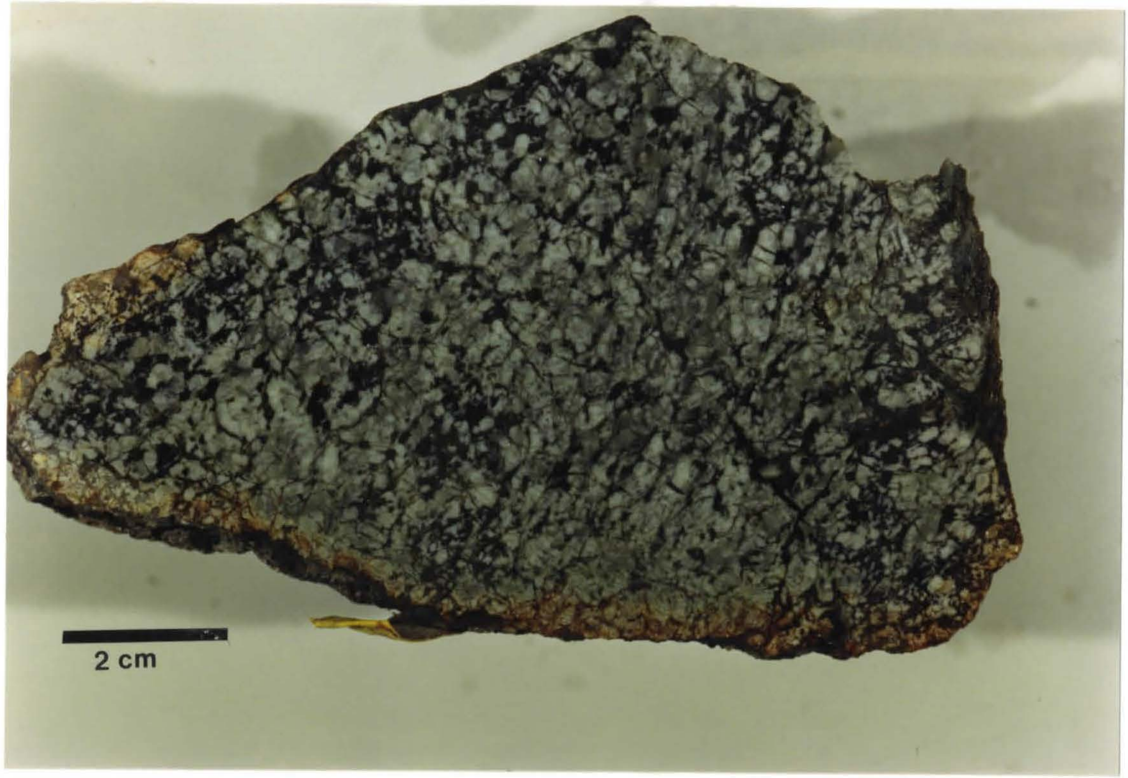
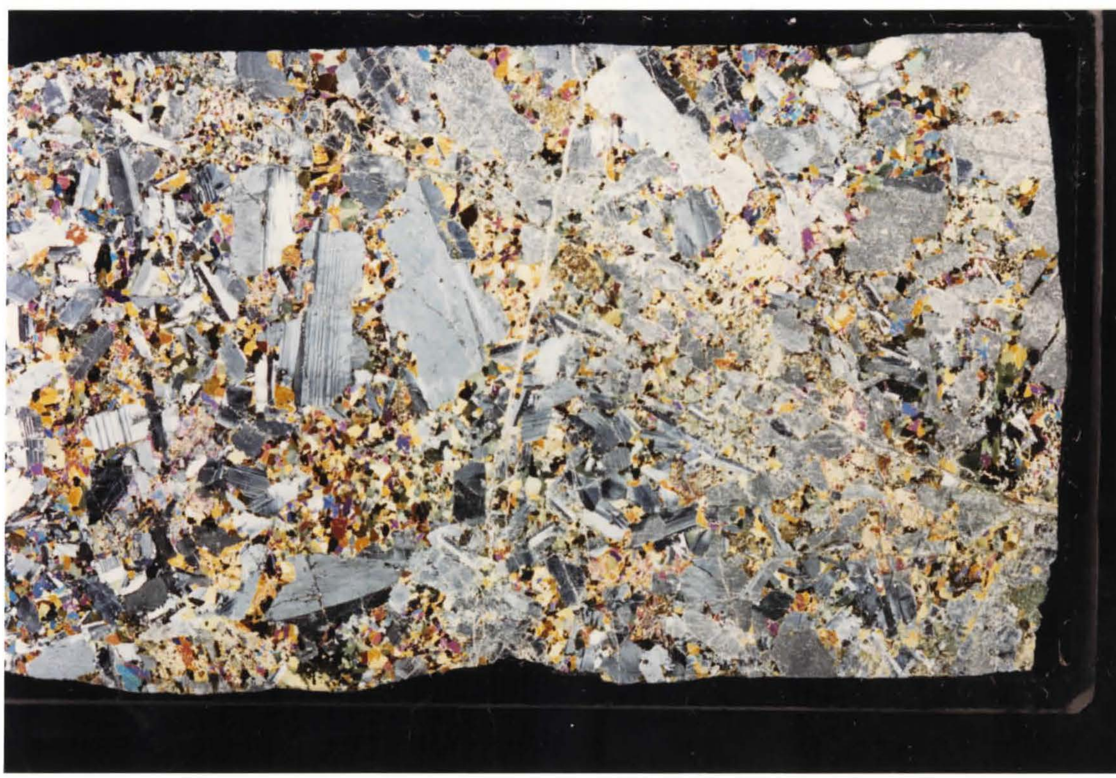


Plate 9: Typical handsample of massive, homogeneous red rhyolite.

Plate 10: Typical handsample of massive, coarse grained gabbro.

Plate 11: Photomicrograph of medium to coarse grained, hypidiomorphic, granular gabbro in polarized light.





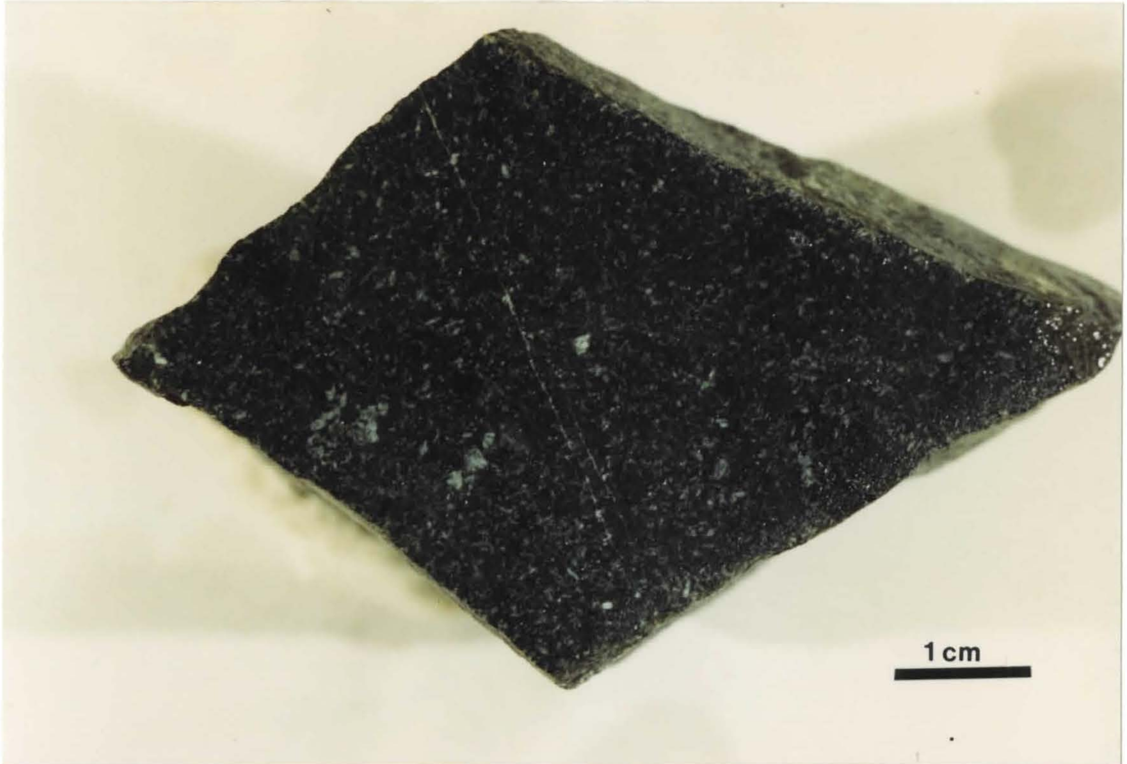
6 mm

surfaces are light green and sugary (Plate 12). Diabase is typically homogeneous and aphyric but local intervals are plagiophyric with randomly oriented, elongate plagioclase phenocrysts up to one mm in length. Pale green epidote pods and veins less than 40 cm thick cross-cut the diabase in all orientations. Petrographically, (Plate 13) fine grained intervals have a uniform, matrix of opaque Fe oxides, green chlorite, carbonate and ?epidote as a dark, intergrown mass. This matrix supports rare, euhedral plagioclase phenocrysts up to one mm in diameter with simple twins. No other fabric, texture or compositional variations are noted.

Felsic intrusive rock is exposed north of Peter Strides Pond as a linear body. It is subdivided into leucocratic adamellite (Plate 14) and mesocratic granodiorite (Plate 15). Adamellite weathers pink to chalky white and contains both muscovite and biotite. Granodiorite is typically greyish black and locally displays millimeter scale compositional pin stripes. Dispersed, accessory garnet is round and red. Both units are medium grained, equigranular, have interlocked grain boundaries and are moderately to well foliated by the alignment of anastomosed mica and elongate, positively weathering quartz plates. Foliation is defined by parallel, milky to glassy, quartz, quartz-carbonate and quartz-biotite veins as 5-10% of any exposure. No lineation has been seen. In thin section, (Plate 16) hypidiomorphic, granular texture is typical of adamellite. Anhedral to subhedral quartz 1-3

Plate 12: Typical handsample of fine to medium grained, massive, homogeneous diabase.

Plate 13: Photomicrograph in polarized light of fine grained diabase showing an interlocked, granular, hypidiomorphic texture.

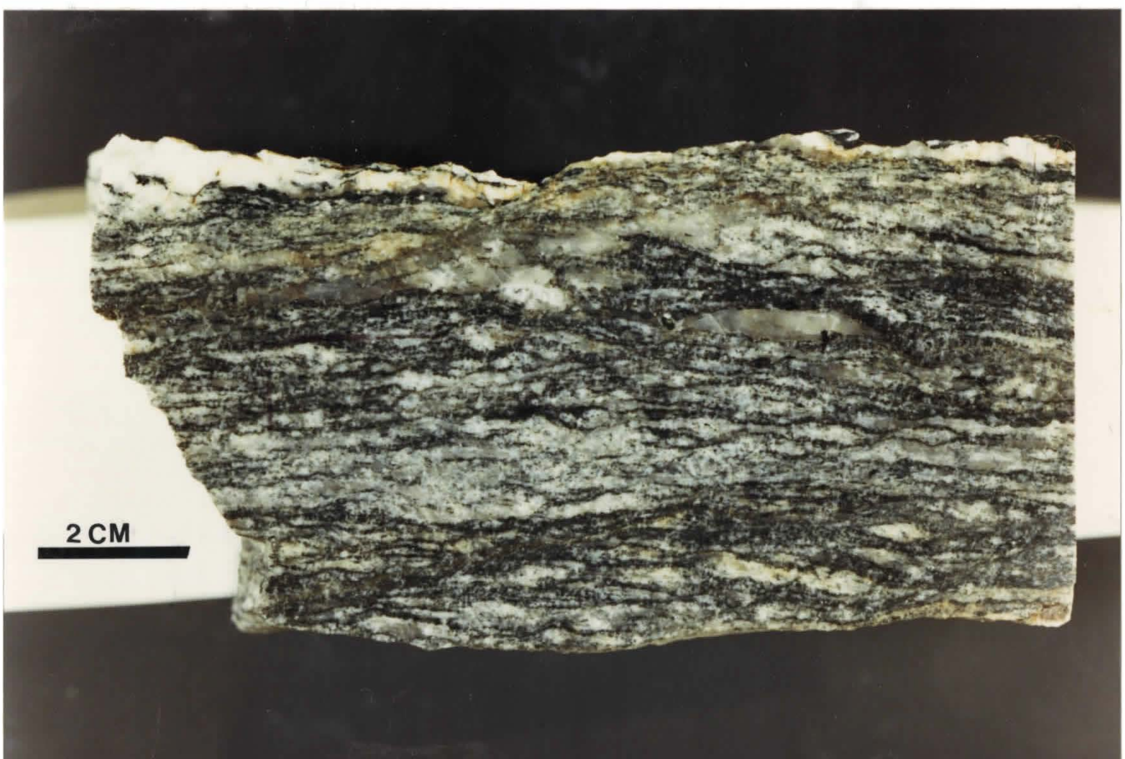


6 mm

Plate 14: Typical adamellite handsample shows moderate foliation defined by elongate quartz and aligned biotite.

Plate 15: Typical granodiorite handsample shows well defined foliation by wispy compositional layers and parallel mica.


3 CM


2 CM

mm in diameter, occurs as interstitial grains with strained extinction and common subgrain development. In zones of local increased strain, quartz becomes elongate as very fine grained (recrystallized) ribbons. Subhedral microcline grains show perthitic texture locally and become more rounded, fractured and displaced with increasing strain. Rare, crypto-crystalline (?crushed) tails form anastomosing fabrics about quartz and feldspar augen. Subhedral oligioclase is simply twinned and may show serrated grain boundaries. Elongate biotite is pleochroic brown and variably altered to green chlorite. Muscovite (up to 10% modally) is intergrown with biotite as ragged flakes. Similar textures are to be seen in granodiorite (Plate 17). Biotite is more abundant and more altered. Green hornblende is present locally. Rare cataclastic intervals show feldspar granulated, recrystallized quartz trails as linear ribbons with undulose extinction and smeared biotite.

Poorly exposed, undeformed megacrystic granite crops out at the southeast end of Peter Strides Pond and extends to the south beyond the study area. It cross-cuts pink, biotite-adamellite. Kean (1983) names this unit Buck Lake Granite. Weathered surfaces show a dull grey, equigranular matrix supporting white, 2-3 cm long feldspar megacrysts (Plate 18). Fresh surfaces are light grey, interlocked and massive. Typically random, block-like phenocrysts become elongate and parallel to locally define a weak, patchy foliation.

Plate 16: Photomicrograph of medium grained adamellite in polarized light with a granular, interlocked matrix. Quartz is equant and feldspar is not granulated.

Plate 17: Photomicrograph in polarized light of medium grained granodiorite showing a moderate foliation defined by parallel biotite, elongate quartz and minor granulated feldspar.

6 MM

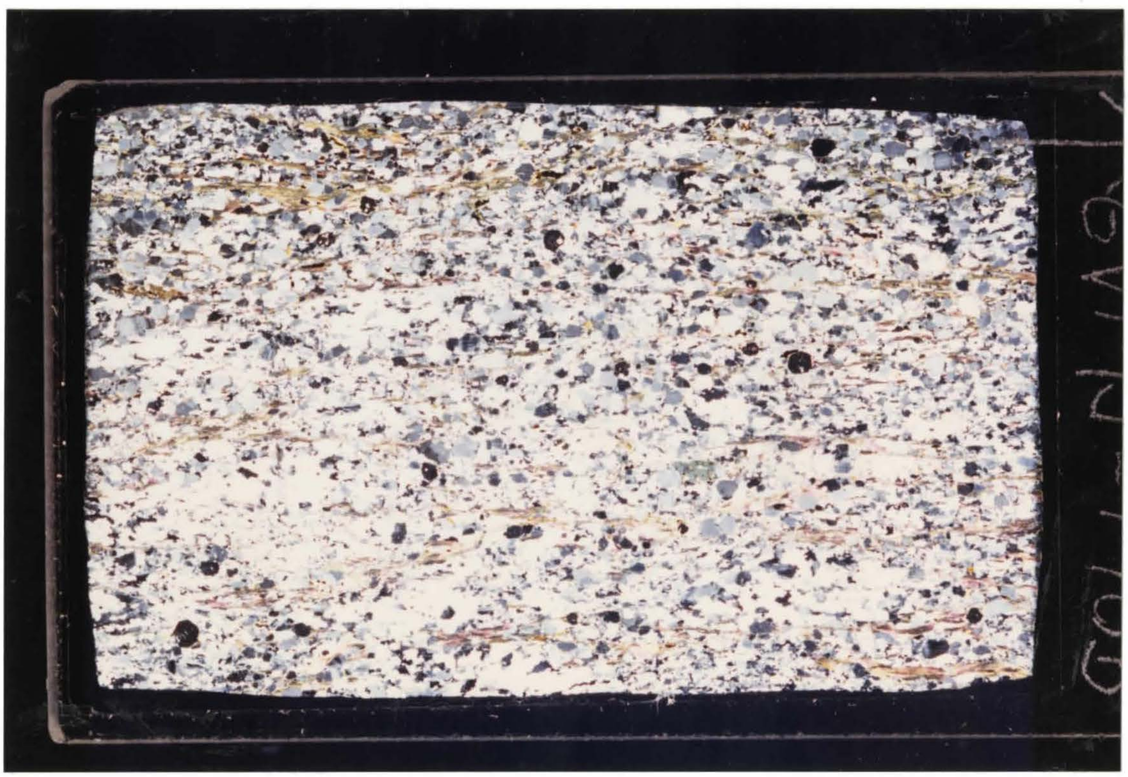
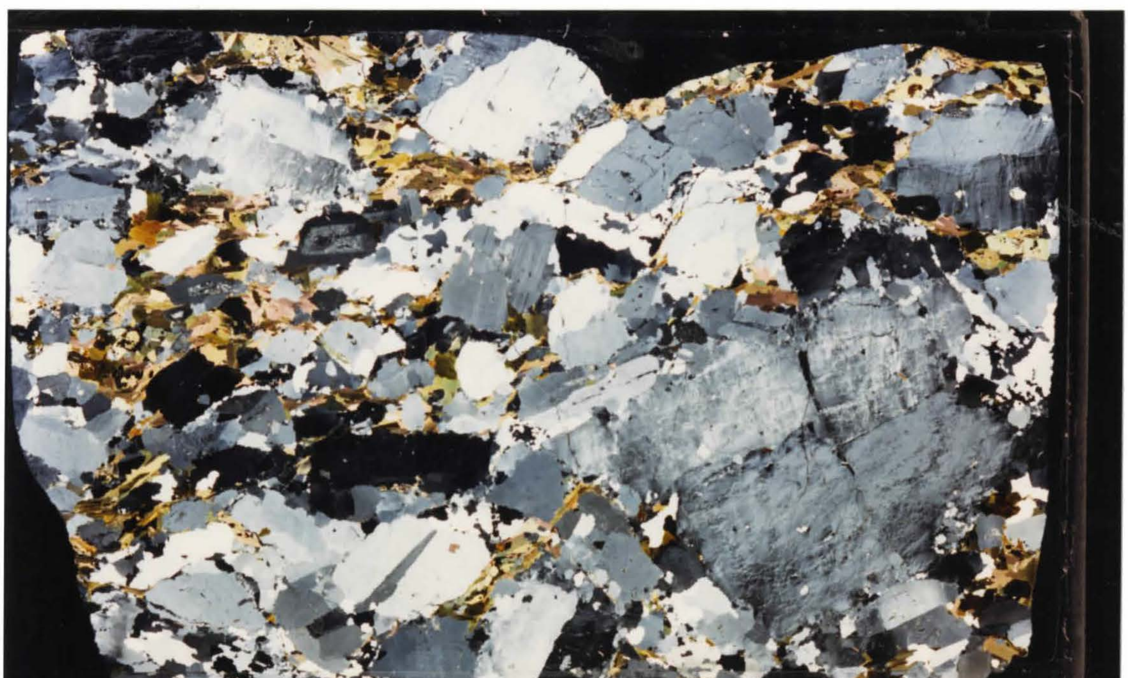


Plate 18: Massive megacrystic granite displays an equigranular matrix supporting 2-3 cm long, blocky phenocrysts.

Plate 19: Photomicrograph of megacrystic granite in polarized light displays equal proportions of quartz and alkali feldspar with undulose extinction and sutured grain boundaries. Interstitial biotite may show chloritic alteration at grain margins.



1 cm

Petrographically, (Plate 19) quartz, alkali feldspar and plagioclase are of approximately equal abundance. Biotite is the primary mafic component at 10% modally. Rare, pleochroic green hornblende is present. Euhedral quartz up to 15 mm in length has undulose extinction and sutured grain boundaries. Fine grained quartz is subhedral and interstitial to other minerals in the porphyritic, hypidiomorphic, granular matrix. Locally, quartz may include biotite flakes. Alkali feldspar as microcline ranges from anhedral, interstitial grains to euhedral, prismatic megacrysts. Megacrysts up to 20 mm long show perthitic twins. Twinned oligoclase forms suhedral to euhedral prismatic grains and phenocrysts up to 10 mm in diameter. Plagioclase grain boundaries may be embayed by epidote, carbonate and sericite. Biotite is pleochroic brown with purple-blue chloritic alteration at the margins. Ragged muscovite is intergrown with biotite. Accessory, opaque Fe oxides are anhedral and uniformly distributed throughout the unit.

3.3 METAMORPHISM

Regional metamorphism displays a stepwise increase in grade across the King George IV Lake map sheet (Table 2). Metamorphic "breaks" are coincident with regional scale deformation zones and may represent progressively deeper levels of the crust uplifted and presently exposed at a common level. In the north part of the study area, between Twin

Ponds and the Victoria River, metamorphic grade in Victoria Lake Group mafic volcanic rock is at or below greenschist facies. Grade is defined by the observed mineral assemblage of chlorite-labradorite-calcite-epidote and minor quartz. Retrograde chlorite, epidote and calcite embay and corrode mafic minerals and plagioclase grains. The felsic pluton between the Victoria River and Peter Strides Pond reached low to middle amphibolite facies based on the assemblage quartz-alkali feldspar-biotite-sporadic muscovite and rare actinolite. Amphibole and mica show ragged, irregular grain boundaries and platy to smeared habit. Felsic minerals are typically equigranular and interlocked. Kean (1983) identified a post-regional metamorphic, thermal aureole containing staurolite and cordierite about the granitoid intrusion. Southeast of Peter Strides Pond, upper amphibolite facies predominates in granoblastic gneiss of the Bay du Nord Group as suggested by the occurrence of biotite-quartz-anorthoclase-microcline and quartz.

3.4 STRUCTURE

Irregular fabric development within a single lithology and between adjacent rock types suggests that mechanical response to regional deformation processes across the King George IV Lake map sheet is not uniform. Most major lithologic units display a consistent, northeast strike and steep, southeast to vertical dips. Lineation is uncommon and

METAMORPHIC ASSEMBLAGES

BASALT	chlorite plagioclase biotite epidote sericite muscovite calcite
ADAMELLITE	quartz K feldspar plagioclase biotite muscovite hornblende garnet sphene
GNEISS	biotite quartz K feldspar plagioclase hornblende garnet sillimanite muscovite

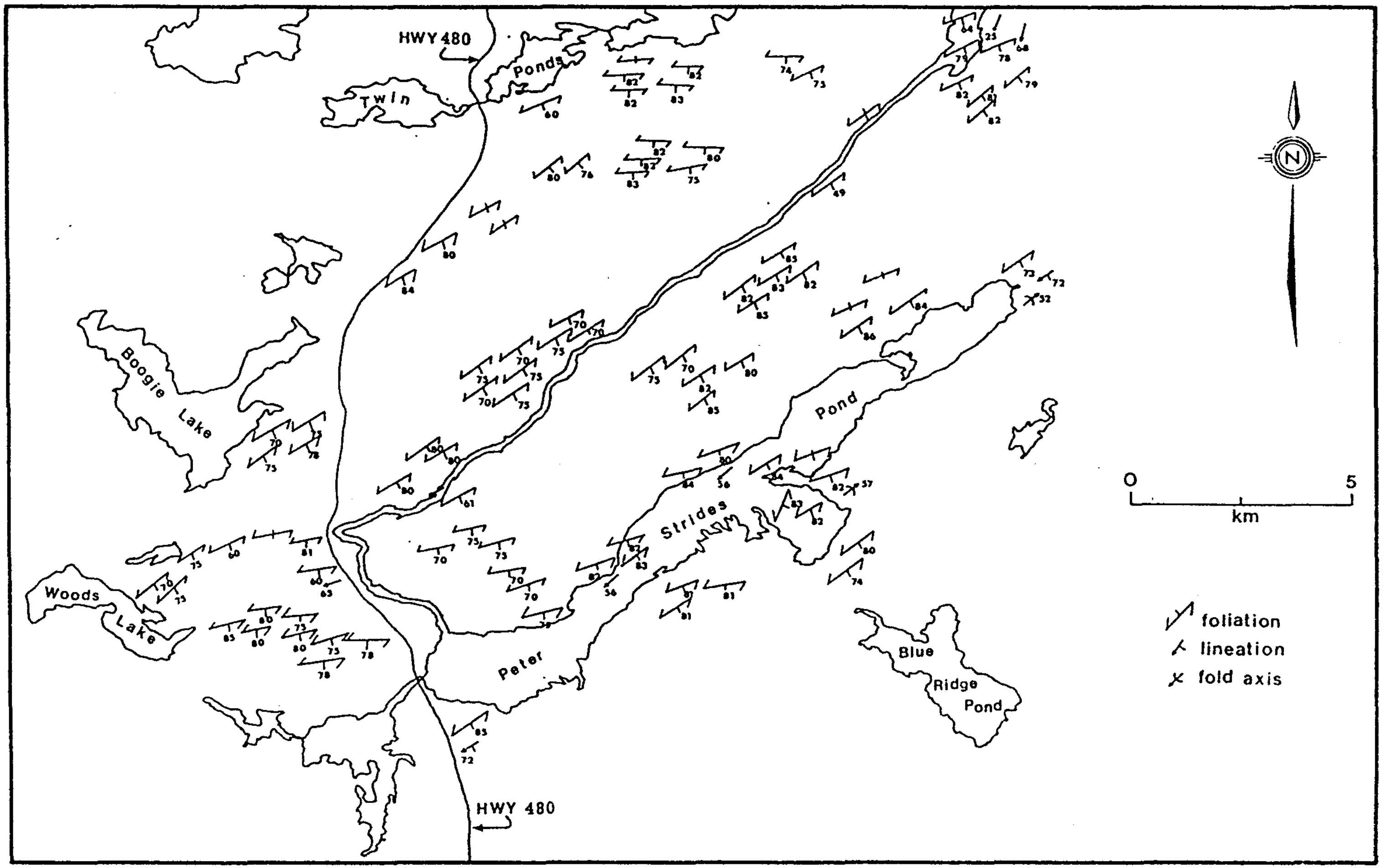
Table 2: Typical maximum phase mineral assemblage for the most abundant rock type within each metamorphic zone across the study area.

poorly defined; it plunges at moderate to steep angles to the southwest. Rare minor, small scale, asymmetric folds were noted locally; axes plunge southeast at shallow angles (Figure 6).

An erratically distributed, scaly fissility has developed in volcanic rock south of Twin Ponds. It is defined by chlorite in mafic compositions, chlorite and sericite in intermediate to felsic intervals. This foliation becomes more intense as the Victoria River is approached. Heterolithic conglomerate north of the Victoria River has a typically phyllitic matrix; rarely it may show an obscure lineation. Matrix supported clasts appear relatively unaffected by deformation, they are not significantly extended parallel to the lineation. Felsic intrusive rock north of Peter Strides Pond displays a moderate to well defined foliation defined by mica, platy quartz and rarely by alkali feldspar. Nebulitic banding and weak lineation in coarse grained gneiss south of Peter Strides Pond is poorly defined but overprints any original fabric. Gabbro, diabase and minor rhyolite display no indication of penetrative, regional deformation.

Two ductile deformation zones parallel the regional structural grain. They will be described in detail and their tectonic significance will be addressed later in the text.

Figure 6: Most lithologies display a consistent NE strike and steep SE to vertical dips. Lineation is uncommon and obscure.


HWY 480
Twin
Ponds
Boogie Lake
Woods Lake
Peter Strides Pond
Blue Ridge Pond
HWY 480
0
5
km
N
foliation
lineation
fold axis

CHAPTER 4: ECONOMIC GEOLOGY

4.1 GENERAL STATEMENT

Plate tectonic concepts can predict the very broad type of lithological and structural assemblages generated by plate interactions. It cannot predict favourable localities for mineralization or even which plate boundaries are likely to be mineralized (Mitchell, 1976). Controversy over deposit genesis makes it difficult to describe the tectonic setting of some occurrences (Sawkins, 1984).

In the Appalachian Orogen, deposit formation, metallogenic patterns and temporal relations have been successfully explained by tectonic processes. Similar zonations are observed in currently active orogenic belts. Older, complex and longer-lived orogens like the North American Cordillera and the East Australian Paleozoic are more difficult to interpret in terms of deposit type versus tectonic setting (Swinden and Strong, 1976; Strong, 1980). Such obscure patterns may be related to later remobilization, destruction of earlier deposits or juxtaposition of unrelated deposits.

4.2 ECONOMIC POTENTIAL IN SOUTHWESTERN NEWFOUNDLAND

The Dunnage zone in southwestern Newfoundland represents the preserved ocean floor and volcanic arc in a convergent plate boundary environment. This compressional tectonic setting has significant potential to host a wide variety of mineral deposit types.

During regional studies and exploration programs, various workers have proposed that the region may host iron, copper, zinc and lead in economic concentrations as volcanic hosted base metal massive sulphide deposits (Brown, 1973; DeGrace, 1973; Dean, 1977; Chorlton, 1980;1983; van Berkel et al, 1986). Island arc intrusive complexes may host porphyry-type copper and molybdenum mineralization within granitoid plutons which show evidence of long-lived, magmatic hydrothermal alteration (Dunning & Herd, 1979; Kean & Jaysinghe, 1981; Whalen & Currie, 1982). Whalen and Currie (1982; 1983) describe S-type granite in the Topsails terrane which exhibits greisen-like alteration and suggest its potential for tin mineralization. Of the myriad of deposit types at compressive plate boundaries, the most favourable exploration targets in southwestern Newfoundland are Kuroko-type (Zn-Pb-Cu) base metal and stratabound/vein-type gold deposits.

Kuroko-type deposits are characterized by the small spacing of separate orebodies and a narrow time-stratigraphic extent (Hutchinson, 1973;1980; Sawkins, 1984). Exploration for this deposit type should be focused at sites identified as the volcanic vent for a complete extrusive cycle of Ordovician age. Brown (1973; 1975), Chorlton (1980; 1983) and others describe such an environment which should be considered for base metal investigation. Buchans is a productive example of the Kuroko-type deposit in southwestern Newfoundland.

Significant Ordovician mafic to intermediate magmatic rocks about the Cape Ray Fault and similar structures (Brown, 1975; Chorlton, 1983; Kean, 1983) are potentially favourable hosts to gold mineralization. Boyle (1979) notes that mafic and ultramafic rocks are generally enriched in gold relative to other magmatic rocks. Mafic rocks with or without intercalated, felsic volcanic and sedimentary rocks are commonly associated with gold producing camps in the Canadian Shield and Cordillera regions (Hodgson et al, 1982). Chorlton (1983) recognized hydrothermal/metasomatic processes along ductile shear zones during conditions of polyphase deformation at lower amphibolite facies as another favourable indicator of gold mineralization in southwestern Newfoundland. Mafic and ultramafic rocks with low water to rock ratios between ductile shear zones would favour gold (and other rare element) enrichment in metamorphic rocks relative to the more abundant base metals (Kerrich and Fryer, 1981; Kerrich, 1981). Kerrich (1981) suggests that the prograde transition from greenschist to amphibolite facies may promote gold remobilization. Therefore, gold rich fluids liberated during metamorphism would tend to migrate preferentially to and precipitate in ductile shear zones. Stratabound gold deposits might form if the fluid focused along fault conduits migrated into nearby, permeable country rocks such as pyroclastic horizons. Fluid overpressuring during migration may initiate hydraulic fracturing and precipitate ore to form vein-type deposits. The Chetwynd deposit serves as a successful example of an exploration project which investigated ductile shear zones through silicified and carbonatized volcanic rock at amphibolite facies metamorphic grade.

Ultramafic and related mafic bodies of ophiolitic affinities are well described in southwestern Newfoundland (Church and Stevens, 1971; Dewey and Bird, 1971; Brown, 1976; 1977; Chorlton, 1980; 1983; Dunning and Herd, 1980; Dunning, 1981; 1984; 1987) and have been recognized as a potential source of platinum group elements (PGE) (Mertie, 1969; van Berkel et al,1986; van Berkel, 1987; Fox and van Berkel, 1988;). Ultramafic rocks associated with ophiolites display a variable Au content (Buisson and LeBlanc, 1985) but less variable PGE range (Naldrett and Cabri, 1976). However, PGE mineralization is not considered as a productive exploration target in southwestern Newfoundland. Naldrett and Cabri (1976) summarize the most significant PGE recovery is associated with chromite occurrences in Sudbury-type intrusions; ophiolite complexes are variable but typically not economic.

4.3 MINERAL OCCURRENCES AND PROSPECTS IN SW NEWFOUNDLAND

Newfoundland is currently a very active prospecting location with base metal and Au exploration projects under investigation (Northern Miner, Nov. 2, 1987). BP Selco's Hope

Brook Gold Mine at Chetwynd is the most significant precious metal occurrence in southwestern Newfoundland. It will support a full scale, underground mining operation for ten to twelve years. Disseminated Au mineralization is associated with an altered and silicified, volcanic-sedimentary sequence of the Ordovician La Poile Group adjacent to the Cape Ray Fault (Northern Miner Magazine, September, 1987). McKenzie (1986) proposes an epithermal model with resultant mineralization and alteration confined to a porous and permeable stratigraphic interval.

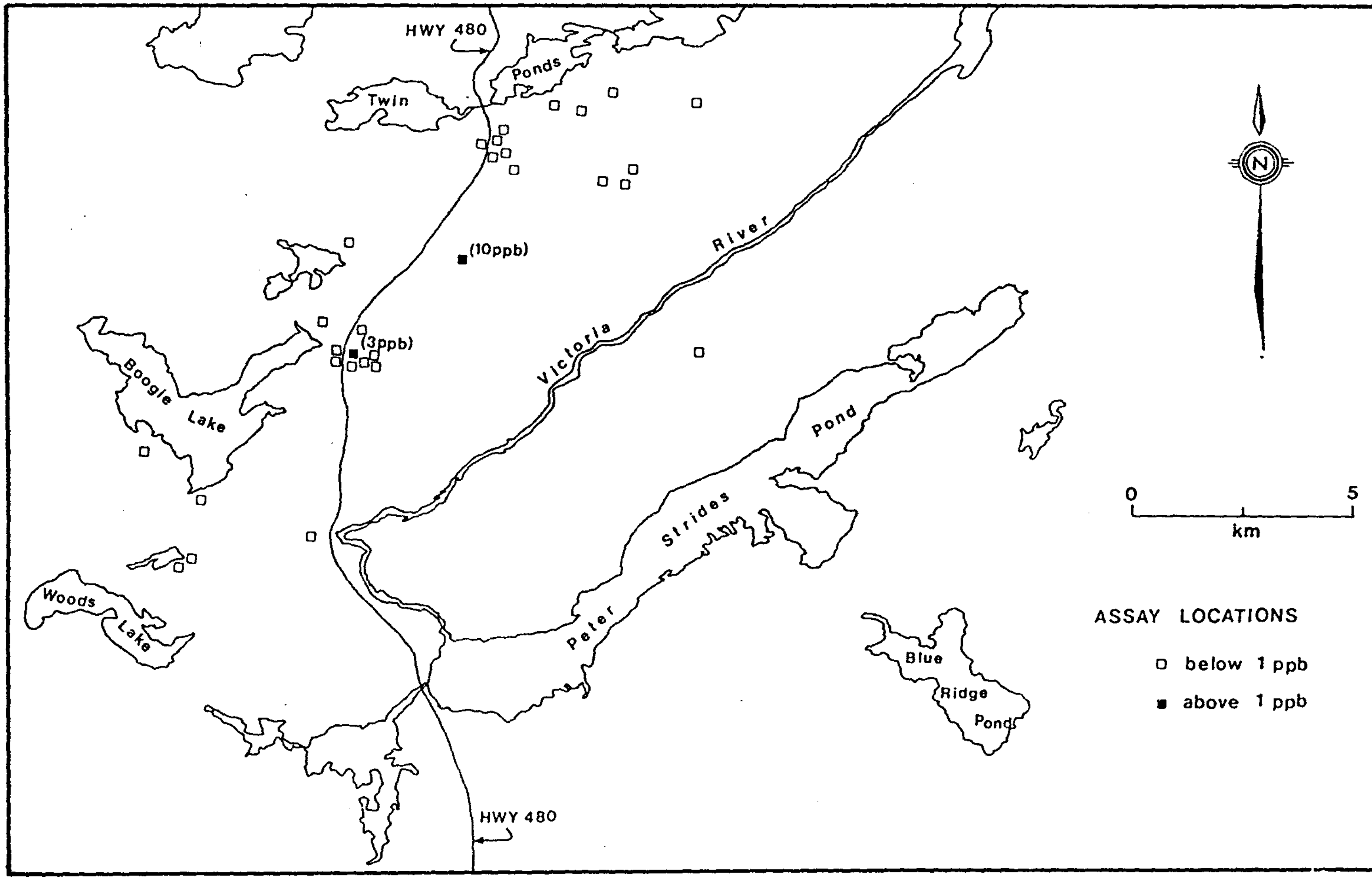
The well-established Buchans mining district near Red Indian Lake in central Newfoundland has produced over 18 million tonnes of ore and on the basis of contained metal, the camp is comparable with the Noranda and Hokuroko districts (Thurlow & Swanson, 1981). Operations focus on syngenetic, Kuroko-type (Zn-Pb-Cu) massive sulphide deposits in felsic igneous and sedimentary rocks about a central, Ordovician volcanic source (Mitchell and Garson, 1981). It is currently being re-investigated during several major mineral exploration and development projects. Similar pyritic, volcanogenic sulphide prospects at nearby Jacks Pond (Evans and Kean, 1986) and Tulks Hill (Kean and Evans, 1986) occur in Ordovician volcanic and volcanoclastic rocks of the Victoria Lake Group. Noranda Exploration is active at Talley Pond on a high grade, polymetallic prospect of mineable dimensions and significant reserves (Northern Miner, Nov. 2, 1987).

Chorlton (1983) summarizes prospecting histories for Au, U, base metals, asbestos and industrial silica in various lithologies and structural settings in the Grandys Lake map area. Kean (1983) reports minor pyrite and magnetite occurrences in granitic rocks of the Lloyds River Intrusive Suite and felsic rocks of the Victoria Lake Group. Galena-sphalerite-pyrite-gold bearing quartz veins in greenish granite was also discovered in float in the King George IV Lake map area (Kean, 1983).

The potential for PGE mineralization was recognized by van Berkel et al (1986), van Berkel (1987) and Fox and van Berkel (1988) in ultramafic rocks of ophiolitic affinities; however Pd-Pt-Au values are highly variable, sporadic and unpredictable in distribution. They also report that Au content in paragneiss adjacent to accessory, disseminated pyrite is below the detection limit of 2 ppb.

The results of thirty six Direct Current Plasma (DCP) assays of samples collected across the study area (Figure 7) established a Au background value of less than 1 ppb. Samples analysed for Au were confined to mafic rocks with or without significant visible sulphide minerals and pyrite-bearing, milky quartz veins. Base metal content established by X-Ray Fluorescence (XRF) methods record values in the low ppb range (Appendix II, Part C). Based on this evidence, the economic potential of the study area appears very low indeed.

Figure 7: Direct current plasma assays of basalt and quartz veins across the study area established a background gold value of less than 1 ppb.



HWY 480
Twin
Ponds
(10ppb)
(3ppb)
Boogie
Lake
Woods
Lake
Victoria
River
Peter
Strides
Pond
Blue
Ridge
Pond
N
0
5
km
ASSAY LOCATIONS
below 1 ppb
above 1 ppb
HWY 480

CHAPTER 5: GEOCHEMISTRY

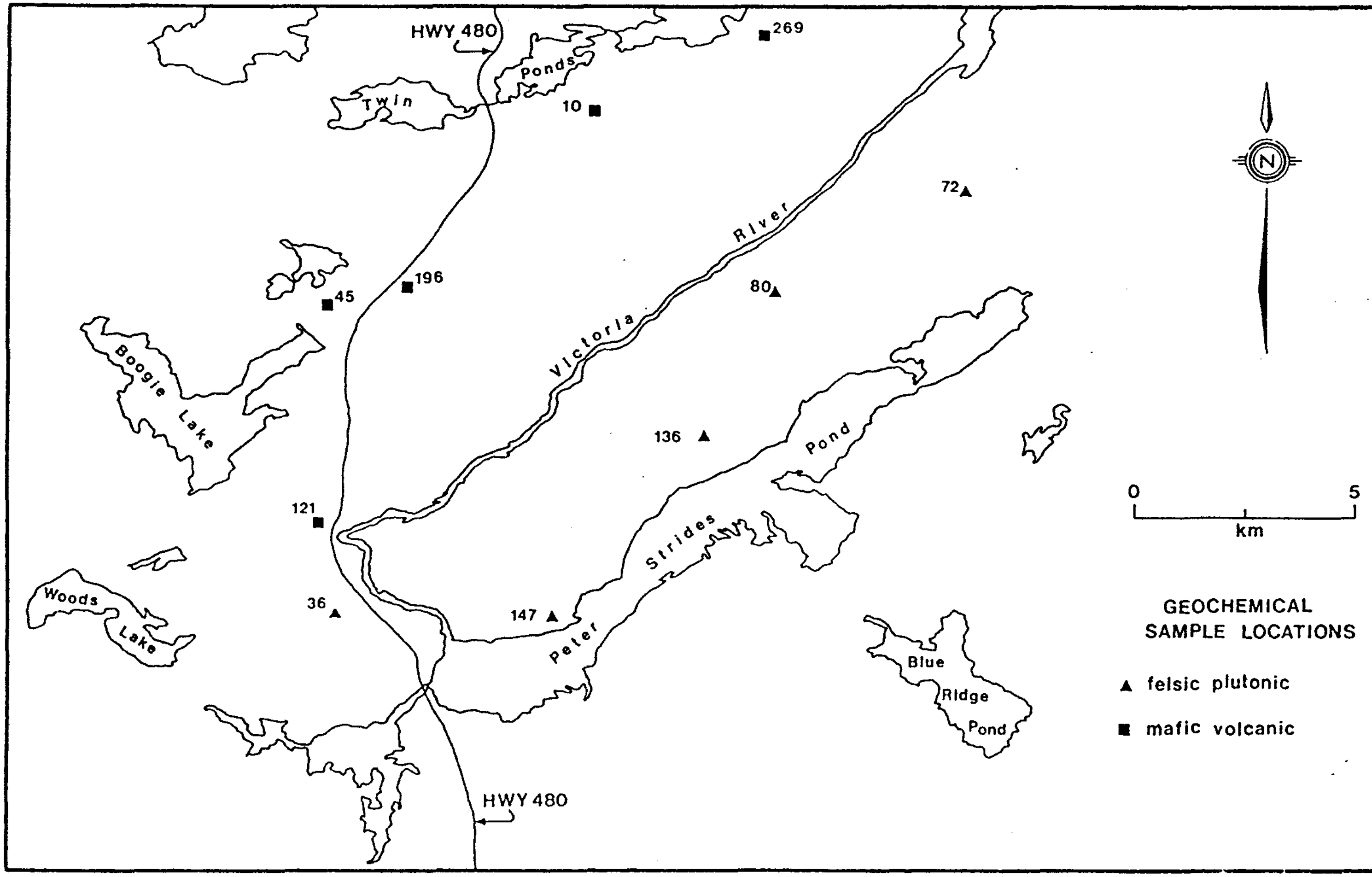
5.1 GENERAL STATEMENT

Mafic volcanic and felsic plutonic rocks of the Peter Strides Pond study area have been analysed for major and trace elements (Appendix II, Part C) in an attempt to characterize their tectonic setting by the use of geochemical discrimination diagrams (Figure 8). It should be noted, however, that the effects of metasomatism and hydrothermal alteration during moderate to intense deformation and low grade metamorphism may cause such tectonic evaluations to be questionable. Hydration, oxidation and extreme, though highly variable, elemental mobility have been well documented in rocks affected by sea water interaction (Vallance, 1969; Walker et al, 1972; Hughes, 1973; Hart et al, 1974; Herman et al, 1974; Andrews, 1977; Seyfried and Bischoff, 1979) and in metamorphosed and deformed igneous piles (Hughes and Malpas, 1971; Kerrich et al, 1977; Morrison, 1978). Trace elements are thought to be less prone to gross relocation under such conditions, hence their use to establish tectonic settings. The analyses also provide a basis for comparison with other igneous and sedimentary terranes in southwestern Newfoundland.

5.2 MAFIC VOLCANIC ROCKS

The classification and general character of mafic volcanic rocks has been much studied. To establish magma type

Figure 8: Location map for samples in mafic volcanic and felsic plutonic rocks used in major and trace element analyses to characterize their tectonic setting.


HWY 480
Twin
Ponds
269
10
72
River
Victoria
196
45
80
Boogie Lake
136
Pond
Peter Strides
0
5
km
121
36
147
Woods Lake
GEOCHEMICAL
SAMPLE LOCATIONS
Blue Ridge Pond
felsic plutonic
mafic volcanic
HWY 480

and distinguish tectonic settings, many workers consider mobile versus immobile major and trace element distribution patterns on geochemical distribution diagrams. Despite the possibility of widespread alteration by alkali metasomatism, Kuno (1968) and Irvine & Baragar (1971) have used alkali elements to characterize tholeiitic versus alkalic magma types for basic rocks. Pearce (1975), Winchester & Floyd (1975), Smith & Smith (1976) and Morrison (1978) treat Ti, Zr and P_2O_5 as less mobile elements during greenschist facies metamorphism, so that plots of Ti versus Zr and P_2O_5 or Ti against Zr may distinguish between alkaline and tholeiitic magma types more reliably than mobile elements. Additionally these immobile elements may distinguish between continental and oceanic tectonic settings. Pearce et al (1975) plot mobile K_2O against less mobile TiO_2 and P_2O_5 to distinguish continental versus oceanic basalt. Ti, Zr and Y have also been used to discriminate between non-alkali basalt of within plate and plate marginal tectonic environments as defined by Pearce & Cann (1973) and Pearce (1975).

Major and trace element analyses have been used to characterize and classify the mafic volcanic rocks. The limited number of analyses reflects the poor exposure across the study area. To establish the general geochemical character of these basic rocks, selected Harker diagrams plot weight percent CaO, MgO, FeO/MgO and LOI versus SiO_2. Results display only limited scatter on these discrimination diagrams to suggest a relatively uniform composition over widespread area. Generally, CaO and LOI decrease slowly with increasing SiO_2 (Figure 9a,d). FeO and MgO versus SiO_2 (Figure 9b,c) display an ambiguous scatter. These results are comparable with other similar mafic volcanic rocks beyond the area of investigation (Chorlton, 1980) but the nature and significance of this signature is difficult to assess. The increase in LOI with decreasing SiO_2 may reflect the relative abundance of hydrous minerals in mafic rocks. Weight percent Na_2O and K_2O versus SiO_2 was plotted despite probable alkali metasomatism across the study area. Rock compositions span the tholeiitic field of Irvine & Baragar (1971) and the alkaline field of Kuno (1968) (Figure 10a). Mafic volcanic rocks plotted on an AFM diagram (Figure 10b) appear to follow a calc-alkaline trend; results fall on the calc-alkaline side of the calc-alkalic-tholeiitic trend of Irvine & Baragar (1971). Mafic rocks across the study area plotted on the Ti versus Zr discrimination diagram (Figure 11) fall in the continental-tholeiitic and oceanic-tholeiitic fields of Winchester & Floyd (1975). Ti-Zr-Y plots (Figure 12) indicate an alkaline affinity in an oceanic environment (Pearce & Cann, 1973). However, results of combined mobile and immobile elements in a K_2O-P_2O_5-TiO_2 plot (Figure 13) imply a continental setting of Pearce _et al_ (1975).

The apparent contradictory results of the applied techniques for the mafic volcanic rocks across the study area

Figure 9: Selected Harker diagrams establish a general geochemical signature for mafic volcanic rocks across the study area.

squares = present study

triangles = Chorlton, 1980

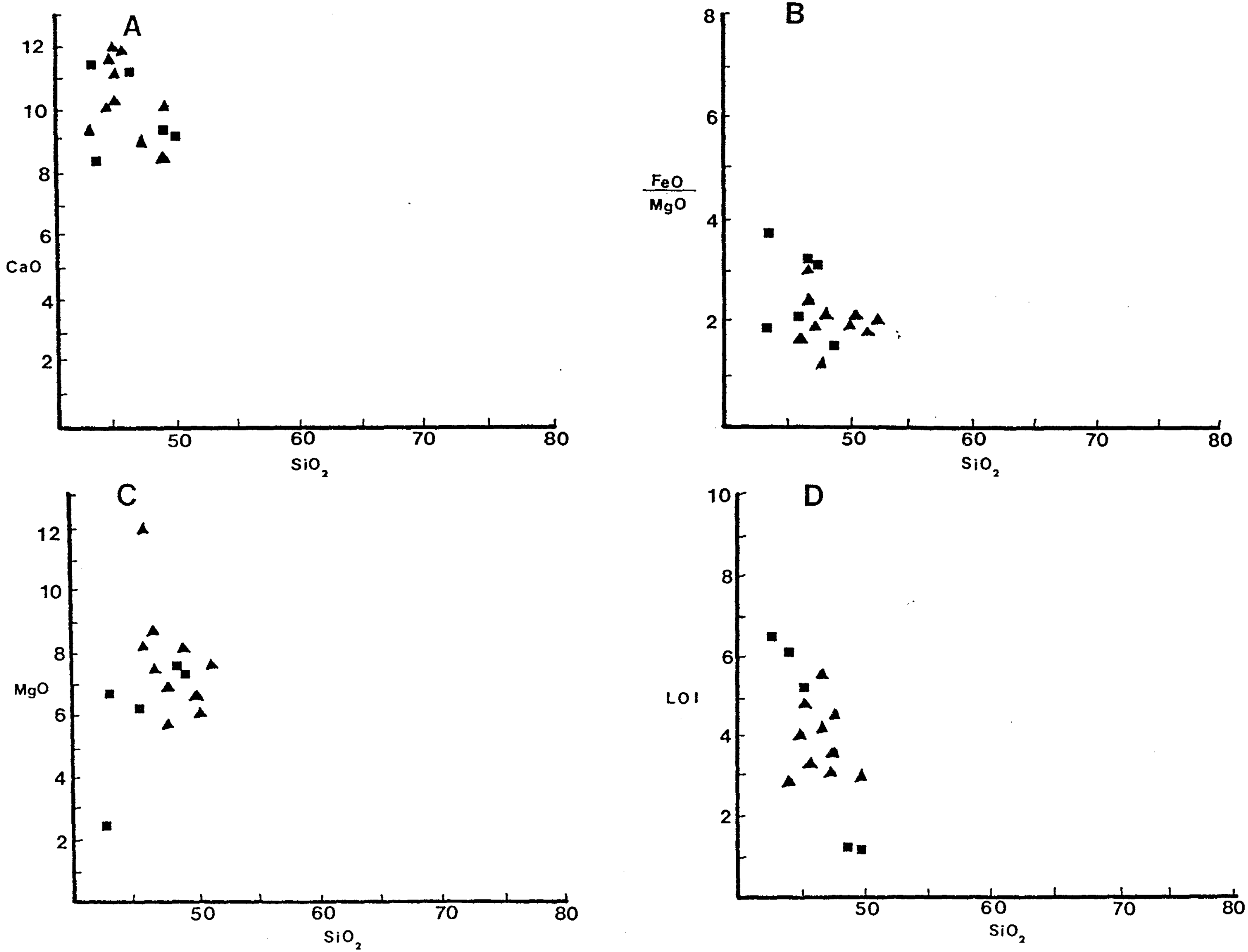
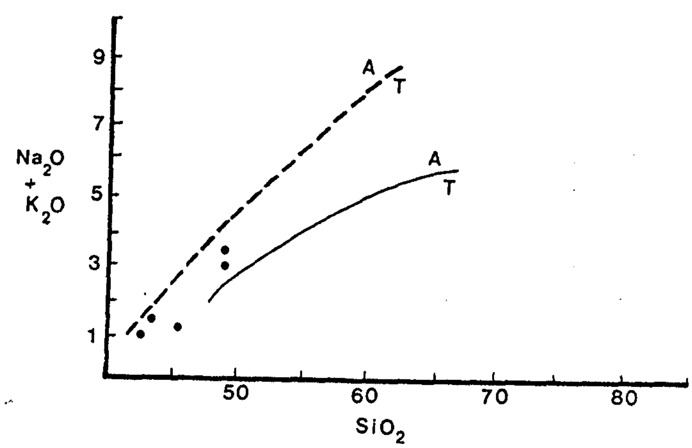

A
CaO
SiO2
B
FeO/MgO
SiO2
C
MgO
SiO2
D
LOI
SiO2

Figure 10: Magma composition as established by alkali elements in mafic rocks.

(A) Mobile alkali elements characterize mafic volcanic rocks across the study area as transitional between tholeiitic and alkaline as defined by Irvine & Baragar (1971) (broken line) and Kuno (1968) (solid line).

(B) Mafic volcanic rocks across the study area appear to follow a calc-alkaline enrichment trend and fall on the calc-alkaline side of the tholeiite - calc-alkaline dividing line of Irvine & Baragar (1971).

A



B

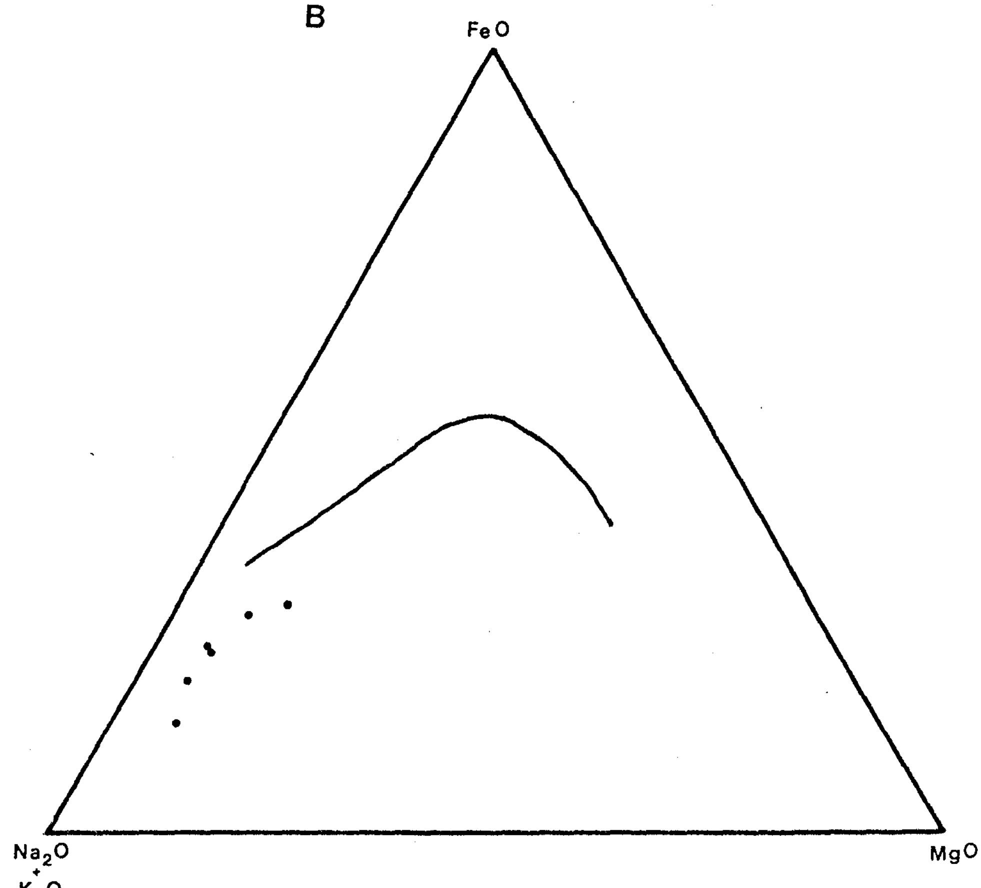
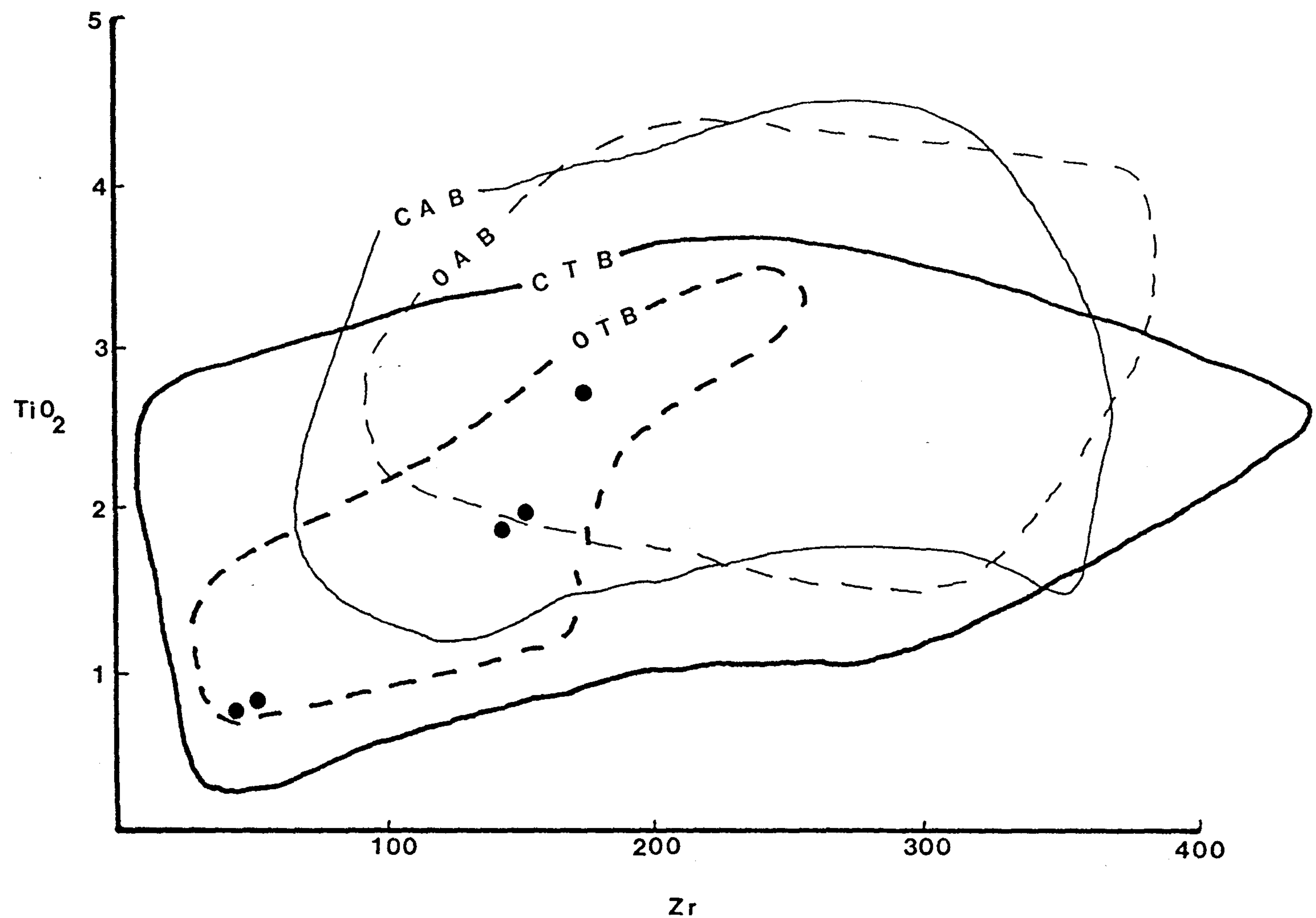


Figure 11: Immobile element analyses of mafic volcanic rocks across the study area suggest a tholeiitic magma type in an oceanic or continental setting based on fields defined by Winchester & Floyd (1975).

CAB = continental alkaline basalt
OAB = oceanic alkaline basalt
CTB = continental tholeiitic basalt
OTB = oceanic tholeiitic basalt



5
4
3
2
1
TiO2
100
200
300
400
Zr
CAB
OAB
CTB
OTB

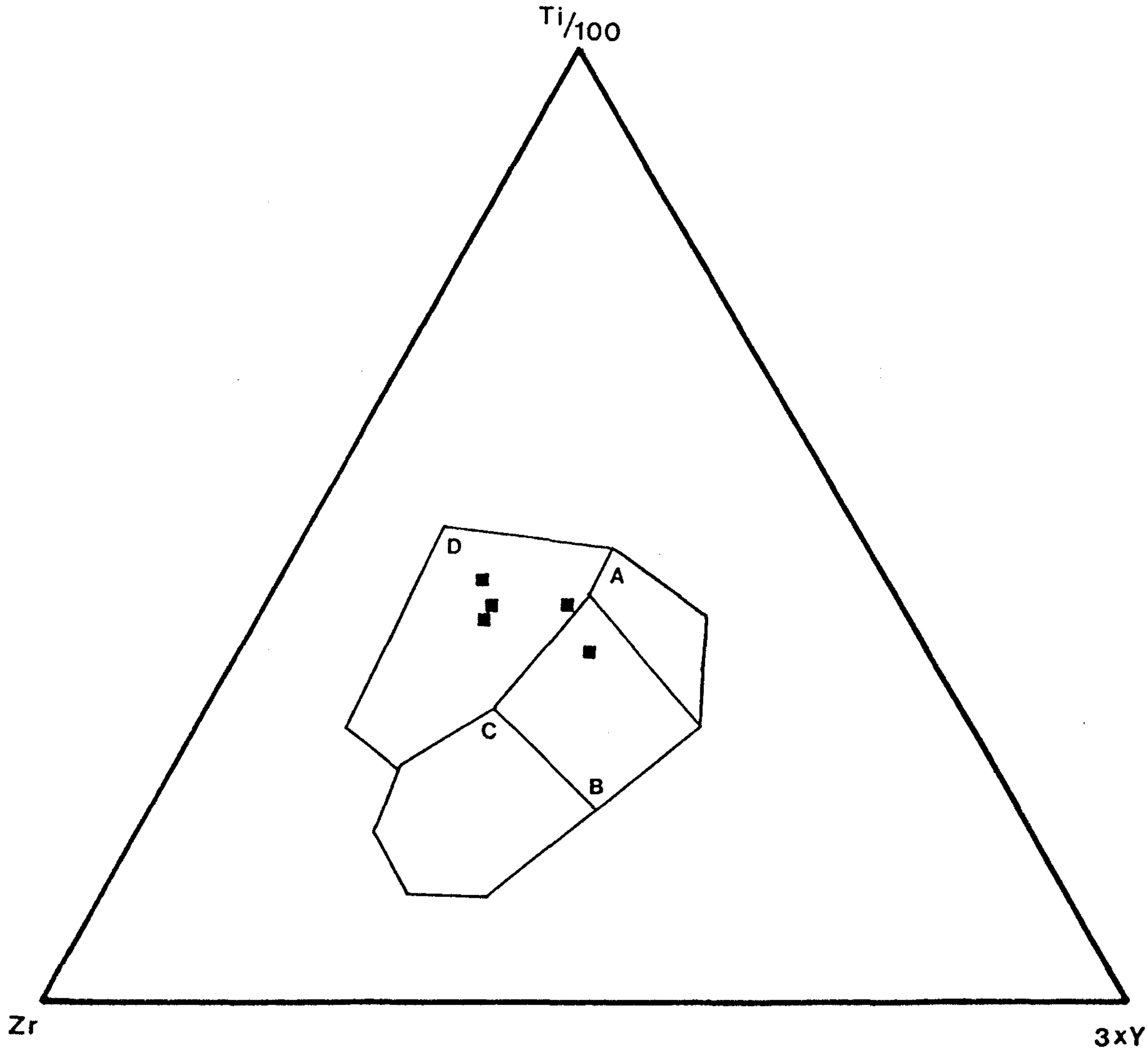


Figure 12: Immobile trace elements in mafic volcanic rocks across the study area using the disrimination fields of Pearce & Cann (1973) distinguish an oceanic environment.

A = low K tholeiites
B = ocean floor basalts; low K tholeiites
C = calc-alkaline basalts
D = within plate basalts (oceanic or cont'l)

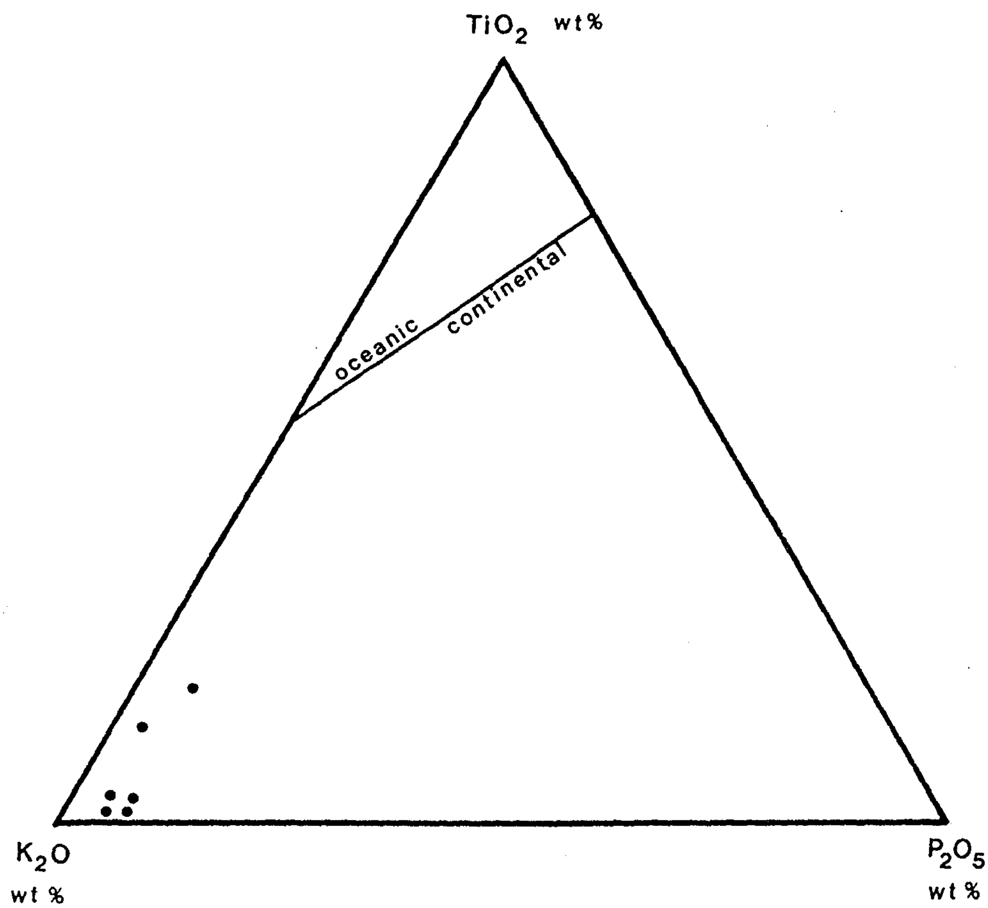


Figure 13: Analyses of mafic volcanic rock across the study area suggest an continental setting based on fields defined by Pearce et al (1975).

show a shortcoming of geochemical classification. Compositional and environmental field boundaries change according to the worker and typically have large areas of overlap. Assuming all workers' fields are accurate and mutually exclusive, one interpretation of the contradictory results for the Peter Strides Pond mafic rocks is to suggest a magma transitional between calc-alkalic and tholeiitic emplaced into a plate marginal setting which incorporated both continental and oceanic geochemical signatures.

Similar geochemical techniques and interpretations have been applied to correlative mafic volcanic rocks south of the study area in the La Poile River (110/16) map area with comparable results. Chorlton (1980) reports that basalts of the Georges Brook Formation form a calc-alkaline suite generated in a plate marginal setting. Metasomatic alteration prevents further environmental distinction between oceanic or continental settings.

5.3 FELSIC PLUTONIC ROCKS

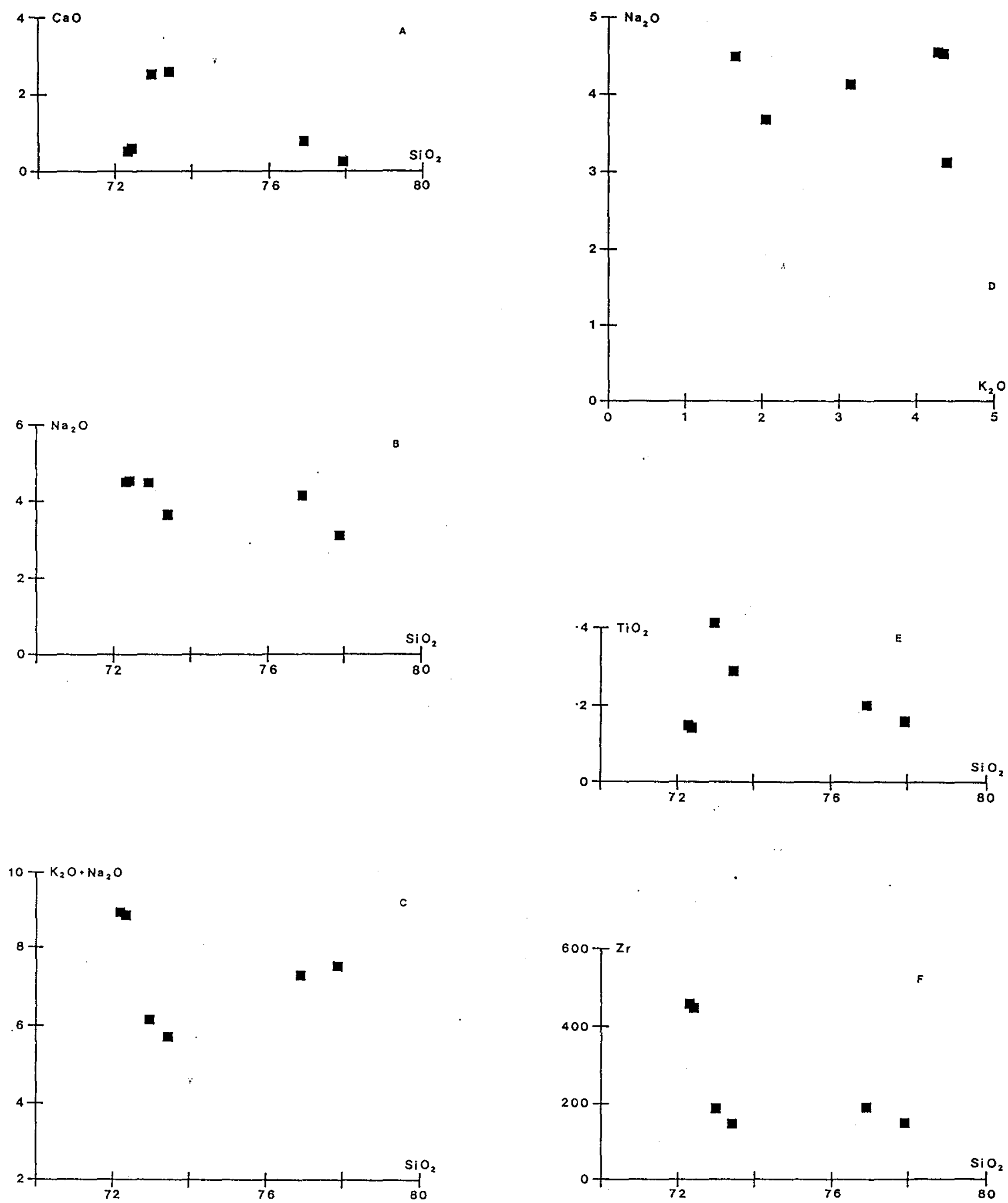
Felsic plutonic rocks are less studied as tectonic indicators than mafic volcanic rocks because of sampling difficulty and compositional diversity by contamination. However, felsic rocks are less susceptible to radical alteration than mafic rocks and therefore they more closely represent the products of formational processes.

Major element classification schemes of felsic plutonic rocks use the alkali-lime index of Peacock (1931) or peralkaline, metaluminous and peraluminous subdivisions (Shand, 1951). Another common classification scheme considers the differences between granitoids by presumed source rock variations. Chappell & White (1974) and others cite a major distinction between granites formed from sedimentary sources (S-type) versus those formed from igneous sources (I-type). This interpretation of granitoid geochemistry emphasizes the restite genetic model. Major and trace element trends on Harker diagrams and diagnostic mineral assemblages are regarded as the result of differing proportions of components by partial melting. Beckinsale (1979) has extended this S-I classification to infer tectonic environments by relating geochemical signatures to well documented tectonic settings. Pitcher (1983) considers S-type granites to be the products of continental collision.

Trace element discrimination diagrams consider mobile and immobile elements and have been used to establish the tectonic environment (Pearce et al, 1984). Characteristic REE patterns may define the magma type and compositional modifications during the melting history for felsic rock compositions. The tectonic setting may also be inferred (Hanson, 1980). Samarium and neodymium are commonly occurring REE in rock forming minerals and may provide a reliable geochronometer. Sm-Nd model ages represent the time when material and its source have an identical isotopic composition. These model ages approximate crustal formation ages and may represent the time of mantle separation (Faure, 1986). Arndt & Goldstein (1987) concede that some model ages do actually measure a segregation age but suggest that they more commonly represent the time for mixing of material derived from the mantle.

Major and trace element analyses have been conducted on the felsic intrusion north of Peter Strides Pond. Selected Harker diagrams plot weight percent CaO, Na_2O, Na_2O+K_2O, TiO_2 and ppm values of Zr versus weight percent SiO_2. Weight percent Na_2O is also plotted against weight percent K_2O. These diagrams establish a general geochemical signature for the pluton. Generally, the pluton is of high silica content with all values of SiO_2 between 70-77% It is consistently peraluminous with molecular $Al_2O_3/CaO+Na_2O+K_2O$ around 1.58. Harker plots display a clustered distribution pattern to suggest a relatively uniform composition across the intrusion (Figure 14). Without linear distribution, trends are obscure; however, all components appear to vary inversely with SiO_2. Scattered variation diagrams and normative corundum suggest the pluton is an S-type intrusion as defined by Chappell & White (1974) and others. High Na_2O and Na_2O against K_2O values typify I-type intrusions as defined by Hine <u>et al</u> (1978) (Figure 14d) however, Strong (1980) proposes an immature sedimentary source in such instances which lack extensive chemical weathering to explain this apparent deviation from the S-type classification. Discrimination diagrams using Nb,

Figure 14: Selected Harker diagrams charcaterize the general geochemical signature for the felsic pluton.

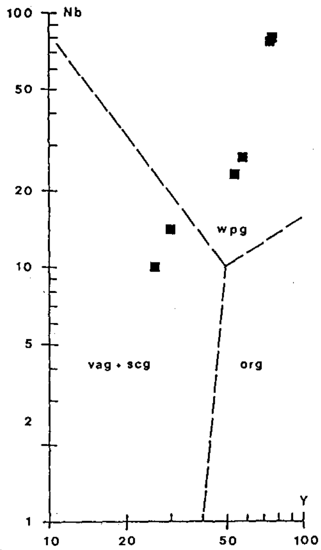


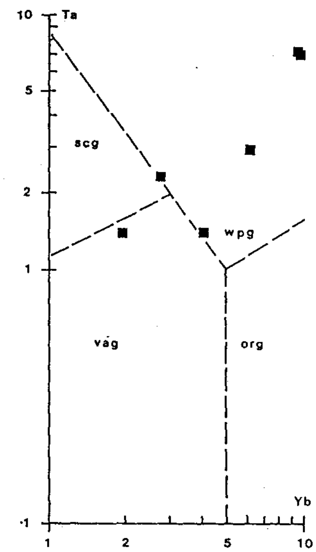
A
CaO
SiO2
B
Na2O
SiO2
C
K2O+Na2O
SiO2
D
Na2O
K2O
E
TiO2
SiO2
F
Zr
SiO2

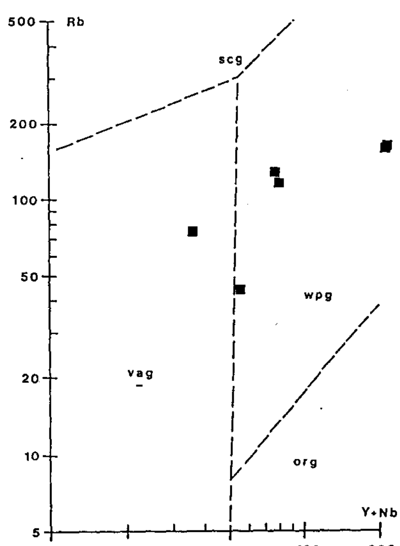
Y, Ta, Yb, Rb and Sr suggest a volcanic arc or intra-plate intrusive setting according to fields defined by Pearce _et al_ (1984) (Figure 15a,b,c,d). Plots of log Rb versus log Sr (Condie, 1973) suggest a magma generation depth of 20-30 km, sufficient to melt felsic magmas (Figure 15e). REE analyses (Appendix II, Part E) display patterns with a strongly negative Eu anomaly for adamellite phases compared to less negative granodiorite phases (Figure 16). The geometry and magnitude of this pattern, particularly the Eu anomaly, is compatible with an evolved (feldspar unmelted) or differentiated (feldspar depleted) magma and may imply a continental crust contribution to the intruding magma (Hanson, 1980; Faure, 1986). Isotopic analyses (Appendix II, Part F) of Sm-Nd yield a model age to augment REE evidence with respect to magma source. A Sm-Nd model age of 1175 Ma is contrasted to the Devonian age reported by Dallmeyer (1979) by U-Pb methods. This suggests that a substantial amount of pre-existing crust from a Proterozoic continent was incorporated into the magma. Without additional analyses, no comment on the crustal mixing history can be attempted.

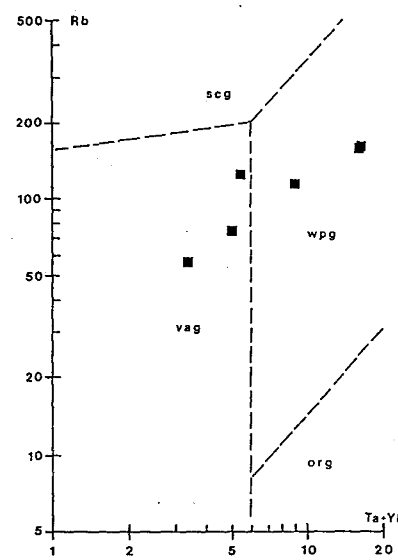
Based on the various geochemical techniques, the felsic intrusion north of Peter Strides Pond may be summarized as an S-type pluton as defined by Chappell & White (1974) and others. It was generated in a volcanic arc intrusive setting. Magma incorporated immature sediments and Proterozoic material at 20-30 km depth possibly in response to melting imposed by

Figure 15: Trace element discrimination diagrams suggest a volcanic arc or within plate tectonic setting for pluton emplacement based on fields defined by Pearce _et al_, 1984. Depth estimates of magma generation are based on plots after Condie, 1973.


Nb
Y
100
50
20
10
5
2
1
10
20
50
100
wpg
vag + scg
org


Ta
Yb
10
5
2
1
·1
1
2
5
10
scg
wpg
vag
org


Rb
Y+Nb
500
200
100
50
20
10
5
10
20
50
100
200
scg
wpg
vag
org


Rb
Ta+Yb
500
200
100
50
20
10
5
1
2
5
10
20
scg
wpg
vag
org

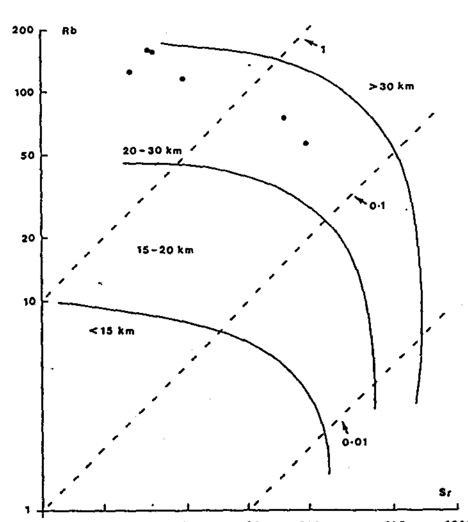
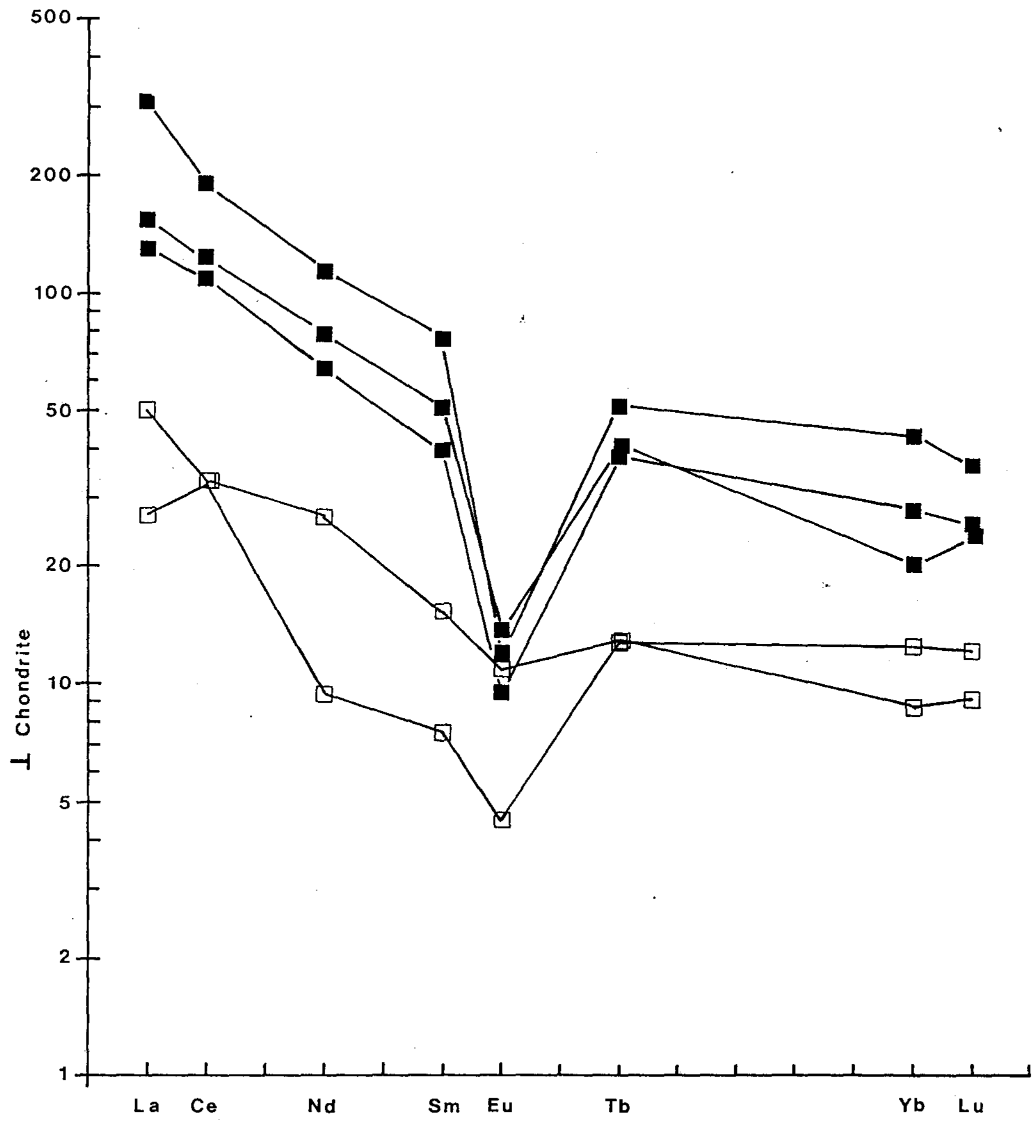

Rb
Sr
200
100
50
20
10
1
10
20
50
100
200
500
1000
1
>30 km
20-30 km
0·1
15-20 km
<15 km
0·01

Figure 16: REE patterns suggest an evolved/ differentiated magma of ?continental derivation contributed to the intrusion.

■ Adamellite

□ Granodiorite



500
200
100
50
20
10
5
2
1
⊥ Chondrite
La
Ce
Nd
Sm
Eu
Tb
Yb
Lu

continued compression and crustal thickening after Iapetus closure.

Late Paleozoic plutonism related to Iapetus closure is analogous to models of the later, thermal development phase of long-lived orogenic belts in North and South America and the collisional zone of India and Asia (Pitcher, 1983; England & Thompson, 1986). Rapid crustal thickening via imbricate thrust faulting with negligible thermal readjustment is followed by a significant period of thermal relaxation with its attendant intrusive activity and regional metamorphism. Strong (1980), Elias & Strong (1982) and Whalen & Currie (1983) observe regional and local compressive tectonic environments within the Dunnage Zone and note a consistent Devonian age for various southern Newfoundland plutons.

CHAPTER 6: DEFORMATION ZONES

6.1 GENERAL STATEMENT

The linear pattern of symmetrical, northeast-southwest zones (Williams, 1964; 1978) has been explained in the plate tectonic framework as due to continental collision (Bird and Dewey, 1970). Some workers (Whalen and Currie, 1982; 1983) question these linear divisions and propose a tessellate pattern of discrete terranes of similar, mappable lithology and structure separated by major discontinuities (presumably faults). These Appalachian terranes can be seen as analogous in overall pattern to accepted tessellate terranes in the Cordillera and Wopmay Orogens. But, however the Appalachians are subdivided, the nature and location of these regional scale zonal/terrane boundaries commonly remain unclear.

In the Peter Strides Pond study area, such boundaries may be exposed. The Peter Strides Pond Shear Zone (PSPSZ) and Victoria River Shear Zone (VRSZ) form two major, northeast striking deformation zones which cross the study area and are tectonically significant elements in the structural development of the region. These narrow zones overprint all earlier fabrics and may merge to the south to form the Cape Ray Fault (Brown, 1973; 1975; Chorlton, 1980). Concentrations of foliation parallel quartz veins with quartz plates in these zones (Plate 20) are taken to represent granulated and recrystallized aggregates and indicate a high strain history

Plate 20: Concentrations of glassy, blade-like quartz plates parallel to the foliation may represent granulated and recrystalized aggregates.

(Piasecki, 1980). The restricted occurrence of these glassy, blade-like quartz concentrations to the PSPSZ appears to conform to this high strain proposal. Van Berkel et al (1986) interpret these zones as major ductile shear zones. Based on observed mineral lineations, Chorlton (1980) considers the zones to have components of both dip-slip and strike-slip displacement of unknown magnitude. Late brittle faults with minor displacement are developed throughout the area. They are usually oriented parallel to major deformation zones (Kean, 1983; van Berkel et al, 1986).

6.2 KINEMATIC INDICATORS

6.2.1 Shear Zone Review

Ductile shear zones represent the localization of high strain into narrow, planar zones having subparallel boundaries outside of which material remains relatively unaffected (Ramsay and Graham,1970; Ramsay, 1980). White et al (1980) postulate shear zones as volumes in which strain softening occurs (the hardening capacity of the host rock is exceeded). These initially form in response to localized stress concentration due to some rock heterogeneity/material anisotropy. These zones deform dominantly by simple shear to accomodate imposed regional and local strain rates which cannot be accomodated in the country rock by bulk deformation. They are considered the deep-seated equivalents to high level, brittle faults (Sibson, 1977; 1983) and occur on all scales from the sub-microscopic to zones several km wide in rock of variable original composition (Bak _et al_, 1975; Watterson, 1979). Deformed rock from within these high strain zones is named mylonite, a poorly defined term and the subject of much debate. In this text, mylonite refers to a rock formed under conditions of non-coaxial deformation, is independent of composition, is well foliated and shows a reduction in grain size by crystal-plastic mechanisms relative to the host rock (cf. Tullis _et al_, 1982; Mawer, 1986; Simpson, 1986).

When shear zone boundaries, or displaced markers are observed, the magnitude and sense of shear displacement may be determined. Very wide shear zones commonly do not show these features, and other criteria must be established to deduce even the sense of displacement. Because rocks in ductile shear zones have been deformed without loss of material continuity, they may provide the opportunity to study the progressive development of microstructures and fabrics associated with focused strain (White _et al_, 1980; Simpson and Schmid, 1983; Simpson, 1986). Most deformation zones are so highly strained that sense of shear criteria are obscure, doubtful or absent. Shear strains of ten or greater develop planar fabrics which approximate the flow plane of simple shear thus destroying any pre-existing oblique fabric (Simpson, 1986). Lower strain zones do contain kinematic indicators from which shear sense may be inferred. Of these, composite planar fabrics, asymmetric augen or pressure shadows and displaced broken grains are considered most useful (Simpson and Schmid, 1983; Simpson, 1986). Also, a distinctive class of kinematic structures form in the extensional field of a shear zone (Platt and Vissers, 1980). Veins, boudinage, shear bands and crenulation cleavage represent commonly developed extensional features which cover a range of observational scales. Each of these kinematic indicators will be discussed separately.

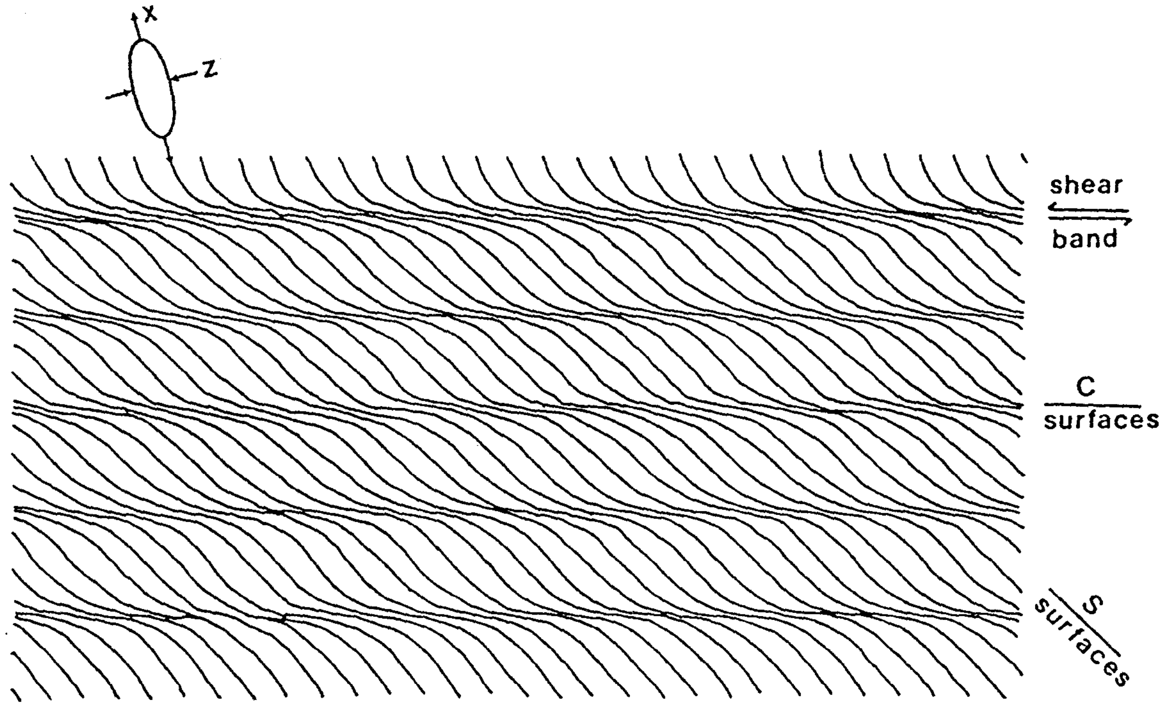
6.2.2 Composite Planar Fabrics

Berthe et al (1979) first outlined the use of composite planar fabrics as a reliable kinematic indicator and described their progressive development. They observed two sets of anastomosing, planar anisotropies developed in mylonite which they termed "cisaillement" (shear) or C-surfaces; and "schistosité" (schistosity, foliation) or S-surfaces (Figure 17). C-surfaces are initiated, and remain aligned, parallel to the main shear zone boundaries with progressive deformation. These planes are considered to represent spaced slip surfaces of very high shear strain or displacement discontinuities with micro-shear sense equal to the overall shear sense (Berthe et al, 1979; Lister and Snoke, 1984). Micostructurally, C-surfaces are thin layers of recrystallized, polymineralic aggregates of reduced grain size relative to the enclosing matrix. S-surfaces are initially oriented 45° to the main shear zone boundaries; with progressive deformation they rotate toward C-surfaces such that looking into the acute angle between C and S planes defines the shear sense. S-surfaces represent an accumulation of finite strain and are defined microstructurally by a mineral shape preferred orientation of pre-existing grains between C-surfaces (Simpson and Schmid, 1983; Lister and Snoke, 1984; Simpson, 1986).

The method and timing of S-C fabric development is not well understood. Composite planar fabrics may form by simple shear, continuous, non-coaxial/rotational strain or non-continuous multi-phase deformation (Simpson and Schmid, 1983). Therefore, before shear sense is inferred from any example of anastomosing fabrics, the prevailing deformational history should be established by independent evidence. Generally, mylonitic foliation anastomoses in and out of zones of high shear strain which is related to intensity variations in the finite strain (Lister and Snoke, 1984). Berthe et al (1979) consider S-C fabric to have developed progressively with increasing strain but the rate of formation was dependent upon any combination of composition, temperature and grain size. They considered S-surfaces to be normal to the short axis of the finite strain ellipsoid which represents the direction of maximum negative extension. Lister and Snoke (1984) concede a systematic relationship between the attitude of observed foliations and the XY plane of the finite strain ellipsoid but they and others (Simpson and Schmid, 1983) consider that S-surfaces do not match the bulk shortening of the whole rock

Figure 17: Composite planar fabrics display two planar anisotropies which form reliable kinematic indicators in mylonitic rock. C-surfaces form and remain parallel to shear zone boundaries. S-surfaces initiate at 45° to shear zone boundaries and rotate into parallelism toward C-surfaces with progressive deformation.

Shear bands are ductile micro-shear zones with the same displacement sense as the overall deformation zone.
(After Lister & Snoke, 1984).


x
z
shear
band
C
surfaces
S
surfaces

volume because of later, discrete shearing along C-surfaces.

Berthe et al (1979) propose that both planar elements develop synchronously because observations show that S-surfaces rarely occur without C-surfaces. Similarly, C-surfaces rarely occur alone. Lister and Snoke (1984) propose that a well developed foliation defining S-surfaces may have developed before localized yield and later plastic deformation formed shear bands which define C-surfaces. They cite as evidence the mechanical response to non-coaxial laminar flow in narrow zones of concentrated shear strains generated by material anisotropies. While the timing of S-C fabric development is debated, anastomosing planar foliations are widely cited as a reliable kinematic indicator (Jegouzo, 1980; Ponce de Leon and Choukroune, 1980; and others).

6.2.3 Asymmetrical Augen and Pressure Shadows

Deformed rock with a significant range of grain sizes may contain augen in hand samples or pressure shadows on the grain scale. The asymmetrical relation of these structures to the mylonitic fabric has been used as an indicator of shear sense (Figure 18) (Eisbacher, 1970; Lister and Price, 1978). Feldspar, quartz, mica or garnet may form larger, rigid more flow-resistant porphyroclasts within a finer grained, more ductile matrix. Foliation planes become deflected about these coarser grains. Some grains display narrow mantles of very fine grained, dynamically recrystallized material of the same composition as the adjacent grain. These mantles may form

Figure 18: Asymmetry of augen tails and pressure shadows about rigid grains provides a reliable sense of shear criterion in deformed rock.

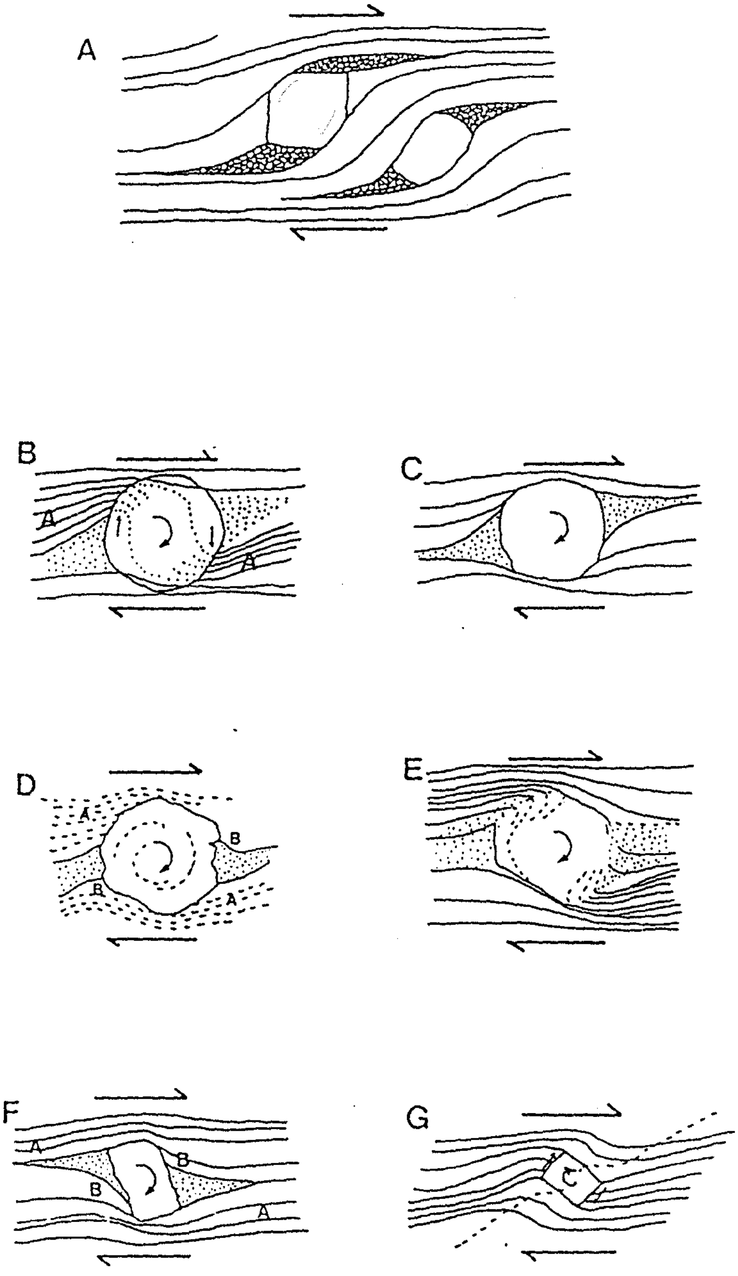
(A) Granulated material of the same composition as the host porphryoclast is extended along foliation planes in the direction of shear.

(B to G) Examples of rotated grains display

(i) foliation microfolds at grain edges become more closely spaced to record the rotation direction.

(ii) sites of most recent deposition are concave toward more widely spaced foliation planes (position B) whereas the opposite side of granulted tails are straight (position A).

(After Simpson & Schmid, 1983).


A
B
C
D
E
F
G

with asymmetrical, elongate tails which rotate into parallelism with the enclosing foliation. Inequant augen rotate more slowly than equant grains and their long axes become oblique to the surrounding fabric (Simpson, 1986). Similarly, high ductility contrasts at the grain scale cause pressure shadows to form characteristic shapes about the rotated grains (Passchier and Simpson, 1986). In both examples, determination of the sense of rotation defines the shear sense (Simpson and Schmid, 1983). Powell and Vernon (1979) and Simpson and Schmid (1983) caution that the overall asymmetry of augen or pressure shadows may cause contradictory results when dealing with round or equidimensional grains. Rosenfeld (1970) and Schoneveld (1977) cite the occurrence of microfolds adjacent to porphyroclasts and the maximum curvature of the recrystallized tail with the foliation as a reliable and consistent method to establish the correct rotation sense and, therefore, the overall shear sense. Generally, asymmetry as a kinematic indicator requires a significant grain size variation, a homogeneous matrix and a simple deformational history.

6.2.4 Displaced Broken Grains

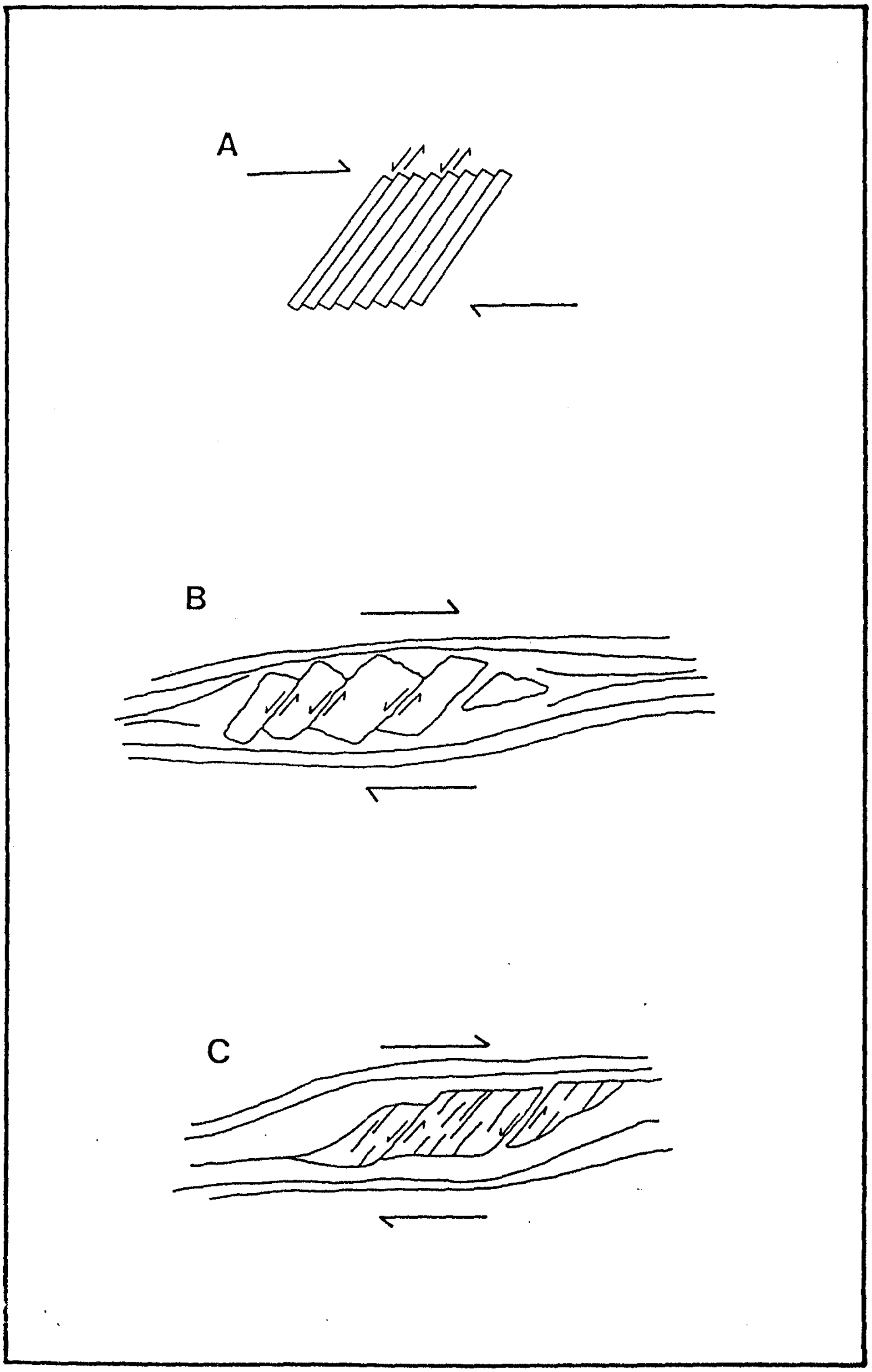
Rigid and platy grains such as feldspar, mica and pyroxene may become broken and displaced within a ductile matrix during continued deformation. As fractures propagate and grains extend, the overall shear sense may be determined (Figure 19) (Simpson and Schmid, 1983; Simpson, 1986).

Figure 19: Rigid materials resist ductile flow and deform by fracture and displacement. The sense of displacement along fractures is related to the initial angle of the fracture to mylonitic foliation. Initial, low angle fractures display synthetic offset; high angle, oblique fractures show antithetic offset.

(A) Sheared cards predict and model the displacement sense along fractures.

(B&C) Rigid or platy grains (garnet, feldspar and mica) fracture oblique to flow foliation at high angles and displace opposite to overall shear sense.

(After Simpson & Schmid, 1983).


A
B
C

Fractures can be in any orientation to the flow foliation by failure along specific crystallographic planes; or they may be in the plane of maximum and intermediate stress. As deformation proceeds, grains rotate and fractures rotate to extend in the flow direction according to their initial orientation. Grains with initial fractures at low angles to mylonitic foliation will extend along thrust faults with synthetic offset to the overall shear sense (Simpson and Schmid, 1983). Fractures initiated oblique to the enclosing fabric at a high angle will displace along high angle, normal or reverse faults, antithetic to the overall sense of shear (Etchecopar, 1977). Therefore, before displacement along fractured grains is used as a kinematic indicator, the attitude of the fracture to the mylonitic fabric must be considered. Only low angle or high angle fractures should be considered; intermediately oriented fractures should be avoided as reliable sense of shear criteria.

6.2.5. Extensional Structures

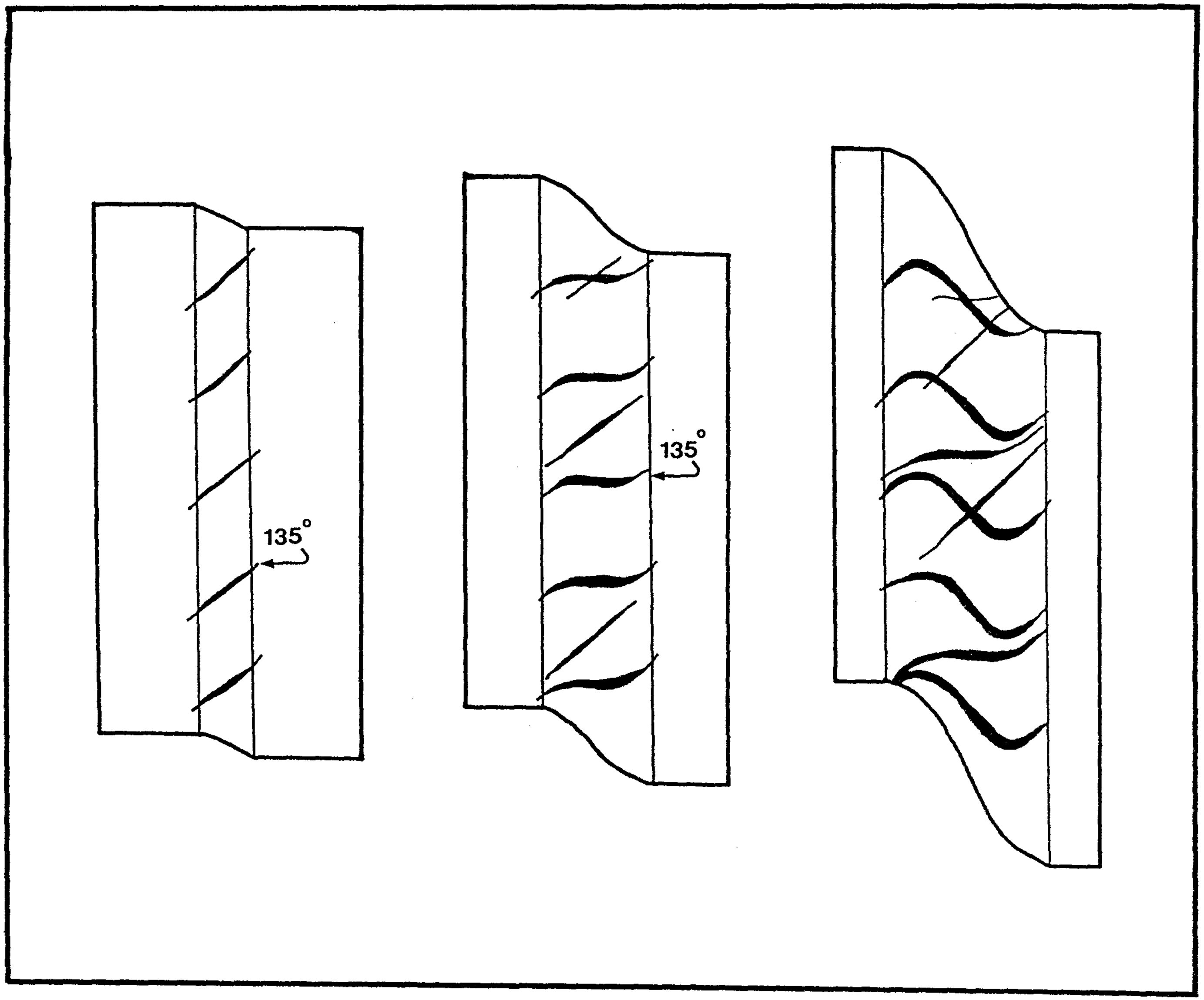
A distinctive class of complex structures form in the extensional field of ductile deformation zones because of the variable mechanical response to strain. These structures indicate the shear sense and perhaps the amount of local displacement across high strain zones. Extensional structures augment other structures considered during the study of the progressive development of, and mechanisms associated with shear zones.

Veins preserve fracture histories. They represent mineral infilling of fractures (Hancock, 1972; Beach, 1975) which formed by a local loss of cohesion within ductile deformation zones. Extensional veins have a characteristic geometry related to brittle failure in response to the prevailing stress field (Figure 20) (Platt and Vissers, 1980). Fissures which form during initial shear displacement are oriented normal to the direction of first, maximum, incremental extension and will form en echelon arrays at 135° to the shear zone boundaries (Ramsay and Huber, 1983). The initial angle of these fissures becomes reduced by later displacements. Incremental rotation by continued shear strain progressively develops a sigmoidal shape. Growth along old, poorly oriented veins terminates as secondary, cross-cutting veins initiate to accomodate further extension. Shear sense may be implied from the morphology of the sigmoidal veins. Displacement is calculated by the amount of shear strain required to rotate veins from their initial 135° orientation. Veins rotate in a predictable manner; therefore, a measure of the change in orientation from 135° is related to the amount of later shear strain after fissure formation (Platt and Vissers, 1980; Ramsay and Huber, 1983).

Isotropic materials have relatively homogeneous compositions with uniform responses to strain and do not develop mechanical instabilities. Deformation is accomplished by overall modifications of the shape and orientation of

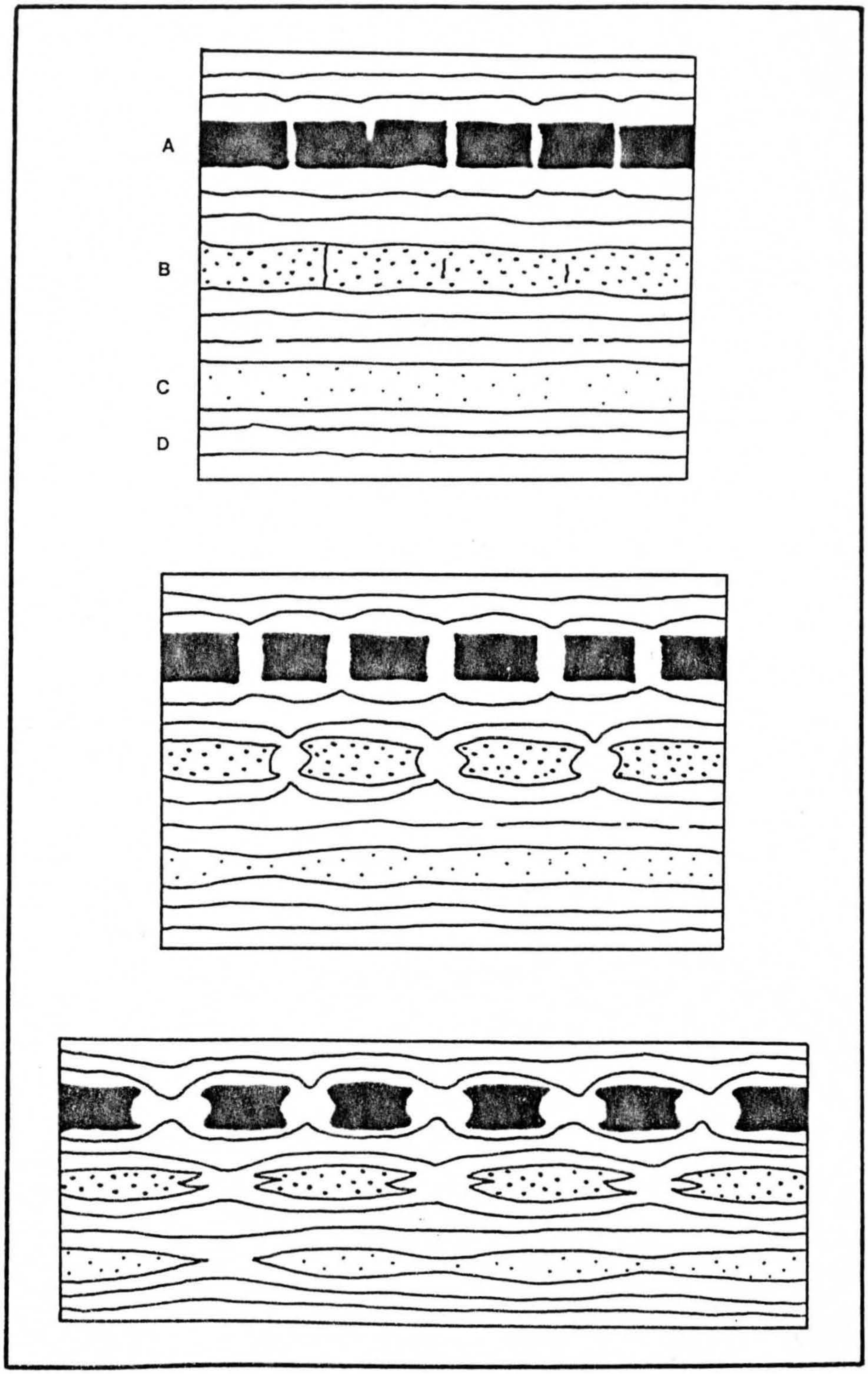
Figure 20: Extensional veins represent mineral infilling during a local loss of material continuity within ductile shear zones. Their characteristic sigmoidal geometry forms by sequential development in a progressively evolving shear zone.

(After Durney and Ramsay, 1973).


135°
135°

constituent particles which may form a preferred fabric (Ramsay and Huber, 1983). Rocks are not homogeneous and compositional or other variations (bedding, banding, dykes etc.) typically result in differing rheological properties. When rocks are extended parallel to this anisotropy, mechanical instabilities related to differing material responses or competency contrasts induce characteristic geometries (Figure 21) (Hobbs et al, 1976). Less competent rocks are more easily deformed and flow while competent rocks are stiffer and resist flow. Streching along a competent layer in a surrounding less competent matrix develops instability by concentrating stress within the stronger layer. Increased local stress causes faster deformation rates and a preferential streching/thinning of the competent layer (Cobbold et al, 1971; Ramsay and Huber, 1983). Eventually failure occurs along a fracture and continued extension isolates individual fragments or boudins. Less competent material flows into neck zones between boudins. High competency contrasts give rise to block-like boudins with minor modification by differential shear during material infilling between boudins. Lower competency contrasts allow considerable stretching without or prior to failure and form pinch-swell structures because of strong ductile flowabout stress concentrations (Ramsay and Huber, 1983). Both boudins and pinch-swell structures may have complex geometries due to progressive length changes during continued deformation.

Figure 21: Boudins form during extensional deformation due to the variable mechanical response of materials. The geometry of boudins relates to the competency contrasts of adjacent layers. Stiff (competent) layers **(A)** form blocky terminations. Ductile (incompetent) layers (D) pinch and fail with "fish-head" terminations (Ramsay & Huber, 1983).


A
B
C
D

Symmetrical boudins form when competent layers are parallel or subparallel to the principal extension direction (long axis of the finite strain ellipse). When oblique layers are in the direction of stretching, asymmetrical boudins form (Platt and Vissers, 1980; Ramsay and Huber, 1983). The amount of extension may be inferred by reconstructing deformed objects and layers into their initial, intact form (Ramsay and Huber, 1983). Calculated values based on these reconstructions are typically lower than actual values because of internal, ductile extension prior to failure and separation. Pinch-swell structures form unreliable estimates of extension because low competency contrasts allow indeterminable amounts of stretching to occur within layers (Platt and Vissers, 1980).

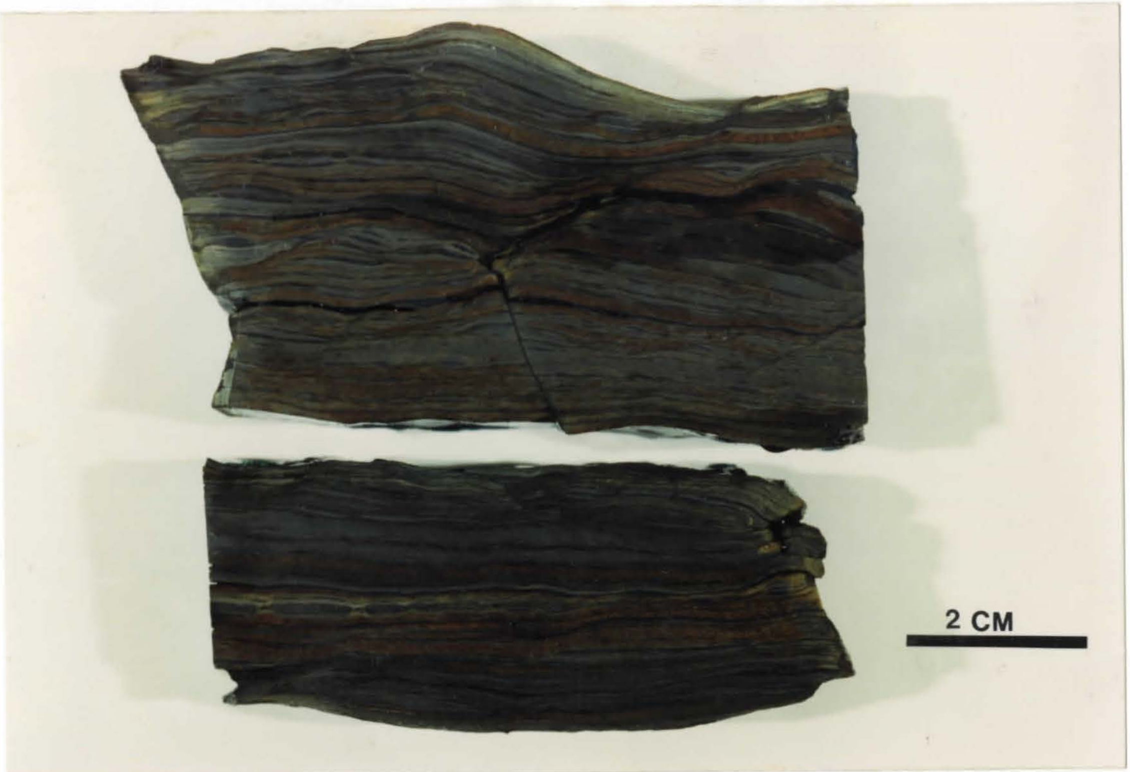
Shear bands are ductile, oblique, micro-shear zones with the same displacement sense as the overall zone and are concentrated in high strain domains of non-coaxial deformation (Figure 17) (Platt and Vissers, 1980; Passchier, 1984). Conjugate shear bands have been developed in layered plasticene models during coaxial shortening experiments by Harris and Cobbold (1984). These structures are considered to form during the hardening of a deformation zone (White _et al_, 1980) and represent the final stages of ductile deformation before the onset of brittle failure (Passchier, 1984). They typically form parallel sets and when closely spaced, shear bands may define a secondary spaced cleavage in foliated rock termed extensional crenulation cleavage. This type of cleavage is not axial planar in folds.

6.3 VICTORIA RIVER SHEAR ZONE

The Victoria River Shear Zone (VRSZ) forms a narrow, straight, northwest-southeast trending zone of ductile deformation. Exposure across and along the zone is poor; it is primarily confined to small streambed and waterfall outcrops. Contacts with adjacent lithologies are nowhere exposed. The effects of shearing are considered to promote rapid weathering. Therefore shear zone boundaries are proposed to coincide with the rapid changes in elevation which form the Victoria River valley. To the northwest, outside the study area, the shear zone passes under the waters of a man-made reservoir, Victoria Lake. The southeastern extension of the zone beyond the limits of this investigation is obscured by thick accumulations of glacial outwash debris.

Rocks representing the VRSZ are fine grained, grey-green to buff phyllonites (Plates 21 & 22). A northeast striking foliation is well developed with steep southeast to vertical dip. Generally, lineations are obscure but some patchy intervals display a faint, mineral-alignment lineation down-dip. The very fissile nature of this unit forms an incompetent rock which is difficult to sample. Petrographically, the unit appears to be composed of very fine grained muscovite, chlorite, sericite and quartz as a banded

Plates 21 & 22: Typical fissile handsamples of fine grained, well foliated VRSZ phyllonites.


2 CM

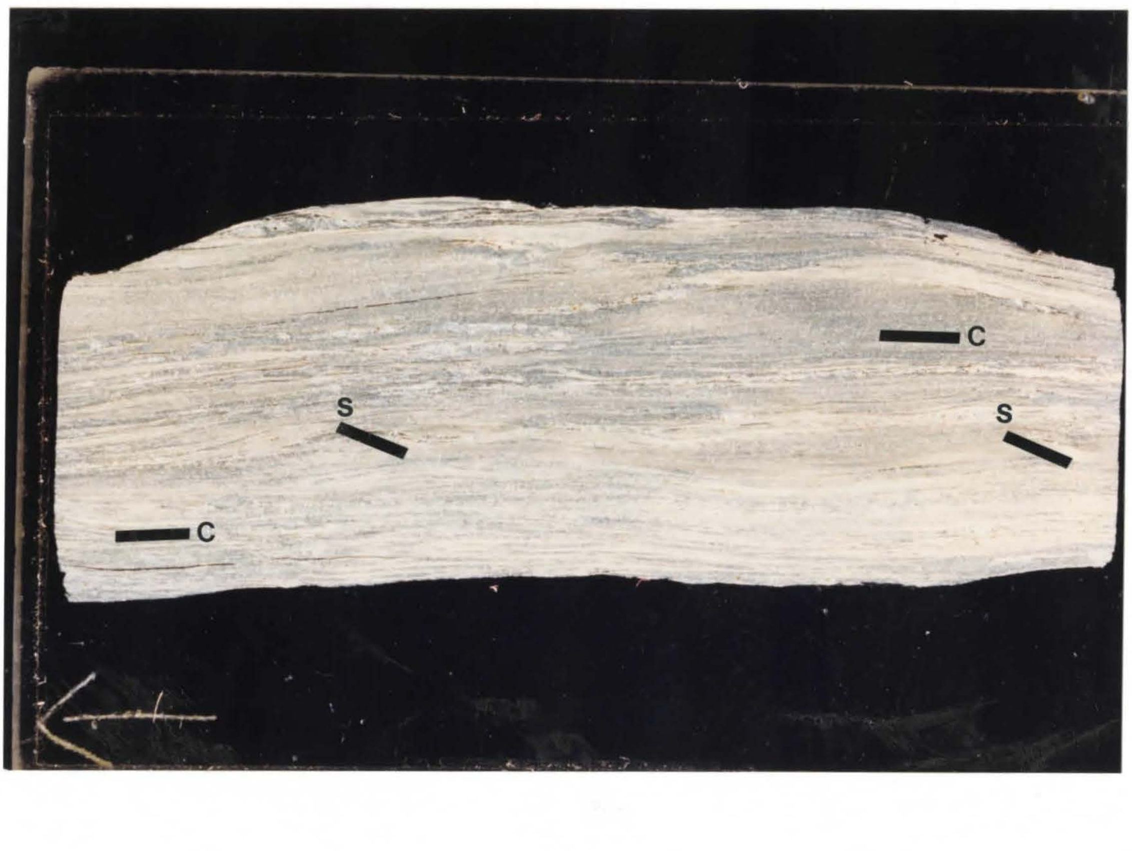

4CM

matrix alternating with elongated quartz ribbons (Plates 23 & 24). Polymineralllic bands may reach widths of 2.5 mm; quartz ribbons do not exceed 0.5 mm in width. Platy matrix minerals display a strong preferred mineral shape orientation. Micas appear as mottled, ragged grains with fractures and serrated edges embayed by sericite and chlorite. Matrix quartz is microcrystalline with equant and interlocked subgrain boundaries and undulose extinction. Rare, subround quartz eyes in the matrix do not show strained extinction but do displace the fabric of adjacent platy minerals. Subhedral to euhedral opaque minerals (? Fe Oxides) are distributed uniformily throughout the matrix. Laterally continuous, locally boudined quartz ribbons have a coarser grain size than the adjacent matrix. Ribbons are composed of interlocked aggregates with irregular margins but simple subgrain boundaries and display sweeping extinction. All ribbons have sharp, tapered terminations. Bificated ribbons are common with no preferred stepping direction; branches have sharp, tapered terminations also.

Several indicators of displacement sense have been identified in VRSZ phyllonites. Normal to the mylonitic foliation, no clear examples of C-S fabrics have been observed in the fine grained matrix. However, quartz ribbons display abundant examples of micro-boudinage and pinch-swell structures with extensional surfaces/planes equally oriented both oblique and normal to the foliation direction.

Plates 23 & 24: Photomicrographs in polarized light show fine grained, well foliated phyllonites of the VRSZ. The primary deformation foliation (S) is anastomosed with a second, oblique planar fabric (C) to suggest a component of sinistral displacement.

1 CM



Recrystallized quartz aggregates in ribbons suggest a mylonitic grain size reduction relative to earlier phases. The extent of grain size reduction is unknown without an undeformed protolith for comparison. Several examples of quartz as rigid grains show sharp walled fractures with no preferred orientation and small displacements. The precise degree of fit across adjacent walls and the lack of alignment in mineral infillings suggests that the fractures are post-kinematic. Parallel to the foliation, the phyllonitic fabric displays several kinematic indicators. Both the fine grained matrix and various quartz ribbons show oblique shear surfaces with left-stepping discontinuities. Locally, discontinuities are spanned by fine grained, fibrous, green chlorite. C and S planes form contained angles of 10° to 35°. Rigid, sub-equant quartz may form tapered grains with aligned mica and chlorite overgrowths parallel or at low angles to the enclosing foliation. These tails are typically symmetrical but rare asymmetric examples are observed.

VRSZ samples display significant evidence of extension and textures in quartz from surfaces normal to the linear fabric suggest flattening perpendicular to foliation. Parallel to lineation, the acute angle formed by the intersection of C and S planes and the asymmetry of overgrowths about quartz augen suggest a consistent, sinistral sense of displacement by simple shear.

6.4 PETER STRIDES POND SHEAR ZONE

The Peter Strides Pond Shear Zone (PSPSZ) forms a kilometer-wide, straight sided, northeast-southwest trending zone of ductile deformation across the south-central portion of the study area. Most of the deformation zone lies beneath the waters of Peter Strides Pond; exposure is confined to small, scattered outcrops accessible only during intervals of low lake levels. Extensions of the shear zone in both directions beyond the limits of the present investigation are obscured by glacial cover.

Rocks representing the PSPSZ are dark grey, medium to coarse grained and gneissic with quartzofeldspathic bands alternating with mafic bands (Plates 25 & 26). Mafic and felsic layers are of approximately equal dimension and range from 1 to 3 mm in width. Anastomosed layers and symmetric pinch and swell textures are common. A well developed northeast striking foliation is defined by a mineral alignment within layers and is augmented by concentrations of parallel, glassy quartz blades (Plate 20). Dips vary from steep southeast to vertical. Faint lineations are developed locally with low to moderate southwest dip. Across the shear zone, extension of elements with large mechanical contrast against the host rock is suggested by 1 to 5 m long amphibolite pods/boudins having blocky to subround terminations (Plate 27). One small-scale shear band oblique to the mylonitic fabric (Plate 28) and an isolated, asymmetrically folded, S

Plates 25 & 26: Typical medium grained, well foliated handsamples of recrystalized PSPSZ mylonite. Anastomosed gneissic layers are common.


B
1 CM

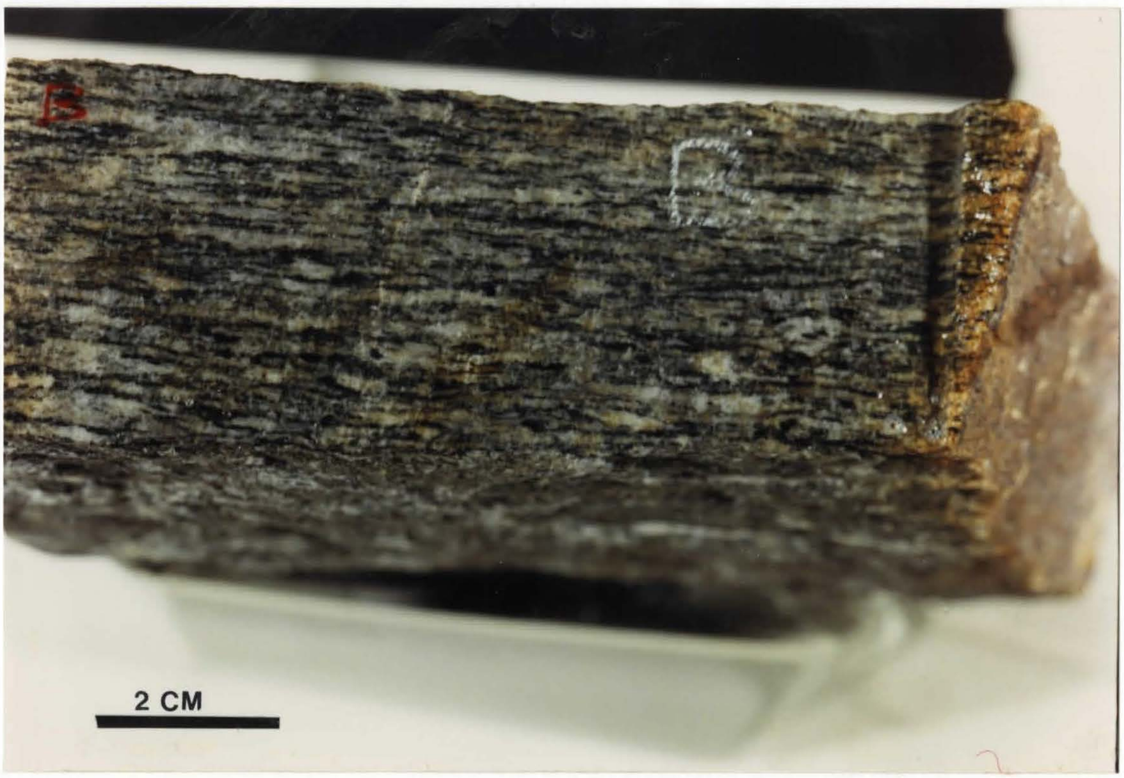

2 CM

Plate 27: Amphibolite boudins with pinched and rounded terminations in the PSPSZ.

Plate 28: Small scale shear band is oblique to mylonitic foliation in rock of the PSPSZ.

shaped quartz vein (Plate 29) imply a sinistral component to shear displacement.

In thin section, the unit is composed predominantly of subhedral to euhedral quartz and feldspar in a medium grained, interlocking aggregate with simple grain boundaries (Plate 30). Concentrations of subhedral biotite, muscovite, minor hornblende, sericite and chlorite are aligned as discontinuous bands to define a wispy foliation. Felsic mineral phases are relatively strain free; mafic minerals may display mottled extinction. Porphyroblastic hornblende contains strain-free quartz and untwinned K-feldspar as subround to round inclusions. Post-kinematic, sharp-walled fractures extend in random orientations through quartz grains and have a high degree of fit across adjacent walls.

Several observations suggest that recrystallization has overprinted and obscured an earlier mylonitic fabric. Coarsest quartz grains may show serrated subgrain boundaries oblique at low angles to the enclosing foliation. Elongate and discontinuous intervals of very fine grained, sugary quartz are parallel to the adjacent foliation. Micro-quartz displays strained extinction and complex grain boundaries. Biotite and rarely muscovite and hornblende form ragged grains with embayed terminations oblique to the fabric. Rare quartz and K-feldspar augen display asymmetric biotite and chlorite overgrowths.

The inclination and asymmetry of these relict, kinematic

Plate 29: Fine grained sugary quartz veins are rare in the PSPSZ. The asymmetrically folded, S-shaped vein suggests a sinistral component to shear displacement.

Plate 30: Polarized light photomicrograph of recrystallized, mylonitic rock of the PSPSZ. The main mylonitic foliation (S) is truncated by anastomosing aggregates of shredded biotite interpreted as shear planes (C). A component of sinistral displacement is suggested.

fabrics strongly suggests a consistent, sinistral sense to shear displacement in the PSPSZ.

CHAPTER 7: VEINS AND LENSES

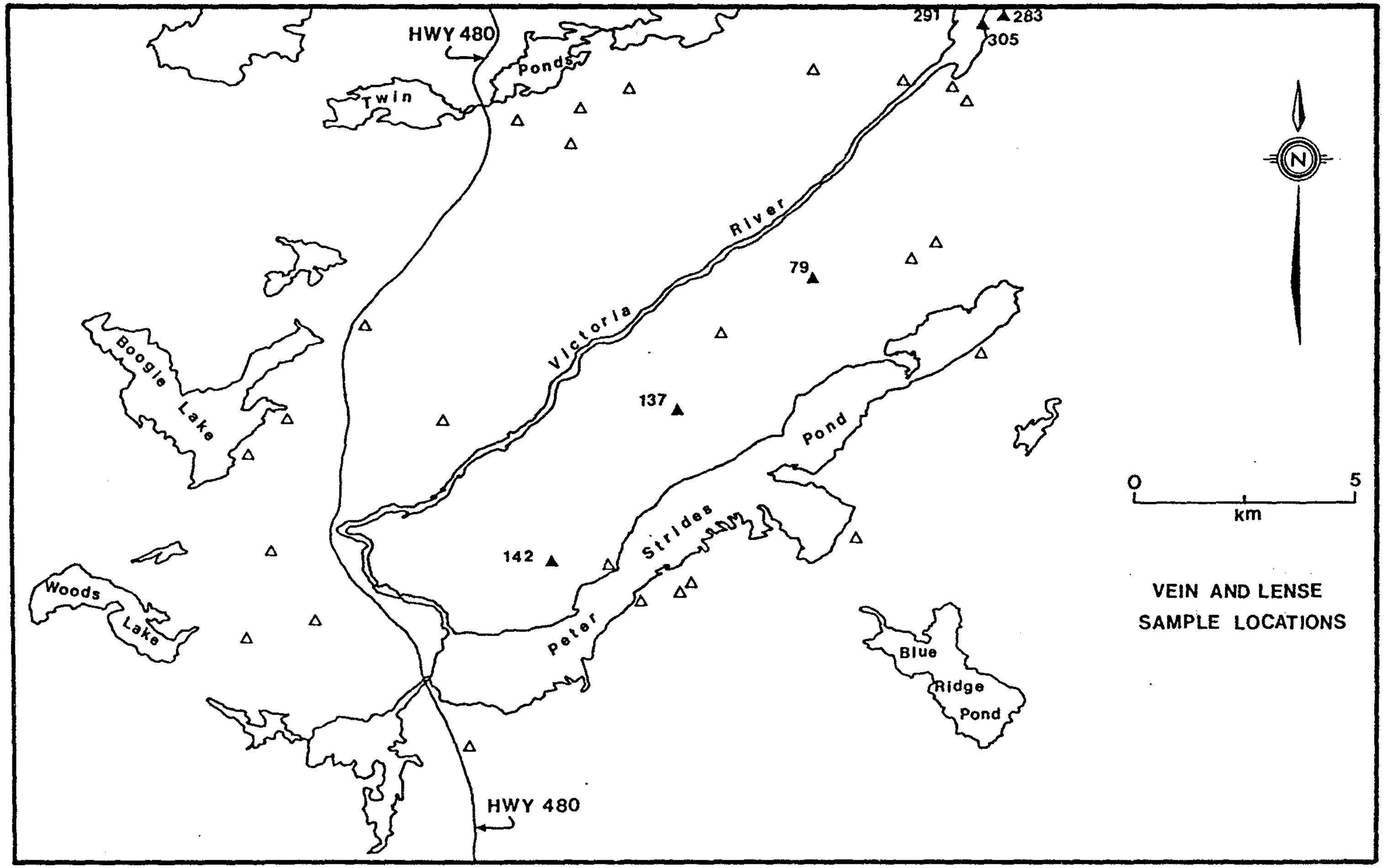
7.1 GENERAL STATEMENT

Veins and lenses represent infilling of fractures by the precipitation of minerals from aqueous fluid and vapor phases (Hancock, 1972; and others). Therefore, these veins and lenses may represent a first order approximation to fractured rock permeability. They may also help clarify fluid composition. Many workers have examined the mechanical (Beach & Fyfe, 1972; Beach, 1977; 1980; Fyfe et al, 1978; Kerrich et al, 1977; 1980; 1984; Etheridge et al, 1984; Mawer, 1986) and chemical role (Price, 1975; Brodie, 1979; Winchester & Max, 1984; Casquet, 1986; Sinha et al, 1986) of fluids in fault-shear zones. Kerrich et al (1984) and others focus on the study of origin, temperature and quantity of fluids transported through fault systems. They also consider fluid evolution through progressive tectonic development.

Quartz, quartz-carbonate and quartz-carbonate-sulphide veins are variably distributed across the study area (Figure 22). These veins and lenses exhibit different habits according to the host lithology and structural setting. Various populations of veins will be discussed individually.

Fine grained basalt of the Victoria Lake Group contains several styles of veins and lenses. Milky white quartz lenses 15 to 20 cm long are sharp walled and tabular. These lenses

Figure 22: Distribution of veins and lenses across the study area. Numbered locations represent samples chosen for further study.


HWY 480
Twin
Ponds
291
283
305
Victoria
River
Boogie
Lake
Woods
Lake
79
137
142
Pond
Peter
Strides
Blue
Ridge
Pond
HWY 480
0
5
km
N
VEIN AND LENSE
SAMPLE LOCATIONS

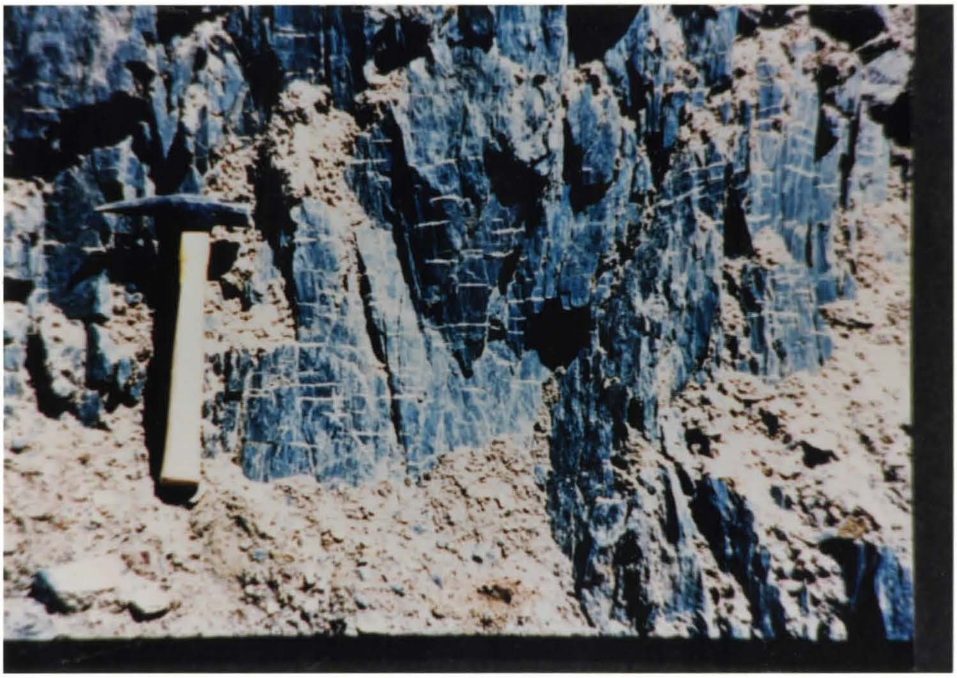
become more abundant, more laterally continuous and have greater carbonate content as fissility increases. Internally massive, sugary carbonate fills sharp-walled fractures associated with a minor, brittle fault through massive and pillowed basalt. These veins, up to 12 cm in width, cut irregularly across massive basalt with no terminations observed (Plate 31). Numerous, elliptical, sharp-walled lenses with blunt terminations are normal to the fabric element through very fissile basalt (chlorite schist) (Plates 32). These lenses, up to 4 cm long and 3 mm wide, are filled with fine grained quartz at the fracture wall before syntaxially textured calcite is deposited. These two styles of veins through mafic volcanic rocks occur over a very confined geographical area and represent the preserved expression of late, positive extension across the study area. Positive vertical extension with an insignificant shear component is suggested by the high degree of fit across adjacent vein walls. A low fluid volume is implied by the extreme rock versus vein ratio.

Heterolithic conglomerate and granoblastic gneiss contain significant, concordant quartz veins and lenses from 10cm to several metres long and 3 to 20 cm wide (Plate 33). These veins are usually very coarse grained, interlocked aggregates of quartz with no carbonate or sulphide minerals present.

In the Peter Strides Pond Shear Zone (PSPSZ), quartz

Plate 31: Sugary, carbonate veins cut irregularly across massive, Victoria Lake Group basalt but terminations are not exposed.

Plate 32: Elliptical lenses with blunt terminations are normal to well developed fabric in fissile basalt (chlorite schist).



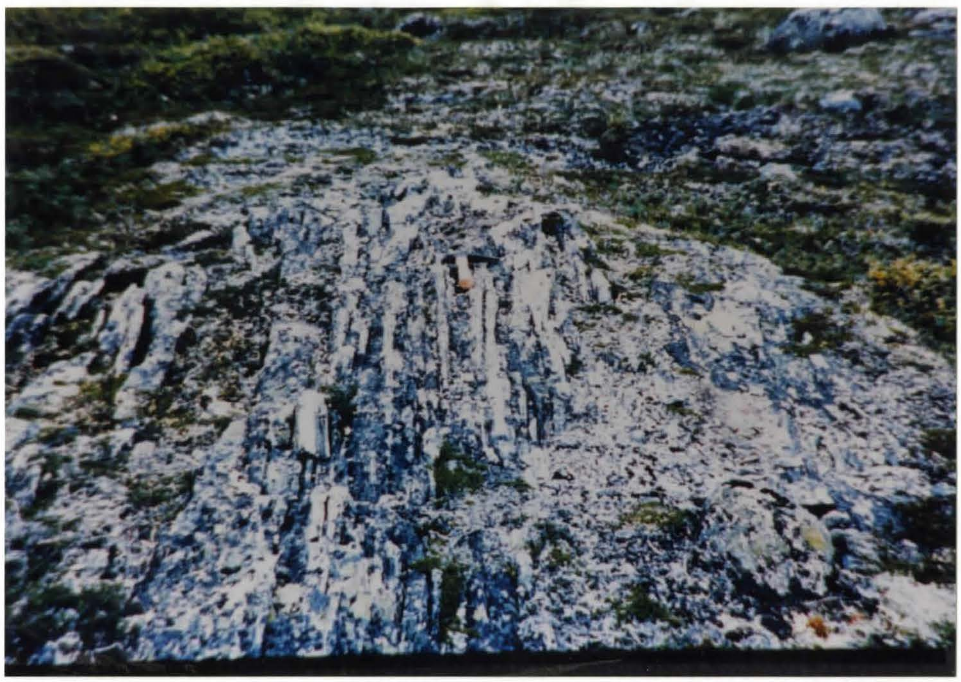


Plate 33: Heterolithic conglomerate shown above hosts significant concordant veins.

veins and lenses are rare. They are typically foliation parallel, internally massive and 30 to 60 cm long, 5 to 7 cm wide. They are milky white with sharp, straight walls and narrow, tapered terminations.

Gabbro, diabase and rhyolite do not contain significant veins or lenses within the study area.

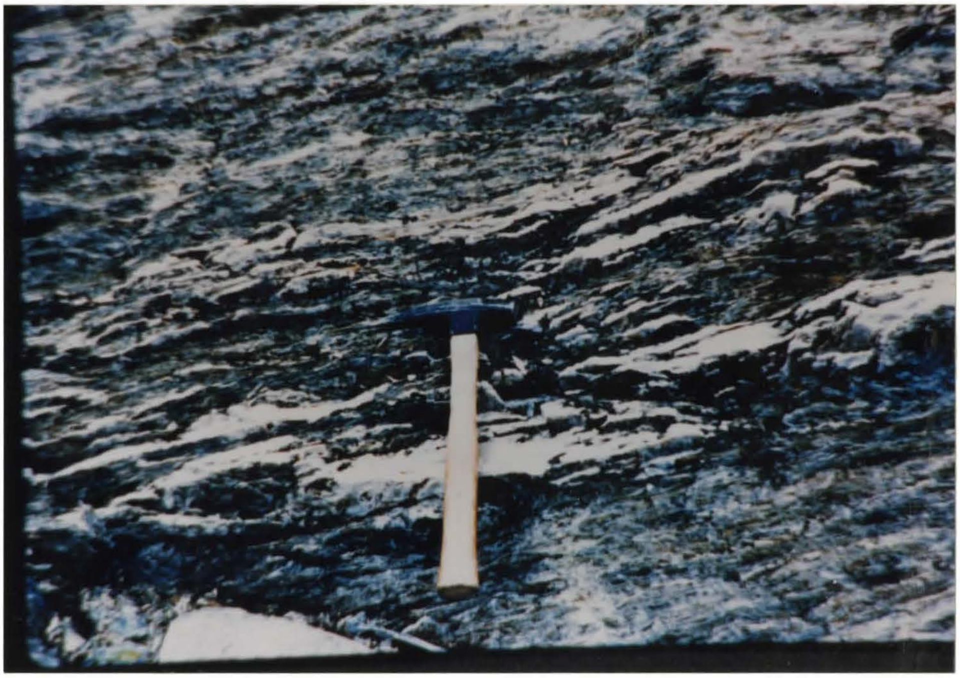
The distribution of veins and lenses do not support temperature and provenance studies related to fluids in fault/shear zones across the study area. The occurrence of veins and lenses will be compared and contrasted within the Victoria River Shear Zone (VRSZ) to those in the adjacent, later felsic pluton. Vein populations for each lithology are considered separately.

7.2 VEINS AND LENSES IN THE VRSZ

In the VRSZ, elongate, tapered lenses are more common than laterally extensive veins and both are usually narrower and shorter than those of the PSPSZ. Veins and lenses are typically sharp walled, straight sided and foliation parallel or discordant at low angles (Plates 34 & 35) but larger veins and lenses are wrapped by the adjacent foliation (Plate 36). Veins may vary in width from 5 to 40 mm. Glassy to milky white, massive quartz may contain pyrite, magnitite and chalcopyrite in trace amounts. Near Victoria Lake, a north to south gradation from vein-poor to vein-rich intervals is noted. Similarly, a vein-poor area in the shear zone near

Plate 34: Quartz veins are typically foliation parallel in the VRSZ.

Plate 35: Locally, VRSZ quartz veins are discordant at low angles to phyllonitic foliation.



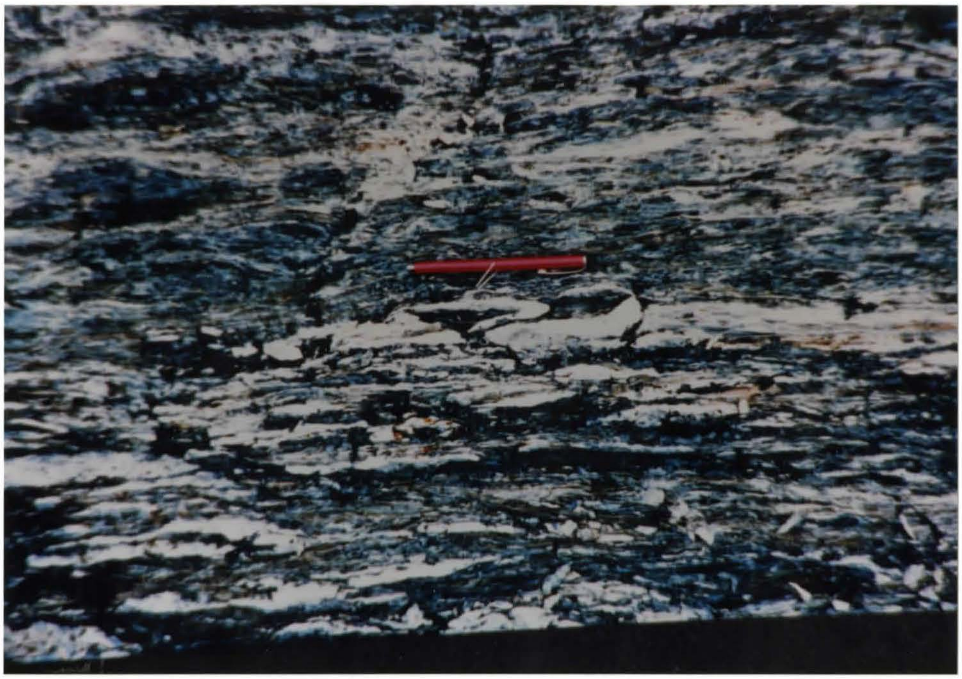


Plate 36: Some veins and lenses are wrapped by the adjacent phyllonitic foliation, VRSZ.

Woods Lake is contrasted to the vein-rich area around Victoria Lake.

In thin section, VRSZ veins display sugary, medium to coarse grained, interlocking quartz aggregates with no preferred grain dimensional orientation. Aggregates are subangular to subround with simple grain boundaries and have abundant, round inclusions to form a dusty texture in plane light. Extinction is strained and mottled. Subgrain development is rare; boundaries are smooth. Randomly oriented, sharp walled dilational fractures are common and extend beyond the grain scale.

Monomineralic, foliation parallel quartz veins from the VRSZ were examined by catholuminescence (CL) methods on a surface parallel to the ground plane. Quartz displays a uniform catholuminescent colour and intensity across the scale of the sample. A lack of significant textural variation suggests that conditions of vein formation must have been relatively uniform from a homogeneous fluid during quartz deposition.

Oxygen isotope signatures on quartz vein samples from the VRSZ differ significantly from similar determinations on felsic intrusive, whole rock samples (Appendix II, Part G). Reasonably close agreement of $\delta^{18}O$ values for each sample grouping implies that individual determinations are valid. Similarly, the value attained for the internal standard is comparable to values reported by Blum (1983). These results suggest the probability of separate fluids to be associated with both the pluton emplacement and vein precipation into the adjacent, permeable deformation zone. Without additional hydrogen isotope and fluid inclusion results, no comment can be made on the source, temperature of emplacement or volume of this fluid.

7.3 VEINS AND LENSES IN THE FELSIC PLUTON

In the felsic pluton north of Peter Strides Pond, laterally continuous veins are more common than elongate, tapered lenses. Adamellite contains most of the quartz veins and lenses; granodiorite is commonly vein-poor. Veins and lenses in the intrusion are of similar form and habit as those of the VRSZ. They are typically milky white, sharp walled, straight sided and concordant to the foliation (Plate 37). Veins may vary in width from <1 to 15 cm. In contrast to the VRSZ population, veins and lenses of the pluton are monomineralic; no calcite, biotite or sulphide has been observed. Veins greater than 2 cm in width exhibit an internal texture of interlocked, recrystallized aggregates.

Petrographically, veins in the pluton are predominantly composed of coarse, subhedral, interlocking grains with simple to serrated grain boundaries. No preferred dimensional orientation is developed in coarse grained quartz. Elongate intervals of fine grained, "fish-scale" quartz aggregates may locally surround coarser quartz grains. These fish-scale

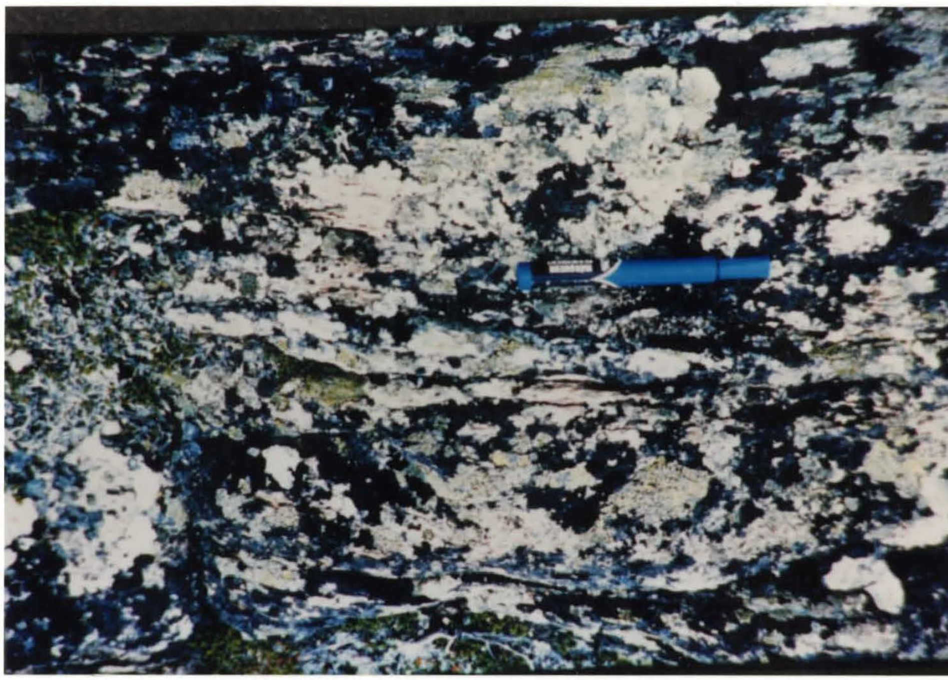


Plate 37: Milky white, coarse grained quartz veins in the felsic pluton are concordant to the foliation and weather in positive relief.

aggregates form a weak fabric by alignment of their long axes parallel to vein margins. Both phases of vein quartz display mottled, undulose extinction with limited subgrain development; subgrain boundaries are relatively simple. Fractures through quartz grains are in random orientations and show no significant displacement.

CL intensity and colour measured from surfaces parallel to the ground plane are uniform across all observed samples. As with the VRSZ vein population, veins of the pluton imply a stable, homogeneous environment of formation but provide no further comment on growth rate, ambient conditions or depositional variation.

The results of oxygen isotope determinations on quartz veins hosted in the pluton are not similar to $\delta^{18}O$ signatures of the VRSZ vein samples. However, they do show significant agreement with whole rock signatures from the felsic intrusion. The confined occurrence of isotopically similar veins and country rock suggests that the veins may have been precipitated from a fluid derived from or circulated through the felsic intrusion. Differing $\delta^{18}O$ signatures for adjacent vein populations implies that circulation of the fluid was of local extent only and there was no mixing of fluids.

Until hydrogen isotope determinations are completed on the veins hosted within the felsic intrusion, an approximation of provenance may be suggested based on several asumptions. If vein precipitation was nearly contemporaneous with pluton emplacement (as suggested by the similarity of vein and whole rock isotopic signatures) and the Devonian U-Pb age represents the time of intrusion, then D values may be estimated from latitude dependent values based on paleomagnetic reconstructions. During the Devonian, Newfoundland occupied latitudes near 20°N (Morel & Irving, 1978) corresponding to D values of about $-80^{0}/_{00}$ (Hitchon & Krouse, 1972). These assumptions coupled with the δ^{18} O determinations suggest either meteroric fluids or primary magmatic fluids (Taylor, 1979) may have precipitated veins within the intrusion. This reasoning is speculative and will be refuted or substantiated after hydrogen analyses are completed. Without the narrow time confinement as determined for the felsic intrusion, similar approximations (prior to δ D determinations) are not possible on vein material within the VRSZ.

CHAPTER 8: INTERPRETATIONS

8.1 DISCUSSION

Outcrop is limited across the study area and contacts are not exposed. Consequently, stratigraphic interpretations, integration of evidence into the plate tectonic framework and the ordering of events are quite tentative.

The stratigraphic succession across the study area is difficult to establish. Regionally extensive mafic to intermediate volcanic rocks of the Victoria Lake Group and metamorphic equivalents of the Bay du Nord Group are probably the oldest north-east striking lithologies in the study area. Psammitic to calcareous gneisses are undated within the area of investigation. They are correlated with parts of the Bay du Nord Group to the south and southwest which have been radiometrically dated at 449±20 Ma (Dallmeyer, 1979). A U-Pb (zircon) age of 462±3 Ma for the Victoria Lake Group (Dunning et al, 1987) accords with the lower to middle Ordovician conodont evidence of Stouge (1980). Kean (1983) regards the Victoria Lake and Bay du Nord Groups as synchronous units of middle Ordovician or older age, deformed and metamorphosed simultaneously. They thus form a single metamorphic series but represent different structural levels now brought to the same level by faulting.

Heterolithic conglomerate and the adjacent mafic volcanic rocks of the Victoria Lake Group are separated by a fault modified unconformity (Kean, 1983). The conglomerate contains both volcanic and sedimentary clasts derived from the underlying group so defining it as younger than the volcanic rocks.

Granodiorite, adamellite, diabase, diorite and gabbro intrude the rocks of the Victoria Lake and Bay du Nord Groups across the study area. The mafic intrusions are undated but may possibly be coeval with the more felsic compositions so forming a complete spectrum of differentiation products. A lack of internal fabric in the mafic rocks as compared with the felsic intrusions, suggests that the diabase, diorite and gabbro were emplaced after regional deformation had occurred. Alternatively, the mafic intrusions may have been emplaced during a deformational episode but beyond the limits of its influence. By the same argument, granodiorite and adamellite were emplaced during a period, and within the influence of, regional deformation. Radiometric age determinations on the felsic pluton suggest an early Devonian intrusion age with some middle Proterozoic contribution to the magma.

Parallel mylonite zones cut across volcanic and sedimentary rocks of the Victoria Lake Group and along the contact between the felsic intrusion north of Peter Strides Pond and Bay du Nord gneiss. Cross cutting relations of the mylonite zones suggest that deformation across the study area was relatively late in the regional framework, probably middle

Devonian or later. These deformation zones are considered as late adjustments in response to continued tectonic compression.

Megacrystic granite cross cuts adamellite, PSP mylonite and Bay du Nord gneiss. It must be the youngest igneous intrusion in the study area. Van Berkel et al (1986) assign the megacrystic granite to the upper Devonian.

The youngest unit in the study area is rhyolite of the Windsor Point Group which unconformably overlies the Victoria Lake Group in this area and several ophiolitic segments beyond the limits of the study area (Van Berkel et al, 1986). Sedimentary interbeds in the rhyolite have been dated as late Devonian to earliest Carboniferous, based on plant fossils (Kean, 1983).

The northeast-southwest linear distribution of lithologies and concordant internal fabric across the study favours a traditional subduction/compressional tectonic framework for this portion of the Newfoundland Appalachians as opposed to the equant tessellate terranes advocated in the Wopmay and Cordilleran regions (Figure 23).

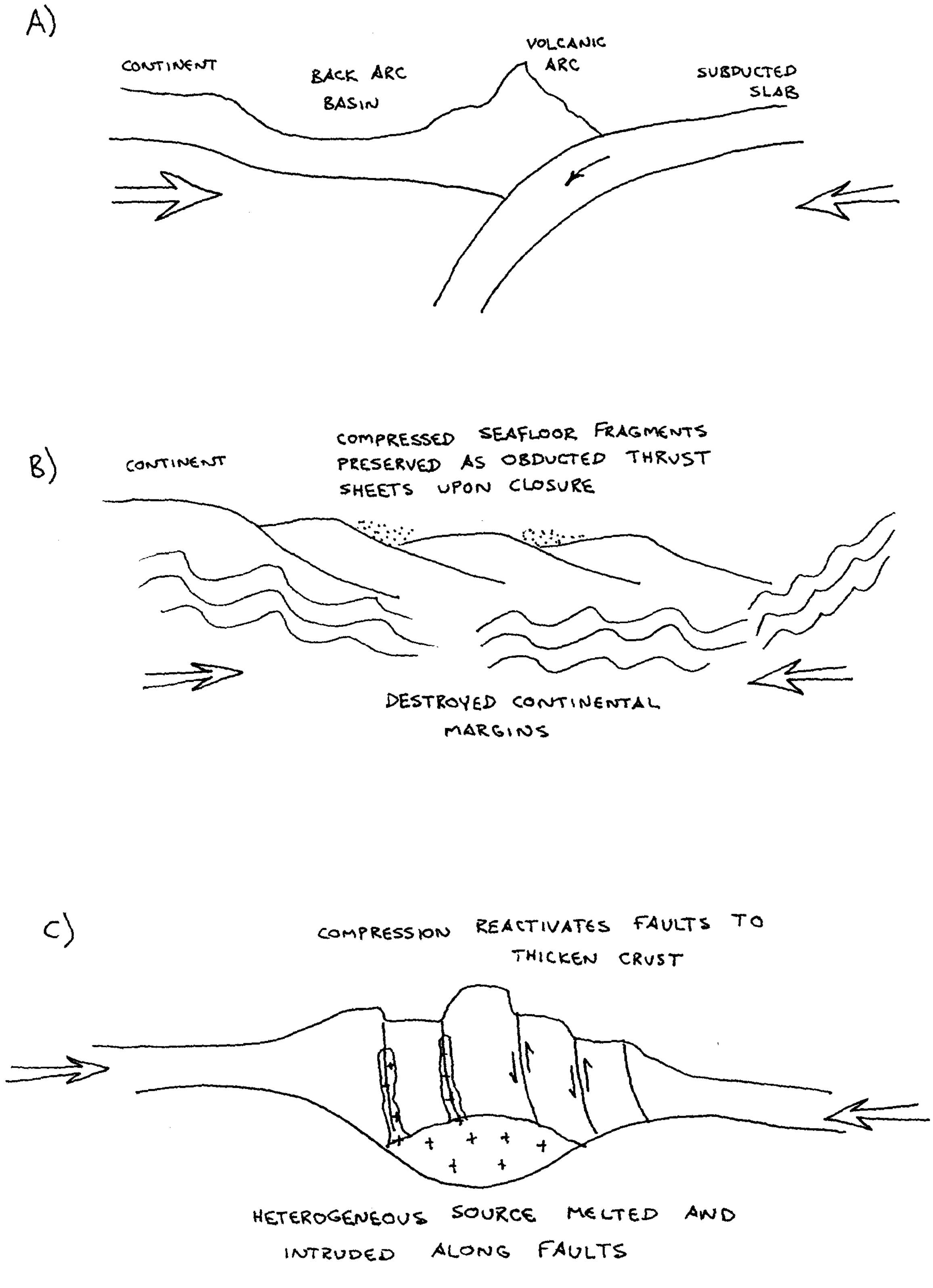
Stratigraphic and geochemical data from the Victoria Lake Group and other sedimentary and volcanic sequences in the Grandy's Lake area suggest that the Central Volcanic Belt represents an island arc complex built upon oceanic crust. Oceanic crust may be tectonically underlain by continental crust near belt margins (Kean et al, 1981). Development of

Figure 23: Cartoon depicting the possible sequential development of the study area.

(A) Formation of a Japanese-style island arc at the destructive plate boundary during Cambro-Ordovician Iapetus closure by subduction.

(B) Final Iapetus closure destroys the island arc however, portions of the arc are preserved as obducted thrust slices onto the continental margin. Weathering and erosion of the exposed imbricate thrusts provides the detritus for the volcanicastic and epiclastic sequences.

(C) Continued compression reactivates pre-existing faults and initiates new splays to thicken the crust at the continental margin. Thickening of the crust induces melting and results in the formation of a heterogeneous magma. After the emplacement of the magma, futher displacement along fault splays imparts a foliation to lithologies proximal to the zones. Uplift and erosion exposes successively deeper portions of the crust at the common level presently observed.


A)
CONTINENT
BACK ARC
BASIN
VOLCANIC
ARC
SUBDUCTED
SLAB
B)
CONTINENT
COMPRESSED SEAFLOOR FRAGMENTS
PRESERVED AS OBDUCTED THRUST
SHEETS UPON CLOSURE
DESTROYED CONTINENTAL
MARGINS
C)
COMPRESSION REACTIVATES FAULTS TO
THICKEN CRUST
HETEROGENEOUS SOURCE MELTED AND
INTRUDED ALONG FAULTS

this arc complex beyond the present study area seems to have occurred in two stages. Early, lower to middle Ordovician and late, upper Ordovician to Silurian volcanic sequences are separated by a quiescent Caradocian stage characterized by the deposition of graptolitic black shale and argillite (Strong, 1977; Dean, 1978; Kean et al, 1981). The Victoria Lake Group is correlated with the early phase of arc formation (Kean et al, 1981). Rb-Sr isochron ages of 447±18 Ma for the Buchans Group (Bell & Blenkinsop, 1981) and 447±7 Ma for the Roberts Arm Group (Bostock et al, 1979) were taken as support for late Ordivician arc formation. However, new U-Pb (zircon) ages of 473±3 and 473±2 Ma for the Buchans and Roberts Arm Groups respectively show them to be early Ordovician sequences. The Victoria Lake Group yields an age of 462±3 Ma (Dunning et al, 1987). Therefore, early versus late volcanic subdivisions to arc development are invalid. Rapid arc formation during late Cambrian to early Ordovician times was followed by equally sudden although incomplete destruction during late Ordovician to early Silurian Iapetus closure. Precambrian zircons incorporated into the Victoria Lake Group imply that the unit may have formed in a tectonic environment transitional between oceanic and continental settings (Dunning et al, 1987).

Felsic plutonism of variable composition in the Appalachian Orogen may provide evidence to reconstruct portions of the tectonic history in southwestern Newfoundland. Strong (1980) notes that most felsic intrusions were emplaced during a 100 Ma interval between the Silurian and Carboniferous, following Iapetus closure (Table 3). Strong & Dickson (1978) and Strong (1980) show that these plutons were emplaced in several local tectonic environments, both compressional and extensional. In this respect, Newfoundland plutons are unlike the subduction- related batholiths of the Eastern Pacific margin. Newfoundland plutons may have been produced in an overall megashear environment through the middle to late Paleozoic. Plutonism with a host of local sources may have followed crustal thickening from continued compression and shearing by plate collision/rotation (Strong, 1980; Hanmer, 1981). The available geochemical data suggest a crustal origin for felsic intrusions in southwestern Newfoundland. The application of S-I type classification provides ambiguous results and may imply that the restite model may not be simply applied to Newfoundland suites. This observation supports the concept of continued compressional thickening to provide a variety of crustal compositions available for melting. The inhomogeneity of the thickened crust in imbricated thrust sheets is reflected in the variable restite composition observed as intrusions over a confined area.

In summary, the following sequence of events is envisioned for the study area and more generally, part of the Newfoundland Appalachians. It is based on the observations and evidence in this field area in addition to the results of

DUNNAGE ZONE GRANITOID INTRUSIONS

DUNNAGE SUBDIVISIONS	INTRUSION	AGE	WORKER
Fleur de Lys	Dunamgon	429±10	DeGrace *et al*, 1976
	La Scie	328±25	Bell & Blenkinsop, 1975
	Burlington Granodiorite	(375)	Degrace *et al*, 1976
	Wild Cove	(358)	Strong, 1980
Notre Dame	Cape Brule	338±14 393±25	Strong, 1980
	Sandy Cove	464±13	Bostock 1978
Exploits	Long Island	(440)	Strong 1980
	Buchans Feeder	426±50	Bell & Blenkinsop, 1981
	Topsails	436±5 402±9	Bell & Blenkinsop, 1981

Table 3: Intrusions across the Dunnage Zone, similar to the pluton north of Peter Strides Pond. The age of emplacement is consistently post Cambro-Ordovician Iapetus closure. Braketed ages were determined by the K-Ar method. Ages without brackets were determined by the Rb-Sr method.

other Newfoundland workers.

1) At the destructive plate boundary of west dipping Iapetus subduction beneath the (future Humber Zone) continent, an island arc complete with a back arc basin is formed overlying continental basement. This situation is analogous to present day Japan.

2) As subduction proceeds toward completion and the Iapetus closes during the Cambro-Ordovician, portions of the volcanic arc, particularly the back arc basin, are obducted onto the continental margin as imbricate thrust sheets. Oceanic crust of the back arc basin is preserved today as ophiolitic sequences of the King George IV Lake and Annieopsquotch Complexes beyond the study area. The basal decollement along which obduction occurred has not been recognized. Geochemically, volcanic rocks of the Victoria Lake Group still retain the arc signature.

3) As these imbricated thrust sheets are exposed at the surface, a spectrum of rock types with a range of metamorphic signatures (reflecting burial depth) become subject to weathering and erosion. Detritus is shed and incorporated into volcaniclastic and epiclastic sequences. The heterolithic conglomerate of the study area accumulated in a sedimentary basin and included clasts from the Victoria Lake Group volcanic pile.

4) Continued tectonic compression after Iapetus closure had two effects. Compression was accomodated by crustal thickening along imbricate, low angle reverse thrust faults. The Cape Ray and Long Range Faults are examples of these regional scale structures. They have significant displacement, indicated by the changes in rock type associated with separate tectonostratigraphic zones. These faults are major tectonic boundaries and may have become active during earliest obduction with periodic reactivation as compression continued. Compression also induced crustal melting in a narrow time span after Iapetus closure. The variety of intrusion compositions and the range of radiometric ages (depending on the method of determination) hint at an inhomogeneous basement as a melt source for a portion of this magma reflecting the variable compostion of successive

thrust slices. The intrusion north of Peter Strides Pond demonstrates this possibility. The pluton yields a 389±20 Ma intrusive age by U-Pb methods; its Nd signature yields a model age of 1175±10 Ma. The two ages are best explained by the acquisition of some melt from an evolved crust perhaps of middle Proterozoic age.

5) Across the study area, tectonic compression is accomodated not so much by reactivation of major structures but rather by the formation of parallel fault splays which merge with the Cape Ray Fault to the south beyond the area of investigation. These splays termed the PSPSZ and the VRSZ are northwest-directed reverse faults with some component of sinistral displacement. Sinistral displacement may be of limited extent because there is no offset of lithologies observed across the fault. However, thrust displacements must be of the kilometer scale as both rock type and metamorphic grade change across the fault. These deformation zones may also have served as conduits for focused fluid flow as suggested by the significant occurrence of foliation parallel quartz veins and lenses in the VRSZ.

8.2 CONCLUSIONS

The essential results from this study are:

1) Fine grained, homogeneous basalt from across the study area falls within the oceanic/volcanic arc field of geochemical classification which is consistent with the tectonic setting of the Dunnage Zone.

2) The felsic pluton north of Peter Strides Pond has been radiometrically dated as 389±20 Ma by U/Pb methods but the intrusion has an 1175±10 Ma Sm/Nd model age. This suggests a contribution to the magma by middle Proterozoic or older, continental basement.

3) Kinematic indicators indicate that displacement along two, regional-scale, parallel deformation zones has a sinistral component with southeast side up motion to expose successively deeper sections of the crust at the surface. A stepwise

increase in metamorphism of higher grade to the south across the study area supports this interpretation.

4) Oxygen isotopic signatures imply a meteoric or magmatic source for fluids which precipitated veins and lenses across the VRSZ and the felsic pluton. Internal isotopic variation between vein populations suggests that differing fluids precipitated each vein population. Veins within the pluton have a similar isotopic signature to the intrusion. Veins within the deformation zone appear unrelated to the felsic intrusion. Widespread fluid circulation may be related to the heat generated during plutonism.

5) A general lack of visible sulphide minerals and gossan in addition to poor assay results suggests that the base metal and precious metal potential of the study area is low.

6) The tectonic interpretation for the study area is based on geochemical and structural evidence and correlates well with the zonal, regional framework as proposed by many Newfoundland workers.

8.3 RECOMMENDATIONS FOR FURTHER STUDY

Beyond this study, other topics which might be addressed within the available rock suite include the following:

1) To characterize any elemental mobility during deformation, major and trace element content across both shear zones might be determined (the sample transect would be normal to shear zone boundaries with a spacing to be determined by exposure).

2) To propose a protolith to PSPSZ mylonite or a possible source for granodiorite intervals/pods in adamellite, major and trace element content of surrounding lithologies, particularly granoblastic gneiss, should be determined and compared to granodiorite and adamellite analyses.

3) To confirm the interpretation of middle Proterozoic basement as a partial component of the felsic pluton and to establish a potential mixing history, additional Sm/Nd analyses should be performed on the pluton.

4) To better define source, temperature and volume for the fluid which precipitated the veins and lenses across the study area, hydrogen isotope analyses coupled with fluid inclusion microscopy should be performed.

These results would contribute significantly to a better understanding of the tectonic/deformational history in this area of southwestern Newfoundland.

REFERENCES

ANDREWS AJ [1977] Low temperature fluid alteration of oceanic Layer II basalts, DSDP Leg 37. Canadian Journal of Earth Sciences 14 911-926

ARNDT NT & GOLDSTEIN SL [1987] Use and abuse of crust-formation ages. Geology 15 893-895

BAK J, KORSTGARD J & SORENSEN KA [1975] Major shear zone within the Nagssugtoqidian of West Greenland. Tectonophysics 27 191-209

BARKER DS [1970] Granophyre, myrmekite and graphic granite. Geological Association of America Bulletin 81 3339-3350

BEACH A [1975] The geometry of en-echelon vein arrays. Tectonophysics 28 245-263

BEACH A [1977] Vein arrays, hydraulic fractures and pressure solution structures in a deformed flysch sequence, SW England. Tectonophysics 40 201-225

BEACH A [1980] Numerical models of hydraulic fracturing and the interpretation of syntectonic veins. Journal of Structural Geology 2 425-438

BEACH A & FYFE WS [1972] Fluid transport and shear zones at Scourie, Sutherland: evidence of overthrusting? Contributions to Mineralogy and Petrology 36 175-179

BECKINSALE RD [1979] Granite magmatism in the tin belt of southeast asia. In Origin of Granite Batholiths: Geochemical Evidence. Edited by M.P. Atherton and J. Tarney, Shiva Publishing Limited; p. 34-44

BELL K & BLENKINSOP J [1875] Geochronology of eastern Newfoundland. Nature 254 410-411

BELL K & BLENKINSOP J [1981] A geochronological study of the Buchans area, Newfoundland. In The Buchans Orebodies: fifty years of geology and mining. Edited by E.A. Swanson, D.F. Strong and J.G. Thurlow, Geological Association of Canada, Special Paper 22 91-112

BERTHE D, CHOUKROUNE P & JEGOUZO P [1979] Orthogneiss, mylonite and non-coaxial deformation of granites: the example of the South Armorican Shear Zone. Journal of Structural Geology 1 31-42

BIRD JM & DEWEY JF [1970] Lithosphere plate-continental margin tectonics and the evolution of the Appalachian Orogen. Geological Survey of America Bulletin 81 1031-1060

BLACKWOOD RF [1978] Northeastern Gander Zone, Newfoundland. In Report of Activities for 1977. Edited by R.V. Gibbons, Newfoundland Department of Mines and Energy, Mineral Development Division. Report 78-1 72-79

BLACKWOOD RF & KENNEDY MJ [1975] The Dover Fault: western boundary of the Avalon Zone in northeastern Newfoundland. Canadian Journal of Earth Sciences 12 320-325

BLUM N [1986] Geochemical studies of the Archean iron formations and associated volcanic rocks (Kirkland Lake and Temagami Ontario areas). Ph. D. thesis, McMaster University, Hamilton, Ontario, 410 pp.

BOSTOCK HH [1978] The Roberts Arm Group, Newfoundland: geological notes on a middle or upper Ordovician island arc environment. Geological Survey of Canada. Paper 78-15, 21 pp.

BOSTOCK HH, CURRIE K & WANLESS R [1979] The age of the Roberts Arm Group, north-central Newfoundland. Canadian Journal of Earth Sciences 6 599-606

BOYLE RW [1979] The geochemistry of gold and its deposits. Geological survey of Canada, Bulletin 280, 584 pp.

BRODIE KH [1979] Variations in mineral chemistry across a shear zone in phlogopite peridotite. Journal of Structural Geology 2 265-272

BROWN PA [1973] Possible cryptic suture in southwest Newfoundland. Nature, Physical Sciences 245 (140) 9-10

BROWN PA [1975] Basement-cover relations in southwest Newfoundland. Ph. D. thesis. Memorial University of Newfoundland, 221 pp.

BROWN PA [1976] Ophiolites in south-western Newfoundland. Nature (London) 264 712-715

BROWN PA [1977] Geology of the Port aux Basques area (110/11), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-2, 11 pp.

BUISSON G & LEBLANC M [1985] Gold in carbonatized ultramafic rocks from ophiolite complexes. Economic Geology 80 2028-2029

CASQUET C [1986] C-O-H-N fluids in quartz segregations from a major ductile shear zone: the Berozsa fault, Spanish Central System. Journal of Metamorphic Geology 4 117-130

CHANDLER FW [1982] Sedimentology of two middle Paleozoic terrestrial sequences, King George IV Lake area, Newfoundland and some comments on regional paleoclimate. In Current Research, Part A, Geological Survey of Canada, Paper 82-1A, 213-219

CHAPPELL BW [1974] Two contrasting granite types. Pacific Geology 8 173-174

CHORLTON LB [1978] Geology of the La Poile area (110/9), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-5, 14 pp.

CHORLTON LB [1980] Geology of the La Poile River area (110/16), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-3, 86 pp.

CHORLTON L [1983] Geology of the Grandys Lake area (110/15), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-7, Part 1, 116 pp.

CHURCH WR & STEVENS RK [1971] Early Paleozoic ophiolite complexes of the Newfoundland Appalachians as mantle-oceanic crust sequences. Journal of Geophysical Research 76(5) 1460-1466

CLAYTON RN & MAYEDA TK [1963] The use of bromine pentafluoride in the extraction of oxygen from oxides and silicates for isotopic analysis. Geochimica et Cosmochimica Acta 27 43-52

COBBOLD PR [1971] Description and origin of banded deformation structures: Regional strain, local perturbations and deformation bands. Canadian Journal of Earth Sciences 14 1721-1731

COBBOLD PR, COSGROVE JW & SUMMERS JM [1971] Development of internal structure in deformed anisotropic rocks. Tectonophysics 12 23-53

COISH RA, HICKEY R & FREY FA [1982] Rare earth element geochemistry of the Betts Cove ophiolite, Newfoundland: complexities in ophiolite formation. Geochemica et Cosmochimica Acta 46 2117-2134

CONDIE KC [1973] Archean magmatism and crustal thickening. Geological Society of America 85 2981-2992

COOPER JR [1954] The La Poile-Cinq Cerf map area, Newfoundland. Geological Survey of Canada, Memoir 254, 62 pp.

COSGROVE JW [1976] The formation of crenulation cleavage. Journal of the Geological Society of London 132 155-178

DALLMEYER RD [1979] Geochronology-insular Newfoundland mapping, progress report 6/1/79-11/1/79. Canada-Newfoundland Mineral Development Subsidiary Agreement (1977-1982), Subproject 1-20, unpublished report, 7 pp.

DEAN PL [1977] A report on the metallogeny of the Notre Dame Bay area to accompany metallogenic maps 12H/1,8,9 and 2E/3,4,5,6,7,9,10,11,12. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-10, 17 pp.

DEAN PL [1978] The volcanic stratigraphy and metallogeny of Notre Dame Bay, Newfoundland. Memorial University of Newfoundland, Geology Report 7, 204 pp.

DEGRACE JR [1973] Notes on the geology of the King George IV Lake area, southwest Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Divison, unpublished report, 12 p. Open File 12A/4 (131)

DEPAOLO DJ [1981] Nd isotopic studies: some new perspectives on earth structure and evolution. EOS 62(14) 137-145

DEWEY JF [1969] The evolution of the Caledonian/Appalachian Orogen. Nature 222 124-128

DEWEY JF & BIRD JM [1971] Origin and emplacement of the ophiolite suite: Appalachian ophiolites in Newfoundland. Journal of Geophysical Research 76 3179-3206

DICKSON WL & MACLELLAN HE [1981] Geology of the Wolf Mountain (12A/2W) and Burnt Pond (12A/3E), central Newfoundland In Current Research. Edited by C.F. Driscoll and R.V. Gibbons, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-1, 96-102

DUNNING GR [1981] The Annieopsquotch ophiolite belt, southwest Newfoundland. In Current Research, Part B, Geological Survey of Canada, Paper 81-1B, 11-15

DUNNING GR [1984] The geology, geochemistry, geochronology and regional setting of the Annieopsquotch Complex and related rocks of southwest Newfoundland. Ph.D. thesis, Memorial University of Newfoundland, St. John's, Newfoundland.

DUNNING GR [1987] Geology of the Annieopsquotch Complex, southwest Newfoundland. Canadian Journal of Earth Sciences 24 1162-1174

DUNNING GR & CHORLTON LB [1985] The Annieopsquotch ophiolite belt of southwest Newfoundland: geology and tectonic significance. Geological Society of America Bulletin 96 1466-1476

DUNNING GR & HERD RK [1980] The Annieopsquotch ophiolite complex, southwest Newfoundland, and its regional relationships. In Current Research, Geological Survey of Canada, Paper 80-1A, 227-234

DUNNING GR & KROGH TE [1985] Geochronology of ophiolites of the Newfoundland Appalachians. Canadian Journal of Earth Sciences 22 1659-1670

DUNNING GR, KEAN BF, THURLOW JG, & SWINDEN HS [1987] Geochronology of the Buchans, Roberts Arm, and Victoria Lake Groups and Mansfield Cove Complex, Newfoundland. Canadian Journal of Earth Sciences 24 1175-1184

DURNEY DW & RAMSAY JG [1973] Incremental strains measured by syntectonic crystal growths. In Gravity and Tectonics. Edited by K.A. DeJong and R. Scholten, Wiley and Sons; New York; p. 67-96

EISBACHER GH [1970] Deformation mechanics of mylonite rocks and fractured granulites in Cobequid Mountains, Nova Scotia, Canada. Geological Society of America Bulletin 81 2009-2020

ETCHECOPAR A [1977] A plane kinematic model of progressive deformation in a polycrystalline aggregate. Tectonophysics 39 121-139

ETHERIDGE MA, WALL VJ & COX SF [1984] High fluid pressures during regional metamorphism and deformation: implications for mass transport and deformation mechanisms. Journal of Geophysical Research 89(B6) 4344-4358

EVANS DTW & KEAN BF [1986] Geology of the Jacks Pond volcanogenic massive sulphide prospects, Victoria Lake Group, central Nwfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, 59-64

FAURE G [1986] Principals of Isotope Geology. John Wiley and Sons; Toronto; 589 pp.

FLETCHER RC [1977] Quantitative theory for metamorphic differentiation in development of crenulation cleavage. Geology 5 185-187

FOX D & VAN BERKEL JT [1988] Mafic-ultramafic occurrences in metasedimentary rocks of southwestern Newfoundland. In Current Research, Part B, Geological Survey of Canada. Paper 88-1B, 41-48

FYFE WS [1986] Fluids in the deep continental crust. Reflection Seismology: The Continental Crust. Geodynamics Series 14 33-39

FYFE WS & KERRICH R [1985] Fluids and thrusting. Chemical Geology 49 353-362

FYFE WS, PRICE NJ & THOMPSON AR [1978] Fluids in the Earth's Crust. Elsevier Scientific Publishing Company; Amsterdam; 383 pp.

GAVINDARAJU K [1984] Compilation of working values and sample description for 170 international reference samples of mainly silicate rocks and minerals. Geostandards Newsletter 8 3-16

GUILBERT JM & PARK CF Jr. [1986] The Geology of Ore Deposits. W.H. Freeman and Company; New York; 985 pp.

GEOLOGICAL SURVEY OF CANADA [1968] Aeromagnetic Series Map, King George IV Lake, Newfoundland. Map 207G (Revised).

HANCOCK PL [1972] The analysis of en-echelon veins. Geology Magazine 109 269-276

HANMER S [1981] Tectonic significance of the northeastern Gander Zone, Newfoundland: an Acadian ductile shear zone. Canadian Journal of Earth Sciences 18 120-135

HANSON GN [1980] Rare earth elements in petrogenetic studies of igneous systems. Annual Reveiws of Earth and Planetary Sciences 8 371-406

HARRIS LB & COBBOLD PR [1984] Development of conjugate shear bands during bulk simple shearing. Journal of Structural Geology 7 37-44

HART SR, ERLANK AJ & KABLE EJD [1974] Sea floor basalt alteration: some chemical and Sr isotopic effects. Contributions to Mineralogy and Petrology 44 219-230

HAWORTH RT, LEFORT TP & MILLER HG [1978] Geophysical evidence for an east-dipping Appalachian subduction zone beneath Newfoundland. Geology 6(9) 522-526

HERD RK & DUNNING GR [1979] Geology of the Puddle Pond map area, southwestern Newfoundland. In Current Research, Part A, Geological Survey of Canada, Paper 79-1A, 305-310

HERMANN AB, POTTS MJ & KNAKE D [1974] Geochemistry of rare earth elements in spilites from the oceanic and continental crust. Contributions to Mineralogy and Petrology 44 1-16

HEYL GH [1936] Geology and mineral deposits of the Bay of Exploits area. Geological Survey of Newfoundland, Bulletin 3, 66 pp.

HIBBARD JP, STOUGE S & SKEVINGTON D [1977] Fossils from the Dunnage Melange, north central Newfoundland. Canadian Journal of Earth Sciences 14 1176-1178

HINE R, WILLIAMS IS, CHAPPELL BW & WHITE AJR [1973] Contrasts between I- and S-type granitoids of the Kosciusko batholith. Journal of the Geological Society of Austraila 15 219-234

HITCHON B & KROUSE HR [1972] Hydrogeochemistry of surface waters of the Mckenzie River drainage basin Canada, III. Stable isotopes of oxygen, carbon and sulphur. Geochimica Cosmochim. Acta 37 1899-1903

HOBBS BE, MEANS WD & WILLIAMS PF [1976] An Outline of Structural Geology. Wiley; New York; 571 pp.

HODGSON CJ, CHAPMAN RSG & MACGEEHAN PJ [1982] Application of exploration criteria for gold deposits in the Superior Province of the Canadian Shield to gold exploration in the Cordillera. In Precious Metals in the Northern Cordillera. Edited by A.A. Levinson, The Association of Exploration Geochemists 173-206

HOLLISTER VF, POTTER RR & BARKER AL [1974] Porphyry type deposits of the Appalachian Orogen. Economic Geology 69 618-630

HORNE GS [1969] Early Ordovician chaotic deposits in the central volcanic belt of Northeast Newfoundland. Geological Society of America Bulletin 80 2451-2464

HUGHES CJ [1973] Spilites, keratophyres and the igneous spectrum. Geological Magazine 109 513-527

HUGHES CJ & MALPAS JG [1971] Metasomatism in the Precambrian Bull Arm Formation in southeastern Newfoundland: recognition and implications. Geological Association of Canada Proceedings 24 85-93

HUTCHINSON RW [1973] Volcanogenic sulphide deposits and their metallogenic significance. Economic Geology 68 1223-1243

HUTCHINSON RW [1980] Massive base metal sulphides as guides to tectonic evolution. In The continental crust and its mineral deposits. Edited by D.W. Strangway, Geological Association of Canada Special Paper 20, 659-684

IRVINE TN & BARAGAR WRA [1971] A guide to the chemical classification of the common volcanic rocks. Canadian Journal of Earth Sciences 8 524-548

JEGOUZO P [1980] The South Armorican shear zone. Journal of Structural Geology 2 39-47

KAY M [1967] Stratigraphy and structure of northeastern Newfoundland bearing on drift in North Atlantic. American Association of Petroleum Geologists Bulletin 51 579-600

KAY M [1975] Campbellton sequence, manganiferous beds adjoining the Dunnage Melange, northeastern Newfoundland. Geological Society of America Bulletin 86 105-108

KAY M [1976] Dunnage Melange and subduction of the Protoacadic Ocean, Northeastern Newfoundland. Geological Society of America Special Paper 175, 49 pp.

KAY M & COLBERT EH [1965] Stratigraphy and life history. John Wiley; New York; 736 pp.

KEAN BF [1976] Geology of the Victoria Lake map area, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 76-6

KEAN BF [1977] Geology of the Victoria Lake map area (12A/6), Newfoundland Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-4, 11 pp.

KEAN BF [1979] Star Lake map area, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 79-1

KEAN BF [1983] Geology of the King George IV Lake map area (12A/4). Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-4, 67 pp.

KEAN BF & JAYASINGHE NR [1980] Geology of the Lake Ambrose (12A/10)-Noel Paul's Brook (12A/9) map areas, central Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-2, 29 pp.

KEAN BF & JAYASINGHE NR [1981] Geology of the King George IV map area (12A/4), Newfoundland. In Current Reasearch, Edited by C.F. O'Driscoll and R.V. Gibbons, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-1, 32-39

KEAN BF & JAYASINGHE NR [1982] Geology of the Badger map area (12A/16), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-2, 37 pp.

KEAN BF & EVANS DTW [1986] Metallogeny of the Tulks Hill Volcanics, Victoria Lake Group, central Newfoundland. Current Research (1986), Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, 51-57

KEAN BF & MERCER NL [1981] Grand Falls map area (2D/13), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division. Map 81-99, with marginal notes.

KEAN BF & STRONG DF [1975] Geochemical evolution of an Ordovician island arc of the Central Newfoundland Appalachians. Americian Journal of Science 275 97-118

KEAN BF, DEAN PL & STRONG DF [1981] Regional geology of the Central Volcanic Belt of Newfoundland. In The Buchans Orebodies: fifty years of geology and mining. Edited by E.A. Swanson, D.F. Strong, and J.G. Thurlow. Geological Association of Canada, Special Paper 22, 65-78

KENNEDY MJ [1976] Southeastern margin of the Northeastern Appalachians: Late Precambrian orogeny on a continental margin. Geological Society of America Bulletin 87 1317-1325

KEPPIE JD [1986] The Appalachian collage. In The Caledonide Orogen, Scandinavia and Related Areas. Edited by D.E. Gee and B. Sturt. John Wiley and Sons Inc.; New York.

KERRICH R [1981] Archean gold-bearing chemical sedimentary rocks and veins: a synthesis of stable isotope and geochemical relations. In Genesis of Archean, Volcanic Hosted Gold Deposits. Edited by E.G. Pye and R.G. Roberts, Ontario Geological Survey, Miscellaneous Paper 97 144-167

KERRICH R & FRYER BJ [1981] The separation of rare elements from abundant base metals in Archean lode gold deposits: implications of low water/rock source regions. Economic Geology 76 160-166

KERRICH R, FYFE WS, GORMAN BE & ALLISON I [1977] Local modification of rock chemistry by deformation. Contributions to Mineralogy and Petrology 65 183-190

KIDD WSF [1977] The Baie Verte Lineament, Newfoundland: Ophiolite complex floor and mafic volcanic fill of a small Ordovician marginal basin. In Island arcs, deep sea trenches and back arc basins. Edited by M. Talwani and W.C. Pitman, American Geophysical Union, Maurice Ewing Series 1, 407-418

KING LH [1972] Relation of plate tectonics to the geomorphic evolution of the Canadian Atlantic provinces. Geological Society of America Bulletin 83 3083-3090

KUNO H [1968] Differentiation of basaltic magmas. In Basalts, Volume 2. Edited by H.H. Hess and A. Poldervaart, Interscience. John Wiley and Sons; 623-688

LISTER GS & PRICE GP [1978] Fabric development in a quartz-feldspar mylonite. Tectonophysics 49 37-78

LISTER GS & SNOKE AW [1984] S-C mylonites. Journal of Structural Geology 6 617-638

LUGMAIR GW & MARTI K [1978] Lunar initial $^{143}Nd/^{144}Nd$: differential evolution of the crust and mantle. Earth Planetary Scientific Letters 39 3349-3357

MALPAS JG [1976] The geology and petrogenesis of the Bay of Islands ophiolite suite, western Newfoundland. Ph.D. thesis, Memorial University of Newfoundland, St. John's, Newfoundland.

MARLOW PC & ETHERIDGE MA [1977] Development of a layered crenulation cleavage in mica schists of the Kanmantoo Group near Macclesfield, South Australia. Bulletin of the Geological Society of America 88 873-882

MASUDA A, NAKAMURA N & TANAKA T [1973] Fine structures of mutually normalized rare-earth patterns of chondrites. Geochimica Cosmochim Acta 37 239-248

MAWER CK [1986] What is a Mylonite? Geoscience Canada 13 33

MAWER CK [1986] Mechanics of formation of gold-bearing quartz veins, Nova Scotia, Canada. Tectonophysics 135 99-119

MCKENZIE CB [1986] Geology and mineralization of the Chetwynd deposit, southwest Newfoundland, Canada. In Macdonald, A.J., ed., Proceedings of Gold '86, an International Symposium on the Geology of Gold: Toronto, 1986, 137-148

MEANS WD & WILLIAMS PF [1972] Crenulation cleavage and faulting in salt-mica schist. Journal of Geology 80 569-591

MERTIE JB [1969] Economic geology of the platinum metals. United States Geological Survey. Professional Paper 630, 120 pp.

MITCHELL AGH [1976] Tectonic settings for emplacement of subduction-related magmas and associated mineral deposits. In Metallogeny and Plate Tectonics. Edited by D.F. Strong, Geological Association of Canada, Special Paper 14, 3-21

MITCHELL AHG & GARSON MS [1981] Mineral Deposits and Global Tectonic Settings. Academic Press, Geology Series, 405 pp.

MIYASHIRO A [1973] Metamorphism and Metamorphic Belts. John Wiley and Sons Inc.; New York; 479 pp.

MOREL P & IRVING E [1978] Tentative paleocontinental maps for the early Phanerozoic and Proterozoic. Journal of Geology 86 535-561

MORRISON MA [1978] The use of "immobile" trace elements to distinguish the paleotectonic affinities of metabasalt: applications to the Paleocene basalts of Mull and Skye, northwest Scotland. Earth and Planetary Science Letters 39 407-416

NALDRETT AJ & CABRI LJ [1976] Ultramafic and mafic rocks: their classification and genesis with special reference to the concentration of nickel sulphides and platinum group elements. Economic Geology 71(7) 1131-1158

NORMAN RE & STRONG DF [1975] The geology and geochemistry of ophiolitic rocks exposed at Mings Bight, Newfoundland. Canadian Journal of Earth Sciences 12 777-797

NORTHERN MINER MAGAZINE [1987] New Found Gold. Northern Miner Magazine 2(9) September 1987 28-38

NORTHERN MINER [1987] Newfoundland's first gold rush. The Northern Miner, Toronto, Canada, November 2, 1987, 73(34) 20

OSBERG PH [1978] Synthesis of the geology of the northeastern Appalachians, U.S.A. Geological survey of Canada. Paper 78-13 137-147

PAJARI GE & CURRIE KL [1978] The Gander Lake and Davidsville Groups of northeastern Newfoundland: a regional examination. Canadian Journal of Earth Sciences 15 708-714

PAJARI GE, PICKERILL RK & CURRIE KL [1979] The nature, origin and significance of the Carmanville Melange, Northeastern Newfoundland. Canadian Journal of Earth Sciences 16

PAPEZIK VS [1972] Late Precambrian ignimbrites in eastern Newfoundland and their tectonic significance. Proceedings 24th International Geological Congress, Montreal, Section 1, 147-152

PASSCHIER CW [1984] The reliability of asymmetric C-axis fabrics of quartz to determine sense of shear. Tectonophysics 99 9-18

PASSCHIER CW & SIMPSON C [1986] Porphyroclast systems as kinematic indicators. Journal of Structural Geology 8 831-844

PEACOCK MA [1931] Classification of igneous rock series. Journal of Geology 39 65-67

PEARCE JA [1975] Basalt geochemistry used to investigate past tectonic environments on Cyprus. Tectonophysics 25 41-67

PEARCE JA & CANN JR [1973] Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth and Planetary Science Letters 19 290-300

PEARCE JA, HARRIS NBW & TINDLE AG [1984] Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology 25 956-983

PEARCE TH, GORMAN BE & BIRKETT TC [1975] The TiO_2-K_2O-P_2O_5 diagram: a method of discriminating between oceanic and non-oceanic basalts. Earth and Planetary Science Letters 24 419-426

PIASECKI MAJ [1980] New light on the Moine rocks of the Central Highlands of Scotland. Geological Society of London, Journal 137 41-59

PICKERILL RK, PAJARI GE, CURRIE KL & BERGER AR [1978] Carmanville map-area, Newfoundland: the northern end of the Appalachians. Geological Survey of Canada. Paper 78-1A 209-216

PITCHER WS [1983] Granite type and tectonic environment. In Mountain Building Processes. Edited by K. Hsu, Academic Press; London; 19-40

PLATT JP & VISSERS RLM [1980] Extensional structures in anisotropic rocks. Journal of Structural Geology 2 397-410

PONCE DE LEON MI & CHOUKROUNE P [1980] Shear zones in the Iberian Arc. Journal of Structural Geology 2 63-68

POWELL C & VERNON RH [1979] Growth and rotation history of garnet pophyroblasts with inclusion spirals in a Karakoram schist. Tectonophysics 54 25-43

PRICE NJ [1975] Fluids in the crust of the earth. Scientific Programs, London 62 59-87

RAMSAY JG [1967] Folding and Fracturing of Rocks. McGraw-Hill Company; New York; 568 pp.

RAMSAY JG [1980] Shear zone geometry: a review. Journal of Structural Geology 2 83-99

RAMSAY JG & GRAHAM RH [1970] Strain variations in shear belts. Canadian Journal of Earth Sciences 7 786-813

RAMSAY JG & HUBER MI [1983] The Techniques of Modern Structural Geology. Academic Press; Toronto; 307 pp.

RAST N, KENNEDY MJ & BLACKWOOD RF [1976] Comparison of some tectonostratigraphic zones in the Appalachians of Newfoundland and New Brunswick. Canadian Journal of Earth Sciences 13 868-875

RICKARD MJ [1961] A note on cleavages in crenulated rocks. Geology Magazine 98 324-332

RILEY GC [1957] Red Indian Lake (west half), Newfoundland. Geological Survey of Canada. Map 8-1957 (scale 1:250,000 with marginal notes).

RODGERS J [1968] The eastern edge of the North American continent during the Cambrian and Early Ordovician. In Studies of Appalachian Geology: Northern and Maritime. Edited by E-an Zen and others, John Wiley & Sons; New York; 141-150

ROEDDER E [1984] Fluid Inclusions. Mineralogical Society of America, Reviews in Mineralogy 12 644 pp.

ROSENFELD JL [1970] Rotated garnets in metamorphic rocks. Geological Society of America. Special Paper 129

SAWKINS FJ [1976] Massive sulphide deposits in relation to geotectonics. In Metallogeny and Plate Tectonics. Edited by D.F. Strong, Geological Association of Canada, Special Paper 14 221-240

SAWKINS FJ [1984] Metal Deposits In Relation to Plate Tectonics. Edited by P.J. Willie, Sprenger-Verlag, New York; 325 pp.

SCHONEVELD C [1977] A study of some typical inclusion patterns in strongly paracrystalline-rotated garnets. Tectonophysics 39 453-471

SEYFRIED Jr., WE & BISCHOFF JL [1979] Low temperature basalt alteration by seawater: an experimental study at 70°C and 150°C. Geochimica et Cosmochimica Acta 43 1937-1947

SHAND SJ [1951] Eruptive Rocks. John Wiley; New York.

SIBSON RH [1977] Fault rocks and fault mechanisms. Journal of the Geological Society of London 133 191-213

SIBSON RH [1983] Continental fault structure and the shallow earthquake source. Journal of the Geological society of London 140 741-767

SIMPSON C [1986] Determination of movement sense in mylonites. Journal of Geological Education 34 246-261

SIMPSON C & SCHMID SM [1983] An evaluation of criteria to deduce the sense of movement in sheared rocks. Geological Society of America Bulletin 94 1281-1288

SINHA KA, HEWITT DA & RIMSTIDT JD [1986] Fluid interaction and element mobility in the development of ultramylonites. Geology 14 883-886

SMITH RE & SMITH SE [1976] Comments on the use of Ti, Zr, Y, Sr, K, P and Nb in classification of basaltic magmas. Earth and Planetary Science Letters 32 114-120

SMITH JV & STENSTROM RC [1965] Electron-excited luminescence as a petrographic tool. Journal of Geology 73 627-635

SMITHERINGALE WG [1972] Low potash Lushs Bight tholeiites: ancient oceanic crust in Newfoundland. Canadian Journal of Earth Sciences 9 574-588

SMYTH WR [1979] King George IV Lake, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 79-56

ST. JULIEN P & HUBERT C [1975] Evolution of the Taconian Orogen in the Quebec Appalachians. American Journal of Science 275A 337-362

STERENBERG V [1979] King George IV Lake sheet, Newfoundland. Hudson's Bay Oil and Gas Company Ltd., unpublished map.

STEVENS RK [1970] Cambro-Ordovician flysch sedimentation and tectonics in west Newfoundland and their possible bearing on a Proto-Atlantic Ocean. In Flysch sedimentology in North America. Edited by J. Lajoie, Geological Association of Canada. Special Paper No. 7 165-177

STOUGE S [1980] Lower and middle Ordovician conodonts from central Newfoundland and their correlatives in western Newfoundland. In Current Research. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 80-1 134-142

STRECKEISEN AL [1973] Plutonic rocks-classification and nomenclature recommended by the IUGS Subcommision on the Systematics of Igneous Rocks. Geotimes 18 26-39

STRONG DF [1974] Plate tectonic setting of Appalachian-Caledonian mineral deposits as indicated by Newfoundland examples. Society of Mining Engineers, AIME, Transactions 256 121-128

STRONG DF [1977] Volcanic regimes of the Newfoundland Appalachians. In Volcanic Regimes in Canada. Edited by W.R.A. Baragar, L.C. Coleman, and J.M. Hall. Geological Association of Canada, Special Paper 16 61-90

STRONG DF [1980] Granitoid rocks and associated mineral deposits of eastern Canada and western Europe. In The Continental Crust and Its Mineral Deposits. Edited by D.W. Strangway, Geological Association of Canada, Special Paper 20 741-769

STRONG DF & PAYNE JG [1973] Early Paleozoic volcanism and metamorphism of the Moretons Harbour-Twillingate area, Newfoundland. Canadian Journal of Earth Sciences 10 1363-1379

STRONG DF & DICKSON WL [1978] Geochemistry of Paleozoic granitiod plutons from contrasting tectonic zones of northeast Newfoundland. Canadian Journal of Earth Sciences 15 145-156

STRONG DF, DICKSON WL, O'DRISCOLL CF, KEAN BF & STEVENS RK [1974] Geochemical evidence for eastward Appalachian subduction in Newfoundland. Nature 248 37-39

STRONG DF, O'BRIEN SJ, TAYLOR SW, STRONG PG & WILTON DH [1978] Aborted Paleozoic rifting in eastern Newfoundland. Canadian Journal of Earth Sciences 15 117-131

SWANSON EA [1952-1960] Maps showing exploration in Crown Lands. ASARCO, unpublished report, Open File Nfld. 324 pp.

SWINDEN HS & STRONG DF [1976] A comparison of plate tectonic models of metallogenesis in the Appalachians, the North American Cordillera, and the East Australian Paleozoic In Metallogeny and Plate Tectonics. Edited by D.F. Strong, Geological Association of Canada, Special Paper 14 443-471

TAYLOR HP [1979] Oxygen and hydrogen isotope relationships in hydrothermal mineral deposits. In Geochemistry of Hydrothermal Ore Deposits. Edited by H.L. Barnes, John Wiley and Sons; Toronto; 236-277

THURLOW JG & SWANSON EA [1981] Geology and ore deposits of the Buchans area, central Newfoundland. In The Buchans Orebodies: Fifty Years of Geology and Mining. Edited by E.A. Swanson, D.F. Strong and J.G. Thurlow, Geological Association of Canada, Special Paper 22 113-142

TULLIS J, CHRISTIE JM & GRIGGS DT [1973] Microstructures and preferred orientations of experimentally deformed quartzites. Geological Society of America Bulletin 84 297-314

TWENHOFEL WH & MCCLINTOCK P [1940] Surface of Newfoundland. Geological Society of America Bulletin 54 1665-1728

UPADHYAY HD, DEWEY JF & NEALE ERW [1971] The Betts Cove ophiolite complex, Newfoundland: Appalachian oceanic crust and mantle. Geological Association of Canada Proceedings 24 27-34

VALLANCE TG [1969] Spilites again: some consequences of the degradation of basalts. Proceedings of the Linn. Society N.S.W. 94 8-51

VAN BERKEL JT [1987] Geology of the Dashwoods Pond, St. Fintan's and Main Gut map areas, southwest Newfoundland. In Current Research, Part A, Geological Survey of Canada. Paper 87-1A 399-408

VAN BERKEL JT, JOHNSTON HP & CURRIE KL [1986] A preliminary report on the geology of the southern Long Range, southwest Newfoundland. In Current Research, Part B, Geological Survey of Canada, Paper 86-1B 157-170

WALKER BM, VOGEL TA & ELRICH R [1972] Petrogenesis of oceanic granites from the Aves Ridge in the Caribbean basin. Earth and Planetary Science Letters 15 133-139

WATTERSON J [1979] Strain and strain rate gradients at ductile levels of fault displacement. In Analysis of Fault Zones in Bedrock. Edited by R.C. Speed and R.V. Sharp, United States Geological Survey; Menlo Park; 235-257

WHALEN JB & CURRIE KL [1982] Volcanic and plutonic rocks in the Rainy Lake area, Newfounland. In Current Research, Part A, Geological Survey of Canada. Paper 82-1A 17-22

WHALEN JB & CURRIE KL [1983] The Topsails igneous terrane of western Newfounland. In Current Research, Part A, Geological Survey of Canada. Paper 83-1A 15-23

WHALEN JB & CURRIE KL [1984] Peralkaline granite near Hare Hill, south of Grand Lake, Newfoundland. In Current Research, Part A, Geological Survey of Canada, Paper 84-1A 181-184

WHITE SH, BURROWS SE, CARRERAS ND, SHAW ND & HUMPHREYS FJ [1980] On mylonites in ductile shear zones. Journal of Structural Geology 2 175-188

WILLIAMS H [1964] The Appalachians in northeastern Newfoundland - a two sided symmetrical system. American Journal of Science 262 1137-1158

WILLIAMS H [1970] Red Indian Lake (east half), Newfoundland. Geological Survey of Canada. Map 1196A.

WILLIAMS H [1978] Tectonic Lithofacies Map of the Appalachian Orogen. Memorial University of Newfoundland, Map No. 1

WILLIAMS H [1979] Appalachian orogen in Canada. Canadian Journal of Earth Sciences 16 792-807

WILLIAMS H & HIBBARD JP [1976] The Dunnage Melange, Newfoundland. Geological Survey of Canada. Paper 76-1A 183-185

WILLIAMS H & PAYNE JG [1975] The Twillingate Granite and nearby volcanic groups: An island arc complex in Northeast Newfoundland. Canadian Journal of Earth Sciences 12 982-995

WILLIAMS H & ST. JULIEN P [1978] The Baie Verte-Brompton Line in Newfoundland and regional correlations in the Canadian Appalachians. Geological Survey of Canada. Paper 78-1A 225-229

WILLIAMS H & ST. JULIEN P [1982] The Baie Verte-Brompton Line: Early Paleozoic continent-ocean interface in the Canadian Appalachians. In Major Structural Zones and Faults of the Northern Appalachians. Edited by P. St. Julien and J. Beland, Geological Association of Canada. Special Paper 24 177-207

WILLIAMS H & STEVENS RK [1974] The ancient continental margin of eastern North America. In The Geology of Continental Margins. Edited by C.A. Burk and C.L. Drake, Springer-Verlag; New York; 781-796

WILLIAMS H, DALLMEYER RD & WANLESS RK [1976] Geochronology of the Twillingate Granite and Herring Neck Group, Notre Dame Bay, Newfoundland. Canadian Journal of Earth Sciences 13 1591-1601

WILLIAMS H, KENNEDY MJ & NEALE ERW [1972] The Appalachian Structural Province. In Variations in tectonic styles in Canada. Edited by R.A. Price and R.J.W. Douglas. Geological Survey of Canada. Special Paper 11 181-261

WILLIAMS H, KENNEDY MJ & NEALE ERW [1974] The northwestern termination of the Appalachian Orogen. In The Ocean Basins and Margins. Edited by A.E.M. Nairn and F.G. Stehli, Volume 2, Plenum Press; New York; 79-123

WILLIAMS PF [1979] The development of asymmetric folds in a cross-laminated siltstone. Journal of Structural Geology 1 19-30

WILSON JT [1966] Did the Atlantic close and then reopen? Nature 211 676-681

WILTON DHC [1983] The geology and structural history of the Cape Ray Fault Zone in southwestern Newfoundland. Canadian Journal of Earth Sciences 20 1119-1133

WINCHESTER JA & FLOYD PA [1976] Geochemical magma type discrimination: application to altered and metamorphosed basic igneous rocks. Earth and Planetary Science Letters 18 459-469

WINCHESTER JA & MAX MD [1984] Element mobility associated with syn-metamorphic shear zones near Scotchport, NW Mayo, Ireland. Journal of Metamorphic Geology 2 1-11

APPENDIX I

PROCEDURE FOR EACH ANALYTICAL METHOD

PART A: Procedure for Major and Trace Element Determination by X-Ray Fluorescence (XRF).

i) Sample Preparation

1) Samples are slabbed with a rock saw to remove all weathered surfaces and ensure homogeneity.

2) Primary reduction is achieved by a two stage method. Slabs are reduced in a 5 cm x 15 cm Braun Chipmunk VD67 jaw crusher followed by a 25 cm Bico UA Pulverizer cone crusher. The product of this system is a pulp typically 99% minus 3 mm.

3) Secondary reduction is achieved by a Spex oscillatory swing mill with alumina ceramic grinding plates. Approximately 50 ml of 3 mm pulp is reduced to minus 300 mesh.

4) Both size fractions of crushed material are stored in labelled, air-tight plastic containers.

ii) Major Element Determination

1) 0.5±0.01 g of material for each sample to be analysed is horoughly combined with 3.0±0.01 g of lithium metaborate and lithium tetraborate as flux.

2) The sample and flux mixture is placed into a Pt/Au reaction crucible with 1 mg/20 ml of mowiol (an organic binding agent) and heated to about 1200°C until a homogeneous liquid forms. This melt is poured into a Pt/Au mold 30 mm in diameter, and allowed to cool and produce a fused glass bead.

3) Major element content of the glass bead is measured on a Philips PW1450 automatic sequential X-ray fluorescence spectrometer. The apparatus uses a Cr filament in the focussing tube during major element analysis.

4) Results are normalized to internal standards and recorded.

iii) Trace Element Determination

1) 4-5 g of material for each sample to be analysed is thoroughly combined with about 1 ml of Mowiol, an organic binding agent.

2) The combined sample and binding agent is placed into a Spex aluminum pellet cup, 30 mm in diameter and compressed to 10 tonnes pressure with a hydraulic press.

3) Trace element content of the compressed pellet is measured on a Philips PW1450 automatic sequential X-ray fluorescence spectrometer. The apparatus uses a W filament in the focussing tube during trace element analysis.

4) Results are normalized to internal standards and recorded.

PART B: Procedure for Gold Content Determination By Direct Current Plasma Fire Assay (DCPFA).

** The following procedural summary was provided by the staff of X-Ray Assay Laboratories Limited (XRAL), Don Mills, Ontario.

1) 400-500 g of material for each sample to be analysed is supplied to XRAL after milling to -300 mesh (see sample preparation procedure as described in Part A).

2) 20±0.01 g of representative sample is added to a 20 g assay crucible which has been pre-charged with 85-90 g of litharge, soda-ash, borax and silica as flux (flux proportions are adjusted to compensate sample compositions based on a pilot assay). A reducing agent is added to ensure the production of a 24-35 g lead button during fusion. 5 mg of silver is added and the sample and flux are mixed together. Thirty samples may be processed simultaneously in each of five furnaces.

3) Fusion is carried out at an average temperature of 980°C for 45 minutes in an electric assay furnace. Melts are poured, cooled and the lead buttons are recovered. The buttons are then deslagged and placed in pre-heated cupels in a cupellation furnace. Cupellation takes 30 minutes at 900°C.

4) The silver bead is recovered after cupellation. Gold content is determined by plasma spectrometry which requires digestion of the bead with aqua regia. Measurement of the gold content in solution is performed by an atomic emission spectrometer, SpectraScan III (manufactured by SpectraMetrics, Inc.). The method is sensitive to 1-2 ppb for a 20 g sample. Analyses are carried out to about 10,000 ppb. Higher values are checked gravimetrically. Regular, systematic cross checks by NAA maintain the integrity of calibrations.

5) Results are normalized to internal standards and recorded. Quality control is maintained by several methods:

   a) for each tray of samples, two reagent blanks are prepared. One blank is run with the samples, the other is run with similar blanks at the end of shift.
   b) a standard reference sample is run with each tray and its position is systematically varied from one tray to the next.
   c) every tenth sample is run in duplicate at a different time from the first.
   d) blanks are run in quantity at reagent renewal and with each new batch of flux.

PART C: Procedure for Rare Earth Element (REE) Determination by Neutron Activation Analysis (NAA).

** The following procedural summary was provided by the staff of Nuclear Activation Services (NAS), Hamilton, Ontario.

1) 100-150 g of material for each sample to be analysed is supplied to NAS after milling to -300 mesh (see sample preparation procedure as described in Part A).

2) 0.5±0.01 g of representative sample is measured and encapsulated into a high purity polyethelene vial.

3) Samples (including internal blanks as standards) undergo thermal irradiation of 7×10^{-12} n cm^{-2} s^{-1} in the McMaster Nuclear Reactor.

4) Samples are stored for a 5-7 day decay period.

5) After the decay period, samples are counted on a high purity germanium detector for a sufficient time to achieve the following detection limits:

ELEMENT	DETECTION LIMIT
La	0.10 ppm
Ce	1.00 ppm
Nd	3.00 ppm
Sm	0.10 ppm
Eu	0.05 ppm
Tb	0.10 ppm
Yb	0.05 ppm
Lu	0.01 ppm

6) Results are normalized to the Leedey chondrite (Masuda et al, 1973) and are presented via graphical plot.

PART D: Procedure for Sm/Nd Modal Age Determination by Mass Spectrometry.

** The following procedural summary was provided by F. Marcantonio, Department of Geology, McMaster University.

i) Sample Preparation

1) 25-50 g of material of each sample to be analysed is milled to -300 mesh (see sample preparation procedure as described in Part A).

2) 100±5 mg of -300 mesh material is dissolved in 10 ml of 42% HF and digested in 5 ml of 12N HNO_3. At this point, the sample is evaporated to dryness and split into halves. The divided sample to be used for Sm and Nd concentration determination is spiked with a known concentration of Sm and Nd. The balance of the sample remains unspiked. Both sample types are converted to chloride form with 5 ml of 6N HCl and re evaporated.

3) For Sm and Nd concentration determinations, the chloride compound is redissolved in 1 ml of 2.5N HCl and passed through cation exchange columns. REE are collected as 13 ml of acid is recovered from the first set of columns and evaporated. The separated REE are eluted with 1 ml of .15N HCl and passed through reverse phase columns. HCl of differing concentrations collect first Nd and then Sm. Both are evaporated to dryness and mixed with H_3PO_4 for final conversion to phospate form.

4) For isotopic ratio determinations, only Nd is collected from the unspiked portion of the sample as described above.

5) The final results of the preparation procedure are 3 vials which contain spiked Sm, spiked Nd and unspiked Nd to be measured on the mass spectrometer.

ii) Sm-Nd Determination

1) Prepared samples are analysed by a VG 354, 27 cm radius, 90° magnetic sector single focussing mass spectrometer. Magnetic field switching and data analysis are controlled by Hewlett-Packard computer.

2) Mass spectrometry results are normalized to known, internal standards and recorded.

3) Calculations based on mass spectrometry results considered the isochron equation and assumed the following:

a) $\lambda = 6.54 \times 10^{-12}\ y^{-1}$

b) $^{147}Nd/^{144}Nd$ (BE) = 0.1967

c) $^{143}Nd/^{144}Nd$ (BE) = 0.512638

PART E: Procedure for the Determination of Relict Textures in Vein Material by Catholuminescence Petrography.

1) Double polished thin sections (prepared by Vancouver Petrographics Limited) for each sample to be analysed are placed in the sample chamber, beneath the viewing window of the ELM-2DRW Nuclide Luminoscope.

2) The air-tight sample chamber is sealed and evacuated.

   A cold cathode ray gun provides a beam energy of up to 18 kV DC and electron currents of up to 1 milliampere. Quartz luminescence becomes visible at about 14 to 16 kV and 0.3 mA with 1/4 original diameter beam focus. The electron beam may be focused via a deflection magnet onto the sample with a spot size which varies from 1 mm to 2 cm in diameter. The sample may be moved in the X and Y planes of the chamber with a click counter.

3) Luminescence occurs as the electron beam excites trace amounts of sample impurites termed activators (abnormally ionized atoms, typically Mn, U, and REE). Note that the observed phenomena is an effect taking place at the material's surface only (hence the requirement of specially prepared thin sections).

4) The intensity and colour of luminescence may be varied by changing the beam intensity (increasing or decreasing the beam current).

5) After viewing has been completed, the electron beam is switched off and the vacuum in the sample chamber is released.

PART F: Procedure for Oxygen Isotope Determinations by Mass Spectrometry.

** Clayton & Mayeda (1963) summarize the BrF_5 extraction procedure of structural oxygen from silicates ; it was demonstrated by F. Ghazban, Department of Geology, McMaster University.

1) 25-50 g of material for each sample to be analysed is milled to -300 mesh (see sample preparation procedure as described in Part A).

2) Prior to the re-use of the system, the line is purged of the gaseous products of the previous reaction.

3) To prevent water vapor from entering the system, the line is flooded with argon gas before being opened to the atmosphere. 10$\pm$.1 mg of -300 mesh material is introduced into a reaction tube for each sample and is heated to 300° C under vacuum for one hour to remove adsorbed surface moisture and air from the sample before mineral oxygen extraction.

4) After outgassing, distilled BrF_5 is expanded into the sample-charged reaction tube and condensed by liquid nitrogen immersion. The tubes are closed and heated by electrical resistance furnaces at 500° C overnight.

5) After reaction, the furnaces are removed and the tubes are cooled. The extracted gas from each tube is moved under vacuum to a glass trap cooled by liquid nitrogen. Of the reaction products, only oxygen passes through this trap. The oxygen is passed over a heated carbon filament for conversion to CO_2. The CO_2 is frozen out in a liquid nitrogen cooled U tube and collected for measurement by mass spectrometry.

6) Analyses on collected CO_2 are made on a VG 602D mass spectrometer. Results are reported in the δ notation as derivations in permil (parts per thousand) for the $^{18}O/^{16}O$ ratio from that of standard mean ocean water (SMOW) (Craig, 1961). Isotopic results are reproducible to within $\pm$.2 permil.

APPENDIX II

RESULTS FOR EACH ANALYTICAL METHOD

PART A: Modal Rock Compositions by Point Count Microscopy.

ROCK UNIT	N	QZ	PG	KFP	MINERALS BI	MU	HB	GT	ACS
GRDT	4	36	18	26	10	5	3	1	1
ADML	7	34	20	31	8	3	-	3	1
GBBR	4	2	39	-	13	-	34	-	12
GNSS	1	26	12	17	33	2	4	1	5
XLGT	1	30	19	31	15	3	-	-	2
DIAB	1	2	32	-	17	4	8	-	37
BSLT	4	-	16	-	15	1	1	-	67
RHLT	0	-	-	-	-	-	-	-	-
VRSZ	3	19	9	2	17	6	-	-	47
PSPSZ	6	30	14	28	13	7	6	-	2

N = number of samples point-counted (>800 points resolution).

MINERALS: QZ = quartz PG = plagioclase KFP = K feldspar BI = biotite MU = muscovite HB = hornblende GT = garnet ACS = accessories (commonly sphene, apatite, chlorite, epidote, opaques, sericite, calcite and clay minerals).

ROCKS: GRDT=granodiorite ADML=adamellite GBBR=gabbro GNSS=gneiss XLGT=megacrystic granite BSLT=basalt DIAB=diabase RHLT=rhyolite VRSZ=Victoria River phyllonite PSPSZ=Peter Strides Pond mylonite.

PART B: CIPW Normative Compositions

FELSIC INTRUSIVE ROCKS

Sample 6VMJ 036 - CIPW Weight Norm

qtz = 37.91 or = 11.98 ab = 31.08 an = 12.14 cor = 1.89
hy = 1.92 il = 0.13 hem = 2.57 ap = 0.16 ru = 0.22
Plag is An 28

Sample 6VMJ 072A - CIPW Weight Norm

qtz = 27.21 or = 25.64 ab = 38.32 an = 2.61 cor = 1.05
hy = 1.78 il = 0.13 hem = 3.14 ap = 0.05 ru = 0.08
Plag is An 6

Sample 6VMJ 072B - CIPW Weight Norm

qtz = 27.48 or = 25.29 ab = 38.51 an = 2.68 cor = 1.07
hy = 1.63 il = 0.13 hem = 3.11 ap = 0.02 ru = 0.08
Plag is An 6

Sample 6VMJ 080 - CIPW Weight Norm

qtz = 38.47 or = 18.51 ab = 35.18 an = 3.62 cor = 0.76
hy = 1.15 il = 0.06 hem = 1.98 ap = 0.09 ru = 0.17
Plag is An 9

Sample 6VMJ 136 - CIPW Weight Norm

qtz = 41.47 or = 25.88 ab = 26.43 an = 1.00 cor = 1.80
hy = 1.75 il = 0.02 hem = 1.43 ap = 0.07 ru = 0.15
Plag is An 4

Sample 6VMJ 147 - CIPW Weight Norm

qtz = 33.66 or = 9.67 ab = 38.05 an = 11.66 cor = 0.15
hy = 3.02 il = 0.13 hem = 3.10 ap = 0.21 ru = 0.34
Plag is An 23

MAFIC VOLCANIC ROCKS

Sample 6VMJ 010 - CIPW Weight Norm

qtz = 11.78   or = 0.19   ab = 9.30   an = 35.95   di = 7.11
hy = 12.56   il = 0.36   hem = 14.23   ti = 6.09   ap = 0.98
Plag is An 79

Sample 6VMJ 045A - CIPW Weight Norm

qtz = 2.77   or = 1.44   ab = 24.35   an = 30.83   di = 7.11
hy = 15.83   il = 0.35   hem = 12.26   ti = 4.40   ap = 0.66
Plag is An 56

Sample 6VMJ 045B - CIPW Weight Norm

qtz = 2.87   or = 1.44   ab = 24.35   an = 30.91   di = 6.88
hy = 15.86   il = 0.35   hem = 12.26   ti = 4.40   ap = 0.68
Plag is An 56

Sample 6VMJ 121 - CIPW Weight Norm

qtz = 5.76   or = 0.82   ab = 14.05   an = 45.44   hy = 18.27
il = 0.37   hem = 14.44   ti = 0.05   ap = 0.35   ru = 0.46
Plag is An 76

Sample 6VMJ 196 - CIPW Weight Norm

or = 0.25   ab = 16.28   an = 43.69   di = 10.20   hy = 16.49
ol = 0.62   il = 0.30   hem = 10.24   ti = 1.48   ap = 0.45
Plag is An 73

Sample 6VMJ 269 - CIPW Weight Norm

qtz = 76.71   or = 1.09   ab = 9.20   an = 3.31   di = 6.62
hy = 0.51   il = 0.11   hem = 2.19   ti = 0.08   ap = 0.19
Plag is An 26

Part C: Major and Trace Element Content by X-Ray Fluorescence Analysis.

FELSIC PLUTONIC SAMPLES

ELEMENTS & UNITS		036	72A	72B	080	136	147
SiO_2	%	73.17	72.05	72.13	76.58	77.54	72.65
Al_2O_3	%	14.53	14.09	14.10	12.27	11.99	13.54
Fe_2O_3 *	%	2.56	3.13	3.10	1.97	1.42	3.09
MgO	%	0.77	0.71	0.65	0.46	0.70	1.21
CaO	%	2.53	0.55	0.55	0.78	0.24	2.46
Na_2O	%	3.66	4.51	4.53	4.14	3.11	4.48
K_2O	%	2.02	4.32	4.26	3.12	4.36	1.63
TiO_2	%	0.29	0.15	0.15	0.20	0.16	0.41
MnO	%	0.06	0.06	0.06	0.03	0.01	0.06
P_2O_5	%	0.07	0.02	0.01	0.04	0.03	0.09
LOI	%	0.34	0.36	0.36	0.41	0.44	0.38
As	PPM	10	8	6	9	11	16
Ba	PPM	730	238	241	510	465	398
Ce	PPM	20	187	193	61	60	15
Co	PPM	35	16	17	12	16	20
Cu	PPM	5	<1	<1	7	<1	<1
La	PPM	8	155	153	12	22	12
Nb	PPM	10	78	76	27	23	14
Nd	PPM	<2	96	105	38	58	8
Ni	PPM	6	3	4	3	2	3
Pb	PPM	15	13	13	20	17	10
Rb	PPM	74	159	156	114	126	56
Sr	PPM	152	33	35	48	27	195
V	PPM	23	7	9	10	5	36
Y	PPM	26	86	86	58	54	30
Zn	PPM	29	125	130	21	14	26
Zr	PPM	149	559	549	192	148	188

* Fe_2O_3 measured as total iron.

** Reference values for internal standards GM and GA in Gavindaraju (1984).

*** Analyses performed by O. Mudroch, Department of Geology, McMaster University.

MAFIC VOLCANIC SAMPLES

ELEMENTS & UNITS		SAMPLE NUMBERS 010	45A	45B	121	196	269
SiO_2	%	45.38	47.89	47.91	43.44	43.47	86.97
Al_2O_3	%	14.21	16.08	16.11	18.24	17.98	3.12
Fe_2O_3 *	%	13.47	12.10	12.10	13.38	9.58	2.14
MgO	%	6.28	7.58	7.55	6.85	2.45	1.40
CaO	%	11.13	9.56	9.53	8.75	11.34	2.45
Na_2O	%	1.04	2.84	2.84	1.55	1.80	1.06
K_2O	%	0.03	0.24	0.24	0.13	0.04	0.18
TiO_2	%	2.53	1.95	1.95	0.63	0.71	0.09
MnO	%	0.16	0.16	0.16	0.16	0.13	0.05
P_2O_5	%	0.40	0.28	0.29	0.14	0.18	0.08
LOI	%	5.36	1.32	1.32	6.62	6.46	2.46
Ba	PPM	101	221	221	19	13	<5
Ce	PPM	32	3	5	5	<3	<3
Cr	PPM	98	62	68	73	430	5
Cu	PPM	31	27	29	49	66	29
La	PPM	18	9	13	17	12	<3
Nb	PPM	6.6	7.9	7.7	1.4	4.9	5.6
Nd	PPM	18	18	12	3	<3	<3
Ni	PPM	58	68	68	32	158	37
Rb	PPM	365.7	334.1	332.6	232.4	181.1	44.0
Sr	PPM	3.9	10.2	7.0	6.6	6.2	2.6
V	PPM	267	240	236	233	132	24
Y	PPM	31.3	29.3	29.3	12.8	18.2	11.8
Zr	PPM	193.5	153.6	149.0	37.5	50.7	23.2

* Fe_2O_3 measured as total iron.

** Reference values for internal standard BE-N in Gavindaraju (1984).

*** Analyses performed by O. Mudroch, Department of Geology, McMaster University.

PART D: Gold Content by Direct Current Plasma Fire Assay Analysis.

SAMPLE	AU PPB
6VMJ 047	<1
6VMJ 083	<1
6VMJ 084	<1
6VMJ 085A	<1
6VMJ 086A	<1
6VMJ 087	<1
6VMJ 090A	<1
6VMJ 091A	<1
6VMJ 098	3
6VMJ 101	<1
6VMJ 104A	<1
6VMJ 110	<1
6VMJ 110	<1
6VMJ 122	<1
6VMJ 126A	<1
6VMJ 131	<1
6VMJ 148A	<1
6VMJ 165	<1
6VMJ 166	<1
6VMJ 178A	<1
6VMJ 181	<1
6VMJ 186	<1
6VMJ 188	<1
6VMJ 190	<1
6VMJ 192	<1
6VMJ 194	<1
6VMJ 197	<1
6VMJ 199	<1
6VMJ 201	<1
6VMJ 203	<1
6VMJ 205	**10**
6VMJ 207	<1
6VMJ 209	<1
6VMJ 211	<1
6VMJ 212	<1
6VMJ 214	<1
6VMJ 216	<1

* Detection Limit = 1.000 PPB

** Analyses performed by X-Ray Laboratories Limited, Don Mills, Ontario

PART E: Trace and Rare Earth Element Content by Nuclear Activation Analysis.

ELEMENT & UNITS		SAMPLE NUMBERS 6VMJ 036	6VMJ 072	6VMJ 080	6VMJ 136	6VMJ 147
Ag	PPM	<2	<2	<2	<2	<2
As	PPM	1	2	2	1	3
Au	PPB	<2	3	<5	<2	<2
Ba	PPM	700	330	550	540	410
Br	PPM	1.1	1.1	1.1	1.1	1.1
CaO	%	2.4	<0.9	1.3	1.1	2.0
Co	PPM	85	38	29	56	40
Cr	PPM	1.2	6.8	1.0	7.0	9.4
Cs	PPM	1.0	4.2	3.5	1.0	0.9
Fe_2O_3	%	2.58	3.23	1.31	1.15	2.75
Hf	PPM	7.3	18	7.1	8.2	6.6
Mo	PPM	5	<2	<2	4	<2
Na_2O	%	3.85	4.75	4.34	3.28	3.43
Ni	PPM	<50	<80	60	<60	60
Rb	PPM	90	170	140	80	90
Sb	PPM	0.3	0.2	0.2	0.3	0.2
Sc	PPM	10.3	8.94	5.82	7.48	9.29
Se	PPM	<5	<1	<1	<2	<5
Sr	PPM	<100	<100	<100	<100	<100
Ta	PPM	2.3	7.0	2.9	1.4	1.4
Th	PPM	8.1	18	22	16	4.5
U	PPM	1.1	5.1	4.3	3.5	0.5
W	PPM	380	360	290	600	360
Zn	PPM	<50	120	30	<50	<50
La	PPM	9.2	105	44.4	52.2	17.1
Ce	PPM	30	173	100	112	30
Nd	PPM	6	73	41	50	17
Sm	PPM	1.46	15.0	7.75	10.0	2.99
Eu	PPM	0.33	0.87	0.70	1.01	0.80
Tb	PPM	0.6	2.4	1.8	1.9	0.6
Yb	PPM	2.73	9.39	6.09	4.50	1.92
Lu	PPM	0.41	1.23	0.86	0.81	0.31
Ir	PPB	<5	<5	<5	<5	<5

* Variable Detection Limits Due To Sample Composition.

** Analyses performed by Nuclear Activation Services, Hamilton, Ontario.

PART F: Sm/Nd Model Age by Mass Spectrometry

SAMPLE 6VMJ 136

Nd	51.1±0.05% ppm
Sm	10.9±0.04% ppm
$^{147}Sm/^{144}Nd$	0.1286±0.08%
$^{143}Nd/^{144}Nd$	0.51239±0.002%
λ	6.54×10^{-12} y^{-1} *
TCHUR (Ma)	563
TDMb (Ma)	1175 **
TCR (Ma)	1367
t = 389±20 Ma	(U/Pb age by Dallmeyer, 1979).
$^{143}Nd/^{144}Nd$ $(BE)_{i,t=389}$	0.51213
$^{143}Nd/^{144}Nd_{t=389}$	0.51206
E_t	-1.37

* Lugmair and Marti, (1978).

** Depleted Mantle Model of DePaolo, (1981).

*** Analyses performed by F. Marcantonio, Department of Geology, McMaster University.

PART G: Oxygen Isotope Determinations by Mass Spectrometry

FELSIC PLUTONIC SAMPLES

SAMPLE #	$\delta^{18}O$ (SMOW) $^0/_{00}$
6VMJ 072	7.8
6VMJ 080	8.4
6VMJ 136	9.1

VEIN SAMPLES FROM THE VRSZ

SAMPLE #	$\delta^{18}O$ (SMOW) $^0/_{00}$
6VMJ 283	16.3
6VMJ 291	11.7
6VMJ 305	14.9

VEIN SAMPLES FROM THE PSPSZ

SAMPLE #	$\delta^{18}O$ (SMOW) $^0/_{00}$
6VMJ 79A	9.0
6VMJ 79B	9.2
6VMJ 082	9.3
6VMJ 142A	8.6

INTERNAL STANDARD

NBS-028	*	9.7

* Reference for O_2 standard, Department of Commerce, U.S.A.

** Theoretrical Yield: 16.643 µmoles O_2/mg SiO_2; Experimental yields were not measured during analyses because of damage to the calibration insturmentation.

*** Analyses performed by F. Ghazban, Department of Geology, McMaster university.

TWIN
PONDS
480
BOOGIE
LAKE
Wood
Lake
VICTORIA
RIVER
Victoria
Lake
PETER
STRIDES
POND
STAG
LAKE
BLUE
RIDGE
POND
SPRUCE
LEGEND
(no statigraphic order implied)
RHYOLITE
MEGACRYSTIC GRANITE
GRANITE: unsubdivided, adamellite and granodiorite
PSPSZ MYLONITE
VRSZ MYLONITE
GRANOBLASTIC GNEISS
HETEROLITHIC CONGLOMERATE: unsubdivided, minor sandstone
BASALT: unsubdivided, pillowed, locally plagiophyric, minor intercalated mafic and felsic tuff
DIABASE
GABBRO
MAJOR FAULT
approximate
assumed
MINOR FAULT
GEOLOGIC BOUNDARY
appoximate
assumed
FOLIATION
vertical
inclined
FOLD AXIS
LINEATION
QUARRY (abandoned)
MINERAL OCCURRENCE
▲ cpy
N
GEOLOGY
0
1
2
km
GEOLOGY BY J.D.F.