ORDOVICIAN TECTONIC EVOLUTION OF THE SOUTHERN LONG RANGE MOUNTAINS, NEWFOUNDLAND

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OF THE
SOUTHERN LONG RANGE MOUNTAINS,
NEWFOUNDLAND

BY

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Abstract

The rocks of the southern Long Range Mountains consist of metamorphosed mafic, ultramafic, sedimentary and felsic intrusive rocks and granite plutons. The mafic and ultramafic rocks constitute the Long Range Mafic-ultramafic Complex, the oldest rocks in the area. Pelitic to psammitic metasedimentary rocks with entrained fragments of the Long Range Mafic-ultramafic Complex comprise the Mischief Mélange. The Cape Ray Igneous Complex consists of deformed and metamorphosed tonalitic, granitic and granodioritic rocks which cut the Long Range Mafic-ultramafic Complex and the Mischief Mélange. This complex includes the Cape Ray Granite (488 (+/-3) Ma), Long Pond Tonalite (472 (+/-2) Ma) and the younger Staghill Orthogneiss which intrudes the other members of this complex and cuts features of early deformation. Four plutons, the Pin (449 (+2/-3) Ma), Red Rocks, Strawberry (384 (+/-2) Ma) and Dragon Lake granites and dykes associated with them cut all older rocks and structures.

The rocks of the southern Long Range Mountains record Ordovician orogenesis, namely, the generation of an ophiolite suite (the Long Range Mafic-ultramafic Complex), its obduction and association with a mélange (the Mischief Mélange), the generation of a continental arc (the Cape Ray Igneous Complex) and further obduction and plutonism (granites). Amphibolite grade peak metamorphism pre-dates the intrusion of the Staghill Orthogneiss, however, the rocks remained in a deformational and metamorphic regime during and after the emplacement of the Staghill Orthogneiss. Dated at 449 Ma, the post-tectonic Pin Granite provides a lower limit for the cessation of penetrative deformation in

this area. Plutonism was renewed in at least one distinct event with emplacement of the 384 (+/-2) Ma Strawberry Granite.

Rocks of the southern Long Range Mountains occur in the hanging wall of the Long Pond Thrust, a southeast dipping thrust which intersects the escarpment of the much younger Cabot Fault. To the southeast the rocks are bounded by the Cape Ray Fault that dips southeast and separates Gondwanan and Laurentian elements of the earlier Iapetus Ocean.

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Without Drs. Hank Williams and Cees van Staal, my supervisors in the university and field respectively, this thesis could not have been done. Dr. van Staal's confidence in the author will always be gratefully remembered. I sincerely thank both of my supervisors.

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CHAPTER 1

Introduction

Studies of Newfoundland geology provide a key to the tectonic interpretation of the Appalachian Orogen. The excellent exposure on the island's northeastern coast reveal the story of the Appalachian Orogen as "a two-sided symmetrical system" documented by Williams (1964). In a landmark paper, Wilson (1966) based the premise of a closing and re-opening Proto-Atlantic Ocean in large part on Williams two-sided system. Since the advent of the "Wilson Cycle" concept, Newfoundland has provided a template from which much of the understanding of Paleozoic plate tectonics is drawn; from obducted ophiolites and island arcs to suspect terranes. For decades, tectonic theory based on Newfoundland and Appalachian geology has been used to further understanding of other mountain belts such as the Cordilleras and Himalaya.

Today, the primary goal of tectonic investigations in Newfoundland is to refine knowledge of timing and accretionary mechanisms (Williams, 1995a). The tectonic setting of southwestern Newfoundland has remained somewhat enigmatic. In this region, the Appalachian Orogen is narrower and displays more intensive deformation and higher grade metamorphism than elsewhere. Thus, correlating the rocks of this area with lithostratigraphic zones established in northeastern Newfoundland is difficult and has proved controversial.

1.1 Regional Tectonic Setting

Numerous attempts have been made to subdivide the Appalachian Orogen into zones, belts, domains and terranes (e.g. Rodgers, 1968; Bird and Dewey, 1970; Williams and Stevens, 1974; Williams, 1978, 1979; Williams *et al.*, 1988). The most widely accepted and comprehensive subdivision is that of Williams *et al.* (1988) which used contrasting structure and stratigraphy of Ordovician and older rocks to distinguish the Humber, Dunnage, Gander, Avalon and Meguma tectonostratigraphic zones. Figure 1 illustrates the tectonostratigraphic subdivision of insular Newfoundland.

Remnants of Laurentian (Humber Zone) and Gondwanan (Gander and Avalon zones) continental margins flank the central oceanic domain (Dunnage Zone) of Newfoundland to west and east respectively (e.g. Williams and Hatcher, 1982).

In northeast Newfoundland, the Dunnage and Gander zones together span up to 250 km, however, in the southwest, they span less than 100 km (Figure 1). Lin *et al.* (1994) proposed that this disparity is the result of an oblique Silurian Laurentia-Gondwana promontory-promontory collision. The resulting constriction is accompanied by higher grades of metamorphism and more intense deformation than is typical elsewhere on the island. Therefore, the rocks of this region are not easily fit in zonal tectonostratigraphic subdivisions defined on rocks farther north (Williams *et al.*, 1988).

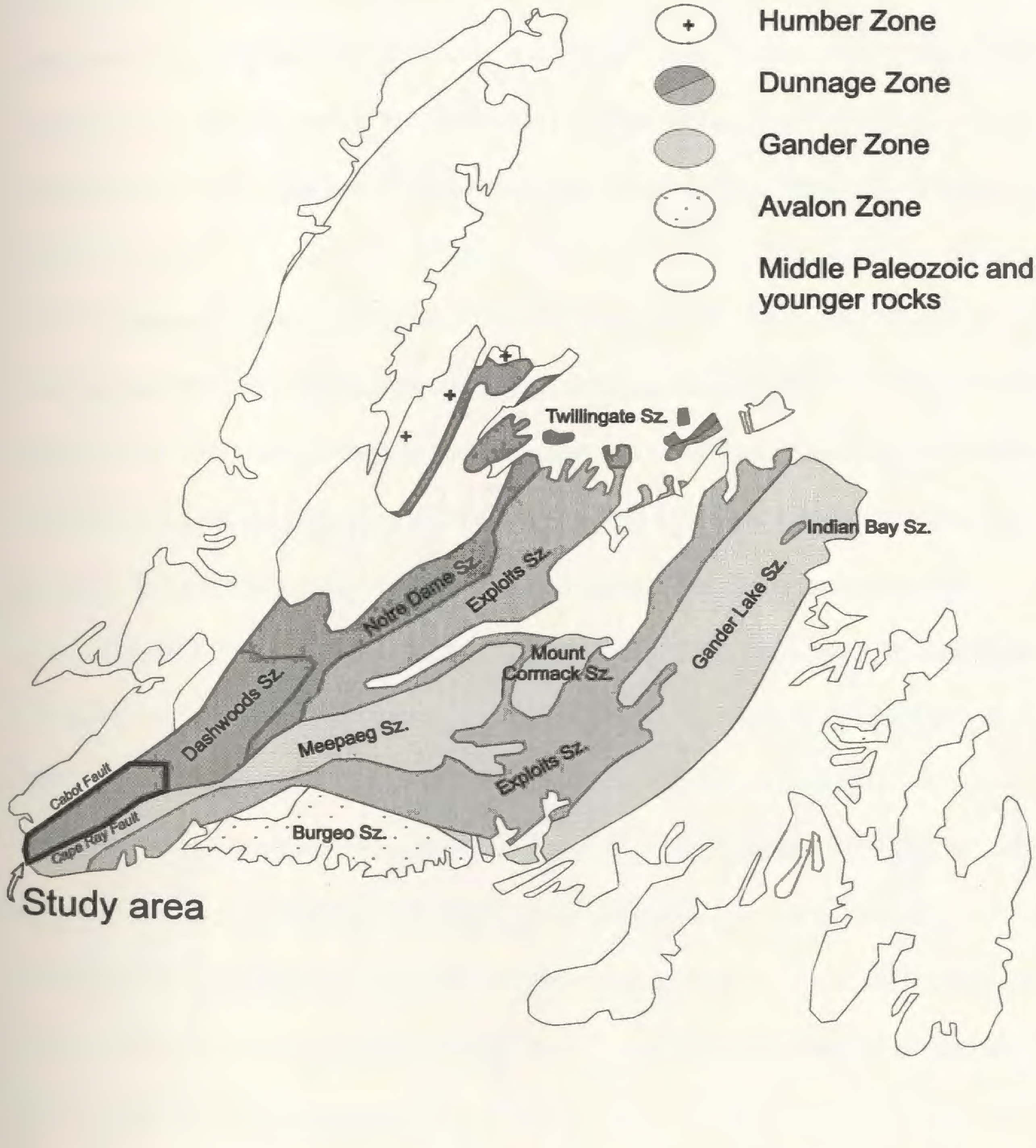


Figure 1: Zonal subdivision of the Newfoundland Appalachians and location of the study area.

After Williams, 1995a.

Rocks of the southern Long Range Mountains in southwest Newfoundland were originally included in the Humber Zone (Williams, 1979). Since then, they have been reassigned to other subdivisions: the Tonalite Terrane (Whalen and Currie, 1983); the Central Gneiss Terrane (van Berkel, 1987; van Berkel and Currie, 1988), the Notre Dame Subzone of the Dunnage Zone (Williams *et al.*, 1988; Whalen *et al.*, 1997), Dashwoods Subzone (Williams, 1995a) and the Dashwoods Belt (Cawood *et al.*, 1996a). They are most widely held, however, to be part of the Dashwoods Subzone of the Dunnage Zone (Williams 1995a) (Figure 1).

The Dashwoods Subzone, as delineated by Williams (1995b), is bordered by faults on all sides except to the south where it's exposures end at the Atlantic Ocean. The faults which bound it to the east are, from south to north, the Cape Ray, Gunflap Hills and Lloyd's Valley faults. To the north, the Little Grand Lake Fault separates the Dashwoods and Notre Dame subzones. The Cabot Fault defines the western margin of the Dashwoods Subzone.

The Cape Ray and Cabot faults bound this study area. The Cape Ray Fault forms part of the Iapetan suture (Brown, 1973b; Wilton, 1983; Chorlton, 1984; van Staal *et al.*, 1992). The Cabot Fault is a significant, though poorly understood structure. The sense of movement on this fault has been described as transcurrent (Wilson, 1962; Gillis, 1972; Knight, 1983), normal (Brown, 1976; Chorlton, 1984) and thrust (Colman-Sadd *et al.*, 1992). This study suggests (Chapter 3.1.2) that two faults intersecting at or near the surface with differing attitudes and senses of movement account for the varied evidence which has led to these contradictory interpretations.

1.2 Location and Access

The study area covers approximately 800 km^2 in the highland region immediately east and south of the Codroy Valley, in southwestern Newfoundland (Figure 2). The Trans Canada Highway runs along the flatlands near the coast and the CN railway bed lies approximately parallel to the highway. Local roads south and west of the Trans-Canada Highway lead to the town of Cape Ray, J.T. Cheeseman Provincial Park, and the Cape Ray Lighthouse. Trails lead north and east from the Trans Canada Highway and give limited access to the study area. The highlands can be reached via a well maintained gravel road leading to a radio transmitter on Table Mountain in the south. From there ATV trails can be followed into the interior of the plateau. Both ATVs and helicopters were used to access the highlands during the course of this work.

1.3 Physiography and Climate

Bounding the study area to northwest and southeast are two major northeast-trending faults which have strong topographic expressions. These are the Cabot Fault to the northwest and the Cape Ray Fault to the southeast (Figure 2). Cliffs and rocky shoreline of the Cabot Strait define the south and southeast boundary. To the north, the map area ends just northwest of the bend of the Cape Ray Fault where it merges with the Gunflap Hills Fault (Lin *et al.* 1994, Figure 2).

The highlands which dominate the map area are a peneplane transected by numerous small ridges and valleys. Elevations of these tablelands vary from about 350 m to over 600 m above sea level. The highlands are deeply incised by uplifted fjords.

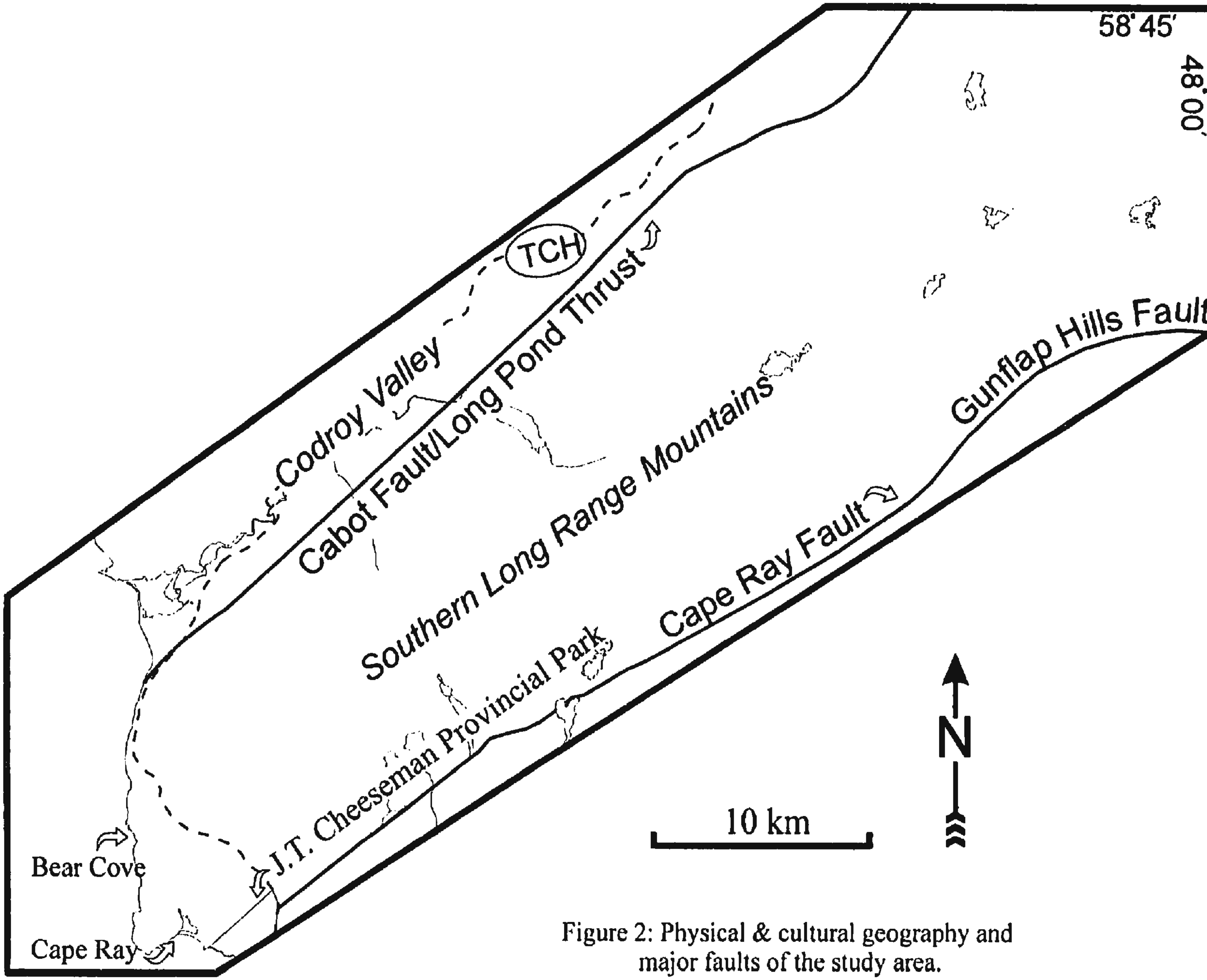


Figure 2: Physical & cultural geography and major faults of the study area.

Bedrock exposure is sporadic, but where present, is extensive (commonly 80-90%). Overall, there is approximately 30% exposure in this study area with large tracts (tens of km^2) covered by bog, tuckamore (stunted, interwoven spruce, fir and larch trees) and numerous shallow ponds. From the coast through the slopes of the fjords and in the vicinity of the Cape Ray Fault the land is covered by a thick boreal forest where outcrops are largely limited to roadcuts and shoreline.

Poor weather typically limits the number of workable days in the field season. Low-lying clouds commonly blanket the highlands, limiting visibility to a few tens of metres. Snow patches disappear in late July or early August, only to return by late September. High winds, known to have overturned railway boxcars, batter the area. August is the best time to conduct fieldwork as the temperatures are mild and fog is less prevalent. This area, with its notoriously inclement weather and limited access, has escaped the close geological attention received by other areas of Newfoundland.

1.4 Previous Work

Following the pioneer studies of Jukes and Murray in the middle of the 19th century, the southern Long Range Mountains have been included in regional mapping projects carried out by Phair (1949), Gillis (1972), Brown (1973a & b, 1976), Wilton (1983), Chorlton (1980), Chorlton (1984), Dubé (1993), Dubé and Lauzière (1995) Dubé *et al.* (1996a & b) and van Staal *et al.* (1992; 1996). Table 1 summarizes the contributions these workers made to the body of knowledge of southwestern Newfoundland.

Table 1: Summary of geological studies in the southern Long Range Mountains

Author	Study type	Geological Contributions
1949, Phair	Ph.D. thesis study of the western side of the Long Range Mountains.	Described Early Paleozoic paragneisses, Devonian stratiform mafic/ultramafic intrusions, younger granitoid intrusions and shear zones in the vicinity of Cape Ray.
1972, Gillis	Geological and geochronological study of the Port-aux-Basques map area.	First recognize the Cape Ray Fault as regionally important, separating a largely granitoid terrane to the northwest from gneisses and schists to the southeast. Suggested that gabbros and metasedimentary rocks northwest of the fault could be as old as Precambrian or as young as Ordovician.
1973 (a & b), Brown	Structural and metamorphic study of the Cape Ray Fault and the adjacent rocks.	(a) Named the rocks north of the Cape Ray Fault the Long Range Mafic-ultramafic and Cape Ray complexes. (b) Refined the geographical trace of the Cape Ray Fault.
1976, Brown	Geological study of the Port-aux-Basques map area.	Subdivided the Cape Ray Complex into the Long Range Gneiss, the Cape Ray Granite and the Red Rocks Granite. Distinguished the Cape Ray Granite from the younger undeformed Red Rocks Granite based on its foliated megacrystic texture.
1983, Wilton	Ph.D. thesis study of the Cape Ray Fault from the coast to the Gunflap Hills Fault.	Described the evolution of the Cape Ray Fault rocks in terms of a three-phase structural history. Related the electrum mineralization found along the Cape Ray Fault to the fault's evolution.
1980, Chorlton	Geology of the La Poile River area.	Assigned the Devonian Billiards Brook Formation to the Windsor Point Group.
1984, Chorlton	Ph.D. thesis study of the geological development of the Long Range Mountains with a 1:100 000 scale compilation map from the Codroy Valley to La Poile Bay.	Divided the area southeast of the Cabot Fault into two terranes: Terrane I (corresponding to this study area) which lies between the Cabot and Cape Ray faults and Terrane II which lies southeast of the Cape Ray Fault. Subdivided Brown's Long Range Gneiss into: (i) biotite tonalite, (ii) garnetiferous biotite tonalite, (iii) garnetiferous tonalite-granodiorite and (iv) leucogranite-tonalite. Noted limited marble and siliciclastic metasedimentary rocks largely in the vicinity of the Long Range Fault (herein called the Cabot Fault).
1985, Dunning and Chorlton	Geochronology and regional correlations.	Established that tonalitic rocks of Brown's Long Range Gneiss are Ordovician, and renamed them the Cape Ray Igneous Complex.

Author	Study type	Geological Contributions
1992, van Staal *et al.*	Reconnaissance geology across southwestern Newfoundland	Noted possible intrusive contact between the Long Range Mafic-ultramafic Complex with paragneissic rocks and suggest that the former are arc-related layered mafic-ultramafic intrusions.
Dubé, 1993	Preliminary study of structure and geochronology of the Cape Ray Fault.	Established a 472 (+/-2) Ma isotopic age for the tonalite of the Cape Ray Igneous Complex and interpreted it as the oldest rock unit deformed by the Cape Ray Fault. Other isotopic dates determined include: the Window Glass Hill Granite (424 +2/-1 Ma); the Strawberry Granite (384 +/-2 Ma); Isle-aux-Morts Brook Granite (386 +/-2).
1994, Hall *et al.*	Geological interpretation of the southern Long Range Mountains between the Cabot and Cape Ray faults.	Identified metamorphosed mélange. Delineated four phases of Ordovician ductile deformation. Documented multiple intrusive events based on the relative degrees of deformation.
1996, Dubé and Lauzière.	Detailed study of the Cape Ray Fault Zone and the lithology of the Windsor Point Group.	Outlined the structural history of the Cape Ray Fault Zone. Delineated three lithological domains: the northern volcanic domain; the central sedimentary domain; and the southern mylonite domain.
1996, Dubé *et al.*	Detailed study of structure and geochronology of the Cape Ray Fault.	Noted a progressive westward increase in strain in the Port-aux-Basques Gneiss Complex ending in the Cape Ray Fault Zone. Characterized the Cape Ray Fault Zone as a broad belt of mylonites which involves both the Port-aux-Basques Gneiss Complex and the Windsor Point Complex. Established a 488 Ma (+/-2) Ma isotopic age for the Cape Ray Granite.
1996, van Staal *et al.*	1:25 000 geological map of NTS sheet 11-O/11.	Mapped the Long Range Mafic-ultramafic Complex, the Cape Ray Igneous Complex, metasedimentary rocks and younger granitoid plutons. Indicated that all units northwest of the Cape Ray Fault are Ordovician or older.

1.5 History of Ideas

Brown (1973a), Kennedy (1975), and Brown and Colman-Sadd (1976) suggested that the Central Mobile Belt (Williams, 1964), comprising the Dunnage and Gander zones, was pinched out at the Cape Ray Fault in southwestern Newfoundland. Brown (1973b) further proposed that this fault represents a suture juxtaposing opposite margins of the Iapetus Ocean. As such, he interpreted (1976) the Long Range Gneiss of the Cape Ray Complex as a correlative of Grenvillian gneisses of northwestern Newfoundland and the Port-aux Basque Gneiss to the southeast of the fault as reworked Gondwanan basement. Brown (1976) interpreted the rocks of the Long Range Mafic-ultramafic Complex as ophiolitic klippen and the Cape Ray Granite as a Paleozoic intrusion.

Observing no basal thrusts beneath the Long Range Mafic-ultramafic Complex, Wilton (1983) concluded that exposures of the complex are not klippen on Grenvillian gneisses as Brown (1973a, 1976) had indicated. Wilton did concur that the Long Range Mafic-ultramafic Complex rocks were ophiolitic, but were roof pendants in the surrounding tonalitic rocks (Brown's Long Range Gneiss of the Cape Ray Complex). Wilton (1983) associated the Cape Ray Fault's three phase deformational history with Devonian Acadian Orogeny. He concluded that the rocks on both sides of the Cape Ray Fault formed a part of the same pre-Acadian allochthonous terrane which was subsequently bisected by the Acadian Cape Ray Fault.

Chorlton (1984, pp. ii) defined Terrane I, which corresponds to the area of this study, as "an Early Paleozoic (?) ocean basin". She proposed that Terrane I was thrust onto the Laurentian margin during the early part of the Ordovician Taconic Orogeny and cut systematically by granitoid rocks (Long Range Gneiss of Brown, 1976). Chorlton further indicated that Terrane I and the Port-aux-Basques Complex of Terrane II were juxtaposed by Acadian transcurrent movements along the Cape Ray Fault. Both Terranes I and II were subsequently intruded by post-tectonic mafic to felsic intrusions which were correlated across the Cape Ray Fault.

Hall *et al.* (1994) identified metasedimentary rocks associated with the Long Range Mafic-ultramafic Complex as ophiolitic mélange. The Cape Ray Igneous Complex was interpreted as the remnant of a magmatic arc. The presence of inherited zircons (G.R. Dunning and L.B. Chorlton, unpublished data) in these arc plutons implied a Grenvillian substrate beneath the arc. Van Staal *et al.* (1998) further developed a model of arc-trench migration for the northern Appalachians and British Caledonides supporting an arc-polarity reversal which was initiated at or near southwestern Newfoundland.

1.6 Purpose and Scope

The Geological Survey of Canada sent a team of geologists led by Dr. C.R. van Staal to map this poorly understood area of southwest Newfoundland at a scale of 1:25 000. This study is part of the van Staal project and concentrates on the rocks of the southern Long Range Mountains (Figure 2). Geologic mapping was carried out over two summers with a total of four months in the field.

The principal goal of this work was to determine the tectonic setting and structural evolution of the rocks of the southern Long Range Mountains by documenting their Paleozoic geological history. Critical relationships including the nature of contacts, structural and metamorphic fabrics, and sedimentary and xenolithic entrainment provide insights into the relative timing of tectonic events. Previously determined isotopic ages

(Wilton, 1983; Dubé, 1993; Dubé *et al.*, 1996 and Dunning and Chorlton, unpublished data) are combined with the relative ages determined in the present study to outline the geologic evolution of the southern Long Range Mountains.

CHAPTER 2

General Geology

Numerous rock units are distinguished in the southern Long Range Mountains of Newfoundland and are represented on the map in the pocket. These rock units include: the Long Range Mafic-ultramafic Complex (∈Olu and ∈Olg); the Mischief Mélange (∈Olum, ∈Olgm and POfm); the Cape Ray Igneous Complex (Oc, Ocg, Oct, Ocs); post-tectonic felsic intrusions (Ogp, OSgr, Osgd and Dgs); the Fleur de Lys Supergroup (P∈g and P∈Of); volcanic and sedimentary rocks of the Windsor Point Complex (OSwv, ODwfv, ODw and Sgw); and late diabasic dykes. Table 2 summarizes the units and their relative ages and Figure 3 is a simplified geologic map of the study area.

The Long Range Mafic-ultramafic Complex consists of gabbro and ultramafic (primarily feldspathic peridotite and dunite) rocks which display, to varying degrees, the effects of both metamorphism and structural deformation. The Long Range Mafic-ultramafic Complex does not intrude any other unit in the study area. It is in fault contact with the rocks of the Fleur de Lys Supergroup and the Windsor Point Complex, in structural contact with the Mischief Mélange and is intruded by the other igneous units. With the possible exceptions of the Fleur de Lys Supergroup and Windsor Point Complex where the faulted contacts make the relative ages ambiguous, it is the oldest rock unit in the area. It is broadly accepted that this complex is the remnant of a dismembered ophiolite (e.g. Brown, 1973b, 1976, 1977; Wilton, 1983; Chorlton, 1984; Dunning and Chorlton, 1985; van Staal *et al.*, 1992, Hall *et al.* 1994, van Staal *et al.*, 1996).

Era	Name		Unit		Lithology
?	Mafic dykes		/		Porphyritic diabase
Ord. to Dev.	Windsor Point Complex		Sgw ODw ODwfv OSwv		Metamorphosed terrestrial clastic sedimentary and volcanic rocks
Ordovician	Strawberry Granite		Dgs		Biotite granite
	Red Rocks Granite		OSgr		Biotite muscovite K-feldspar granite
	Dragon Lake Granite		OSgd		Biotite muscovite granite to monzogranite
	Pin Granite		Ogp		Muscovite granite to monzogranite
	Cape Ray Igneous Complex	Staghill Orthogneiss	Oc	Ocs	Gneissic granodiorite
		Big Pond Tonalite		Oct	Foliated to gneissic tonalite
		Cape Ray Granite		Ocg	Foliated to gneissic granite
	Mischief Mélange		POfm		Fragmental (ЄOlgm, ЄOlum) paragneiss
	Long Range Mafic-ultramafic Complex		ЄOlg ЄOlu		Metagabbro Metagabbro
Neoprot. To Ord.	Fleur de Lys Supergroup		PЄof PЄg		Marble and calcsilicate Quartzo-feldspathic gneiss

Table 2: Table of formations

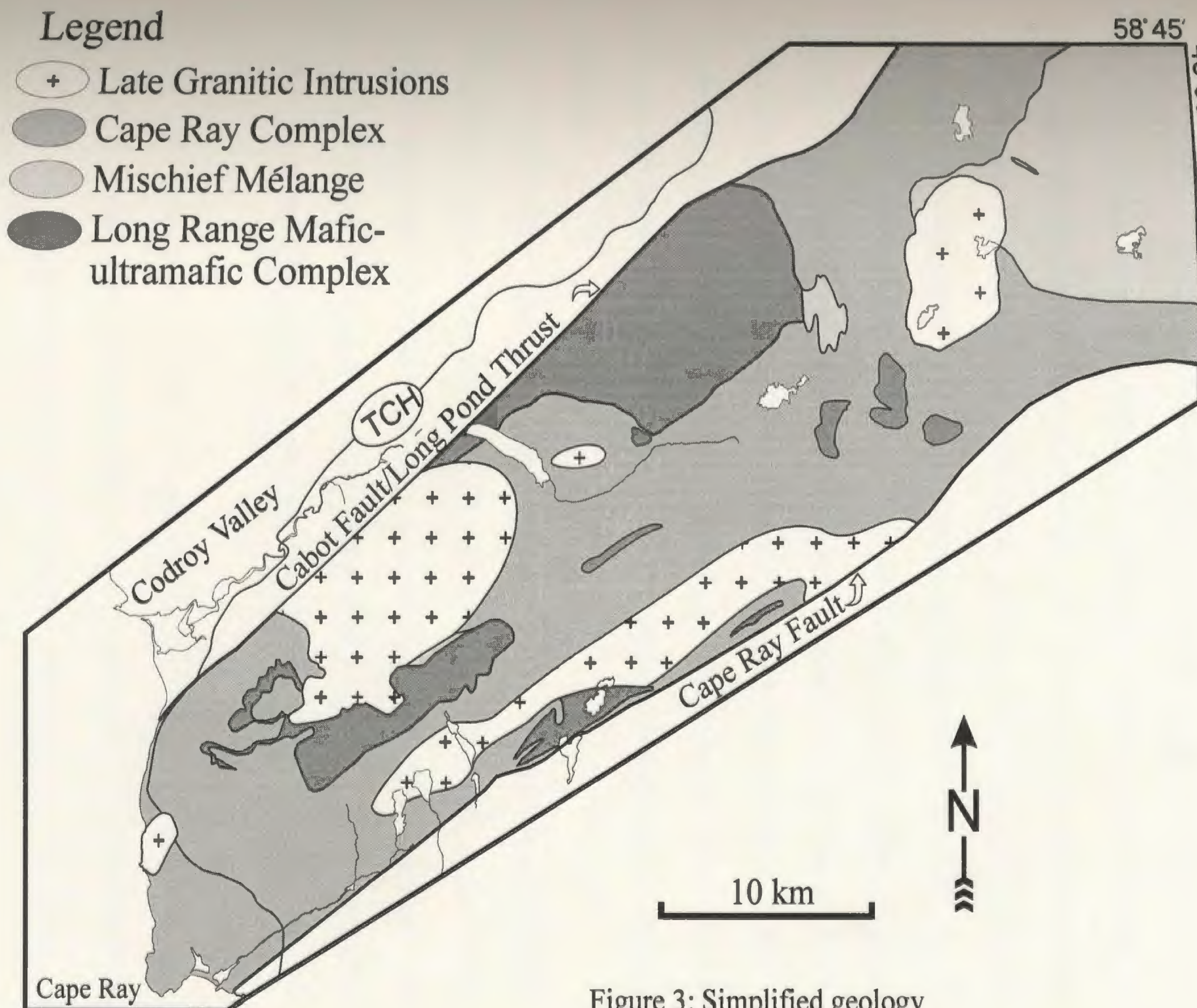


Figure 3: Simplified geology

The Mischief Mélange is composed of coarse clastic sedimentary rock which is intensely deformed and metamorphosed. A variety of fragments occur in a pelitic to psammitic matrix. The mélange is associated with the Long Range Mafic-ultramafic Complex and contains fragments of mafic and ultramafic rock. These chaotic rocks display the aspect of a metamorphic mélange, herein named the Mischief Mélange.

Foliated to gneissic felsic to intermediate intrusive rocks typify the Cape Ray Igneous Complex. Included in this complex are the Cape Ray Granite, Big Pond Tonalite and the Staghill Orthogneiss which are distinguished on the basis of both composition, structural features and over-printing relationships. These Early Ordovician (Dubé, 1993; Dubé *et al.*, 1996) rocks intrude both the Long Range Mafic-ultramafic Complex and the Mischief Mélange.

Intruding the Long Range Mafic-ultramafic Complex, Mischief Mélange and Cape Ray Igneous Complex are four felsic plutons and associated dykes. These largely undeformed, potassium-feldspar granite to granodiorite plutons include the Strawberry Granite (Wilton, 1983) (Dgs), the Red Rocks Granite (Brown, 1976) (OSgr) and two other hitherto unnamed plutons, herein named the Dragon Lake Granite (OSgd) and the Pin Granite (Ogp).

The rocks of the Fleur de Lys Supergroup and Windsor Point Complex lie at the western and eastern edges of the study area respectively, associated with the bounding faults. Marble and calc-silicate rocks (P€Of), herein correlated to the Fleur de Lys Supergroup, are only exposed within the Long Pond Thrust (Chapter 3.1.2) at the northwestern extremity of the map area. These thin, elongate slices are intensively deformed by the fault. Locally underlying the carbonate rocks is highly strained quarzo-feldspathic gneiss (P∈g). The Windsor Point Complex (OSwv, ODwfv, ODw and Sgw) is a sequence of deformed and metamorphosed clastic sedimentary and volcanic rocks of Ordovician through Devonian ages intruded by the Silurian Window Glass Hill Granite (Dubé et al., 1996). It is cut by and lies east of the Cape Ray Fault, unconformably above the Cape Ray Igneous Complex. The Windsor Point Complex is largely outside the scope of this work.

Diabase dykes are too small to be shown to scale on the map (pocket), but they are represented by a symbol. They are late stage intrusions which have been observed cutting all other units except the Fleur de Lys rocks. They are commonly sheared or displaced by faulting.

2.1 Long Range Mafic-ultramafic Complex

The Long Range Mafic-ultramafic Complex (e.g. Brown, 1973; Chorlton, 1983; Wilton, 1983) is predominantly metagabbro of varied character (∈Olg) with ultramafic components (∈Olu). Metadiabasic and metabasaltic rocks were reported, in limited amounts, by Chorlton (1984).

The discrete occurrences of the Long Range Mafic-ultramafic Complex appear to be strung out in a single folded sheet. Folded fabrics (Chapter 3) and stratigraphic reversals support the hypothesis that the large bodies of the Long Range Mafic-ultramafic Complex trace large folds with an amplitude of tens of kilometres.

Ultramafic rocks (∈Olu)

A large (approximately one square kilometre) exposure of ultramafic rock lies to the southeast of a large metagabbro body in the center of the study area. Fragments of ultramafic rock are also present in the surrounding orthogneissic and metasedimentary rocks. These range from cobble sized to fragments of 20 m diameter. However, the ultramafic components of the Long Range Mafic-ultramafic Complex most typically form layers (1 m to 10 m thick) within the metagabbro bodies. These layers are included in unit ∈Olg, the metagabbroic rocks, as they are not distinguishable at this scale of mapping.

The ultramafic rocks are easily identifiable in the field as the outcrops display distinctive whaleback geometry, marked dun to reddish brown colour and classic elephant skin texture. Fresh surfaces appear black and resinous and the textures are difficult to discern. Textures are more obvious on the weathered surface. These include: compositional and grain size layering, fine serpentine webs which overprint olivine aggregates, and disseminated grains and veinlets of magnetite which stand out in positive relief.

A range of original compositions including dunite, harzburgite, wehrlite and peridotite are present. However, primary compositions are obscured by replacement of mafic minerals by serpentine minerals. These include both chrysotile and lizardite, which have developed in at least two alteration episodes in some samples. Relic crystal shapes and cores allow the approximate determination of the original mineral components.

The large exposure of ultramafic rock displayed near the center of the map (pocket) is primarily massive harzburgite; however, within 10 m of the northern boundary of this ultramafic body, folded cumulate layering is present at a scale of 15 cm. This exposure includes the least altered ultramafic rock. It is characterized, in thin-section, by domains of optically continuous olivine in a network of serpentine and opaques (magnetite and chromite). Deformed orthopyroxene crystals and crystal aggregates comprise up to 15% of the rock. Small, anhedral olivine grains are enclosed by some of the orthopyroxene crystals.

Fragments of ultramafic rock found in the Mischief Mélange and the Cape Ray Igneous Complex show extensive serpentinization. Talc, chlorite and tremolite were also observed in thin section. The shapes and traces of the original minerals allow the determination of approximate modal compositions which include dunite, peridotite and wehrlite (Appendix 1). Folded bronzite layers (Plate 1) are displayed in one outcrop.

Metagabbroic rocks (∈Olg)

The dominant component of the Long Range Mafic-ultramafic Complex is metagabbro (∈Olg). The term metagabbro is used here as these rocks are no longer composed of primary pyroxene and plagioclase, although relic gabbroic textures can in places be discerned. Unit ∈Olg is exposed in large (up to 150 km^2), mostly elongate bodies throughout the study area.

The metagabbroic rocks of the Long Range Mafic-ultramafic Complex display relic igneous stratigraphy to varying degrees as well as post-depositional layering and fabrics imposed through deformation and metamorphism. To gain a better understanding of the stratigraphy of this complex, three metagabbroic bodies were mapped in detail. Figure 4 outlines the relative positions of these bodies (A, B, C) in the study area. Lithological layering, or igneous stratigraphy within the bodies is summarized in Figure 5. The widths

Plate 1: Folded bronzite layer in ultramafic fragment in the Mischief Mélange. Camera for scale. Site 1 on Map 1.

Plate 2: Bedding in the Mischief Mélange highlighted by colour variations, abundance of garnet and cleavage intensity. Hand lens for scale. Site 1 on Map 1.

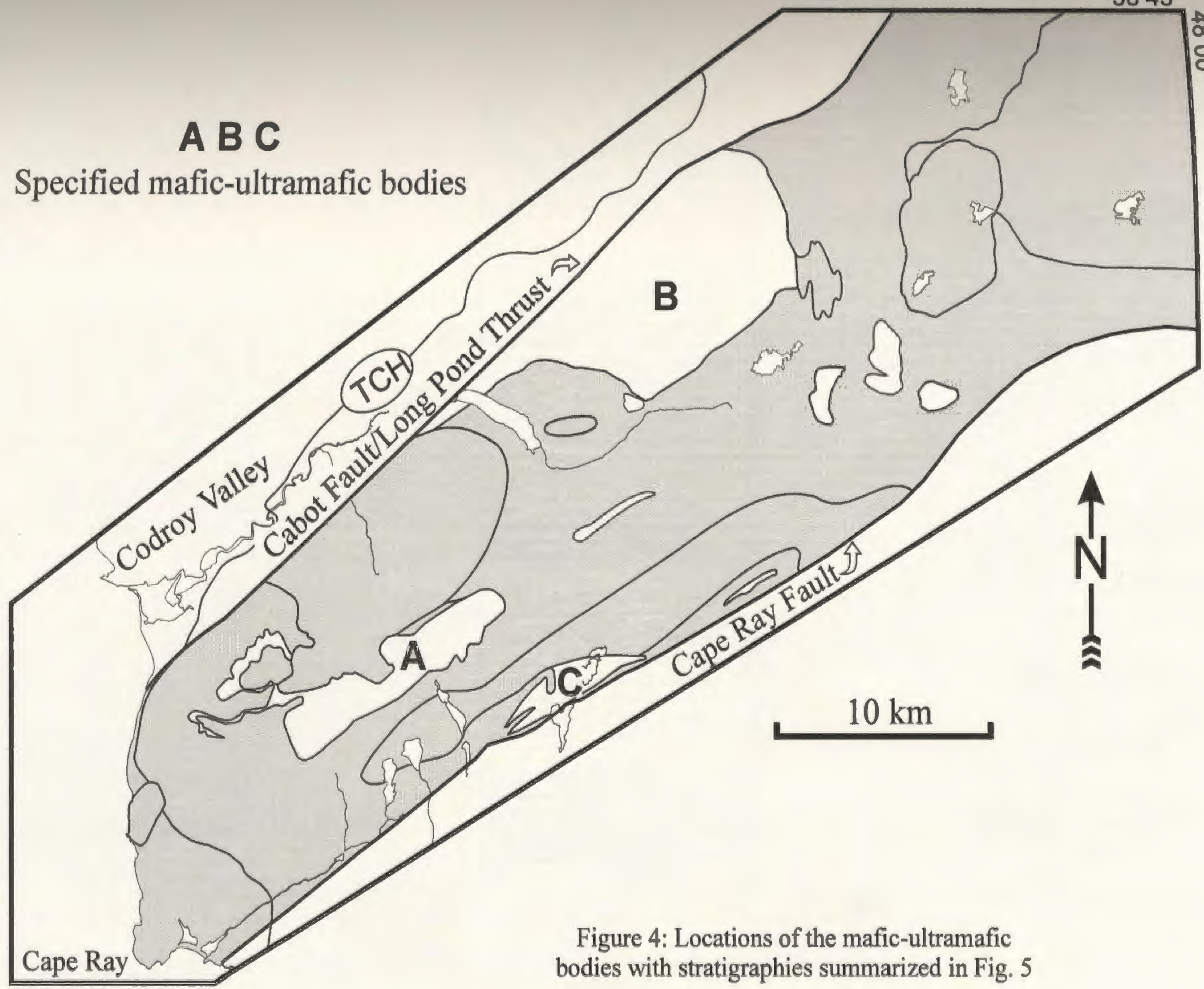


Figure 4: Locations of the mafic-ultramafic bodies with stratigraphies summarized in Fig. 5

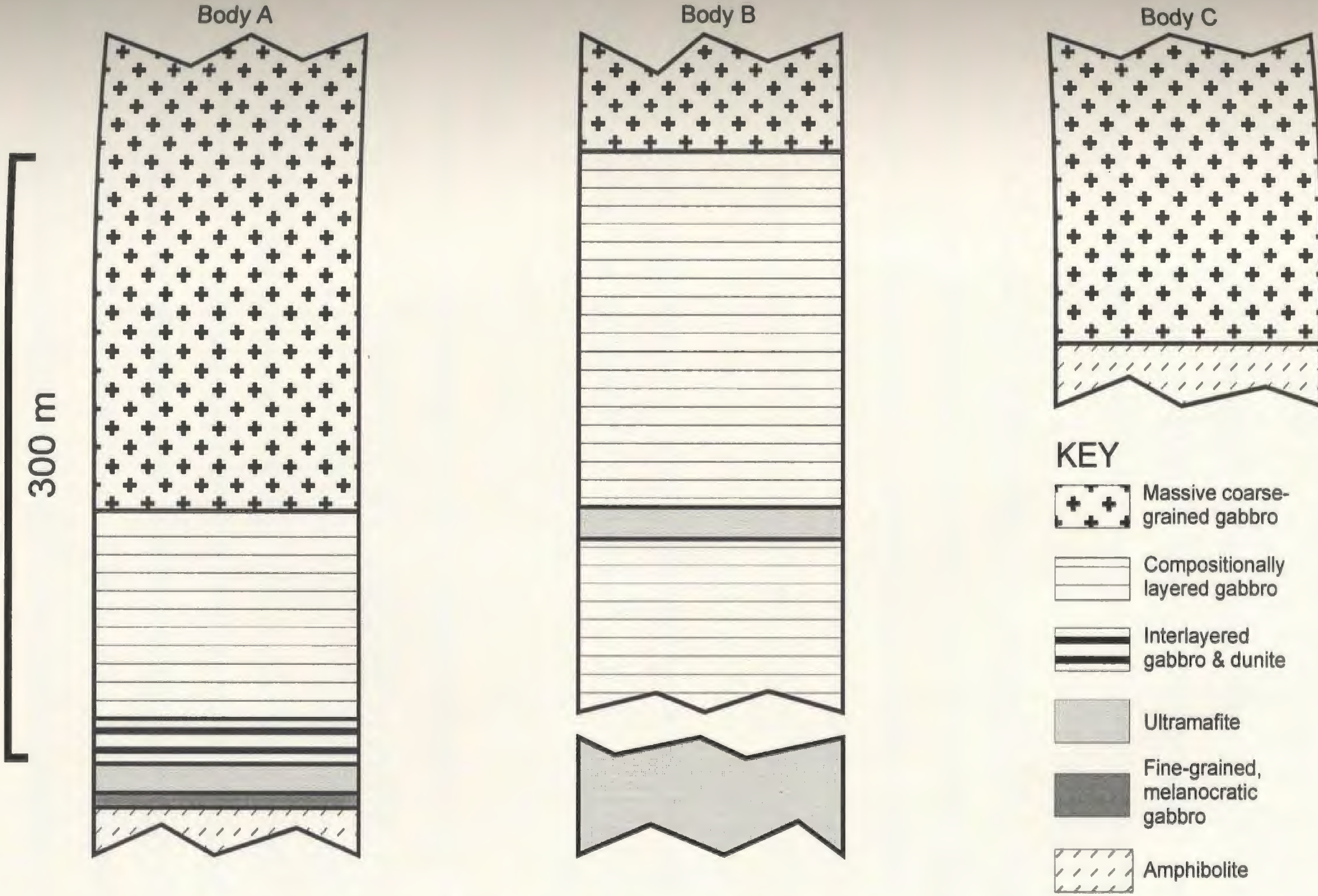


Figure 5: Igneous stratigraphy of the Long Range Mafic-ultramafic Complex

of these layers vary and in places they are discontinuous. This lack of continuity may be due to incomplete igneous layering throughout the body during its petrogenesis, but is compounded by structural deformation, which has truncated the layers both by folding and small shear zones.

In the south-central part of the map area, body A shows the most complex stratigraphy. The largest and northernmost body, B, is deformed by at least three different generations of folding. The stratigraphy of this body is, therefore, difficult to determine. Body C lies in the eastern limits of the field area truncated by the Cape Ray Fault. This metagabbro is strongly affected by the fault and is cut by several smaller related shear zones.

The rock types which comprise the unit ∈Olg metagabbros are described from the stratigraphic bottom to the stratigraphic top as outlined on Figure 4.

Amphibolite

Amphibolitic phases of the Long Range Mafic-ultramafic Complex are everywhere associated with shear zones. Amphibolite is most extensively exposed in body C near the Cape Ray Fault, but is present in the other bodies discussed here associated with minor shear zones (bodies A, B, and C) and the Long Pond Thrust/Cabot Fault (body B). The amphibolites weather black and show strong mineral (hornblende) lineations and foliations. Locally, fine banding which developed through the metamorphic segregation of hornblende and plagioclase is present. Predominantly, these amphibolites are composed of hornblende (with blue-green pleochroism) and plagioclase, with diopside, epidote or clinozoisite, local cummingtonite, local quartz and accessory opaque minerals. This amphibolite grade mineral assemblage has been largely over-printed in the vicinity of the Cape Ray Fault by greenschist retrograde metamorphism which is associated with late stage movement on the fault (Chapter 3). This greenschist assemblage consists of actinolite, epidote, abundant chlorite, sericitized plagioclase and accessory opaques and zircons (Appendix 1). The amphibolitic metagabbroic rocks have been metamorphosed to such a degree that their igneous nature is impossible to ascertain.

Fine grained melanocratic gabbro

Fine grained melanocratic metagrabbro is exposed between strained amphibolitic and ultramafic layers near the northwestern boundary of body A. This layer is 30 m wide and is exposed over a strike-length of approximately 500 m. Outcrops are weakly magnetic and weather dark grey to black. This unit lacks the intense gneissic fabric of the amphibolite, though it displays a well developed foliation. Clinopyroxene crystals rimmed by hornblende constitute up to 70% of this rock and sub-ophitically enclose grey plagioclase laths. Fine grained, subhedral magnetite is the dominant accessory mineral.

Ultramafic layers

Ultramafic rock is exposed within the gabbroic sequences in bodies A and B. In both occurences, the ultramafic rock is largely confined to a single layer 10 m to 15 m wide and isolated pods of 20 m or smaller diameter.

In body A, the ultramafic layer is flanked by interlayered gabbro and dunite to one side and either amphibolite or fine-grained melanocratic gabbro to the other side. This layer is traceable over 3 km and is folded. In body B, the ultramafic layer is flanked on both sides by layered gabbro and is traceable for up to 1 km truncated by the Cabot Fault. Ultramafic outcrops are easily distinguished within the gabbro bodies by their distinct red-brown colour and elephant skin texture. Banding (10 cm to 30 cm wide) within the ultramafic layers is defined by grain size and highlighted by the presence of very thin (2 mm to 4 mm) seams of chromite. This internal banding parallels the boundaries of the ultramafic layers. Fresh surfaces are black and resinous and the layering is difficult to distinguish. With the exception of the contact described below under the subheading "Interlayered gabbro and dunite", contacts of the ultramafic layers and pods with the hosting gabbro are gradational. The dunites grade into the gabbro (over 2 cm to 30 cm) through feldspathic peridodite with the plagioclase and pyroxene content rising proportionately.

Petrographic examination of the ultramafic layers within the gabbro bodies revealed that olivine was the dominant mineral phase prior to serpentinization and that these rocks are serpentinized dunite. Olivine is present as elliptical domains of uniform extinction cut by a network of serpentine and magnetite. Up to 5% plagioclase, largely labradorite, is present as broken anhedral grains. Clinopyroxene and brown primary hornblende, small grains of orthopyroxene, rare phlogopite and spinel were also identified in thin-section. Tremolite and actinolite locally rim olivine which had been in contact with plagioclase. Up to 20% of the ultramafic rocks are composed of opaque minerals. These include chromite, magnetite and titanite in all samples, with pyrite present in some (Appendix 1).

Interlayered gabbro and dunite

A 20 m wide unit of interlayered gabbro and dunite is exposed in body A between the ultramafic layer described above and compositonally layered gabbro. This rock type is a gradation between the ultramafic layer and the layered gabbro in that the thickness of the dunite layers dwindles from 120 cm to 5 cm and the thickness of the gabbro layers increases from 10 cm to 300 cm as it progresses toward the layered gabbro. Dunite layers are brown and weather positively relative to the grey gabbroic layers. Since the large scale lithological stratification roughly parallels these layers they are interpreted to be an igneous feature. Over-printing this layering is a sub-parallel foliation.

Petrographic examination of the ultramafic layers reveals that olivine was the dominant mineral phase prior to serpentinization. Olivine is present as elliptical domains of uniform extinction cut by a network of serpentine and magnetite. Up to 10% plagioclase, largely labradorite, is present as broken anhedral grains. Minor clinopyroxene, brown hornblende, small grains of orthopyroxene, rare phlogopite and spinel were also identified in thin-section. Up to 20% of the ultramafic rocks are composed of opaque minerals including chromite, magnetite and titanite.

Compositionally, the gabbroic layers are olivine gabbro with olivine, clinopyroxene, minor orthopyroxene and primary brown hornblende representing the mafic components. Labradorite to anorthite laths and aggregates are partially to wholly enclosed in large, polygonal clinopyroxene crystals. Accessory magnetite grains poikiolitically engulf the brown hornblende. Other accessory minerals include spinel and biotite.

Compositionally layered gabbro

Compositionally layered gabbro is a major component of bodies A and B. It is as much as 600 m thick in body B. On the outcrop scale, the layering reflects both grain size variations and plagioclase content. Layering varies from centimetre through metre scales. Cumulate textures are observed locally in the layered metagabbro. Since the large scale lithological stratification roughly parallels these cumulate layers most of this stratification is interpreted to be a primary igneous feature. In addition to variations in the plagioclase content, modal variations between layers involve olivine, clinopyroxene and to a lesser degree orthopyroxene and hornblende. Layer compositions include cumulate olivine gabbro, troctolite, anorthosite, troctolitic gabbro, and clinopyroxene gabbro. Plagioclase laths and aggregates are partially to wholly enclosed in large, polygonal clinopyroxene crystals. Accessory magnetite grains poikiolitically engulf brown hornblende. Other accessory minerals include spinel, biotite and rare phlogopite. Much of the igneous mafic mineral content is altered to blue-green hornblende, epidote and titanite, and the plagioclase minerals shows locally intensive sericitization (Appendix 1).

Massive gabbro

Dominating bodies A and C, massive gabbro is also a significant component of body B, and constitutes the main component of the other large and small bodies of the Long Range Mafic-ultramafic Complex. The low olivine content and absence of compositional layering distinguish the massive gabbro from the layered gabbro described above. The massive gabbro is a medium to coarse grained rock weathering a wide spectrum of grey commonly with a pale pinkish hue. The modal percentage of plagioclase and clinopyroxene varies, but it is largely a clinopyroxene metagabbro. Altered clinopyroxene comprises 30-70% of the modal composition of these rocks; the plagioclase content varies accordingly. Minor brown hornblende and accessory magnetite and pyrite are also primary igneous components. Alteration minerals include blue-green amphibole and chlorite (after the clinopyroxene), clinozoisite, zoisite and sericite (after the plagioclase), brown biotite, and titanite. Rare rutile is associated with the opaques (Appendix 1). Pegmatitic phases of the massive metagabbro also display compositional variations including markedly leucocratic and magnetite-rich phases. Primary brown hornblende is most abundant in the pegmatitic massive metagabbro.

Some minerals and textures are present in all lithologies of the metagabbroic rocks of the Long Range Mafic-ultramafic Complex. The pyroxene minerals are mostly replaced by amphibole and locally, to a lesser degree, chlorite. Plagioclase is anhedral and of varied calcium/sodium compositions, with An components ranging from 28% to 90%. The plagioclase is also characteristically replaced by epidote and white mica. There is commonly an opaque component to these rocks which is comprised largely of magnetite, titanite and pyrite (Appendix 1).

The Long Range Mafic-ultramafic Complex is widely interpreted as ophiolitic (Brown, 1973b, 1976, 1977; Wilton, 1983; Chorlton, 1984; Dunning and Chorlton, 1985; van Staal *et al.*, 1992; Hall *et al.*, 1994; van Staal *et al.*, 1996), though much of the classic ophiolite stratigraphy is absent. There is little direct evidence indicating that the Long Range Mafic-ultramafic Complex is ophiolitic. However, the relationship between the Long Range

Mafic-ultramafic Complex and the Mischief Mélange, wherein the predominant lithic clast types in the Mischief Mélange are metagabbros and serpentinites, is consistent with the typical relationship between a transported ophiolite suite and its ophiolitic mélange. The absence of intrusive contacts is also typical of ophiolitic rocks. Many well established partial and complete ophiolite complexes (ie. Bay of Islands, Betts Cove and Annieopsquotch) are present within several hundred kilometres of the study area, supporting the premise that the Long Range Mafic-ultramafic Complex is also ophiolitic.

2.2 Mischief Mélange

Psammitic to pelitic metasedimentary rocks with clasts or blocks up to 100 m in diameter are present in the study area and are herein referred to as the Mischief Mélange. Clastic metasedimentary occurrences and inclusions in the Cape Ray Igneous Complex were grouped with carbonate rocks under the heading of Metasedimentary Rocks of Terrane I (Chorlton, 1984). In this work, the carbonate rocks are separated out as they are not intimately associated with the other lithologies in the study area. The clastic metasedimentary rocks of Chorlton's Metasedimentary Rocks of Terrane I comprise the Mischief Mélange.

Small exposures (5 km^2 or less) of Mischief Mélange abut or lie within a few kilometres of the statigraphic bottom of the Long Range Mafic-ultramafic Complex. In the northeastern part of the map area, however, the unit extends both north and east across an undetermined area. This unit may extend into and form part of the Keepings Gneiss described by Cooper (1954). The Mischief Mélange is not exposed southwest of the large fold pair described by the trace of the Long Range Mafic-ultramafic Complex.

The Mischief Mélange is composed of deformed and metamorphosed clastic metasedimentary rock (POfm). Gneissic banding warped around large lithoclasts characterises the megascopic appearance of this unit. Lithoclasts, or blocks, are unsorted and display a range of shapes including rounded through angular, and equant to elongate (parallel to the gneissic banding). Some of the elongate blocks are folded. The percentage of matrix to blocks at outcrop surfaces varies from 40% to 100% matrix (not including those outcrops which represent part of a single huge block).

The most common block lithology is metagabbro (∈Olgm) comprising at least 80% of the exposure. A variety of other lithologies are present including serpentinite (∈Olum), metadiabase, metabasalt, red chert, bedded (folded and planar) green-grey metasiltstone and metacarbonate rocks. Blocks range in size up to hundreds of metres. Blocks which are larger than cobble size are limited to metagabbro and several large serpentinite blocks with diameters of up to 30 m. The metagabbro blocks resemble the metagabbros of the Long Range Mafic-ultramafic Complex.

Mineralogical layering, highlighted by the presence of abundant garnet grains (Plate 2), is interpreted to represent relic bedding. This relic bedding is 2 cm to 30 cm thick and commonly folded. The bedding is disrupted and truncated by large blocks, and where block density is high, bedding is absent. Although bedding is present in some outcrops, the combined affect of limited exposure, deformation and metamorphism and the intrinsically chaotic nature of this rock renders it impossible to establish an internal stratigraphy.

The matrix of the Mischief Mélange (POfm) displays extreme compositional variation. Compositions range from psammite to pelite, though they are predominantly semi-pelitic. Quartz, plagioclase, sillimanite, biotite, muscovite, limited chlorite and garnet are present everywhere. Compositions vary from 70% quartz and plagioclase; 30% muscovite, biotite, sillimanite, garnet and chlorite (psammitic composition) to 40% sillimanite and muscovite; 40% garnet; and 20% quartz, plagioclase, biotite and chlorite (pelitic composition). The plagioclase is largely replaced by sericite. Titanite is a common accessory mineral in both clear and opaque forms. Appendix 1 includes a summary of modal proportions of samples of the Mischief Mélange examined petrographically.

Cutting the Mischief Mélange are the Cape Ray Igneous Complex and the Pin and Dragon Lake granites and their associated dykes. These relationships clearly demonstrate that the metasedimentary rocks are older than the intrusive rocks of units 3, 4 and 5. The tonalitic gneisses of the Cape Ray Igneous Complex are intimately associated with the Mischief Mélange, and the two units display similar metamorphic grades and structural deformation. These rocks preserve upper amphibolite grade metamorphism (Chapter 3), extensive deformation and are everywhere gneissic.

Based largely on its chaotic nature, characterized by a lack of sorting, a large range of block sizes, a variety of block lithologies and disrupted bedding, this unit is interpreted as mélange and named the Mischief Mélange. The metagabbroic and serpentinite blocks within the Mischief Mélange are interpreted to be derived from the Long Range Mafic-ultramafic Complex. Therefore, this chaotic metasedimentary rock is younger than the Long Range Mafic-ultramafic Complex, and is interpreted to be related to its obduction and emplacement. The origin of the matrix material of this unit is unclear and it's deposition may predate the formation of the Long Range Mafic-ultramafic Complex.

2.3 Cape Ray Igneous Complex

The term Cape Ray Igneous Complex (Dunning and Chorlton, 1985) was first used to describe the Ordovician tonalitic rocks of the Long Range Gneiss (Brown, 1976). Van Staal *et al.* (1996) included the Cape Ray Granite (Brown, 1976) in the Cape Ray Igneous Complex. This study follows van Staal *et al.* (1996) in that the Cape Ray Igneous Complex encompasses both Brown's Long Range Gneiss and Cape Ray Granite.

These rocks were once considered part of a Grenvillian basement (Brown, 1976, 1977) and correlated with the rocks of the Long Range Inlier of the Great Northern Peninsula. Wilton (1983) and Chorlton (1984) recognized that the Cape Ray Igneous Complex intruded the Long Range Mafic-ultramafic Complex. Wilton called the whole intrusive suite the Cape Ray Granite and distinguished the two predominant lithologies as the megacrystic and tonalitic phases. He used Rb/Sr techniques to date the megacrystic phase at 242 (+/- 298) Ma and 439 (+/- 82) Ma. Wilton held limited credence in these data as the errorchrons are so large. Chorlton (1984) associated the Cape Ray Granite with the Red Rocks Granite and described these rocks as intruding the tonalites of the Cape Ray Igneous Complex.

Dubé *et al.* (1993) and Dubé *et al.* (1996) dated the Cape Ray Igneous Complex to determine the absolute ages of rocks involved in the Cape Ray Fault. They established igneous crystallization ages of 472 (+/- 2) (1993) Ma for the tonalitic phase, herein named the Big Pond Tonalite (Oct) and 488 (+/- 3) Ma (1995) for the Cape Ray Granite (Ocg). This relationship refutes Chorlton's interpreted intrusive relationship between the Cape Ray Granite and tonalite, as the Cape Ray Granite is older. A third sub-unit of this complex is locally distinguished and herein referred to as the Staghill Orthogneiss (Ocs).

The Cape Ray Igneous Complex is exposed throughout this map area and occupies the greatest areal extent of all the units (see map in pocket). It is a suite of felsic to intermediate orthogneissic and foliated meta-plutonic rocks. Biotite-tonalite to leucogranite-tonalite lithologies dominate the Cape Ray Igneous Complex. Outcrops typically weather light to medium green-grey. This coarse grained, equigranular rock is most commonly composed of minerals 6 mm to 10 mm. Compositional variation within the Cape Ray Igneous Complex is made evident by the presence, absence and relative abundance of microcline both as megacrysts (in the Cape Ray Granite, unit) and as equigranular crystals. Where microcline is present, it's modal proportion varies across a few metres.

The presence of abundant mafic xenoliths (Plate 3) is characteristic of the Cape Ray Granite (Ocg) and Big Pond Tonalite (Oct) of the Cape Ray Igneous Complex. These vary in size from centimetre to hundreds of metres. Metagabbro, peridotite and amphibolite xenoliths are present, though coarse grained metagabbro xenoliths are the most common (as high as 95% for many outcrops). Distinctive blue quartz occurs in some of the small mafic xenoliths and near the rims of some of the large ones. This is most likely the result of contact metasomatism between the xenoliths and the host pluton. In the immediate vicinity of exposures of Mischief Mélange, small (less than 2 m diameter) xenoliths lithologically similar to the Mischief Mélange are also entrained in the Cape Ray Igneous Complex.

Plate 3: Mafic xenoliths derived from the Long Range Mafic-ultramafic Complex in the tonalitic phase of the Cape Ray Igneous Complex. Hammer for scale. Site 3 on Map 1.

Plate 4: Leucocratic dyke associated with the Pin Granite cutting a foliated fragment of the Long Range Mafic-ultramafic Complex entrained in the Mischief Mélange. Pencil for scale. Site 4 on Map 1.

The number and size of the mafic and ultramafic xenoliths increases adjacent to exposures of Long Range Mafic-ultramafic Complex. This xenolithic gradation requires that the locations of the contacts between the units is subjective. Where the Long Range Mafic-ultramafic Complex is 70% of exposure, and the Cape Ray Igneous Complex does not exceed a 3 m dimension between xenoliths, exposure is assigned to the Long Range Mafic-ultramafic Complex. Otherwise, it is mapped as the Cape Ray Igneous Complex.

The Cape Ray Granite (Ocg) and Big Pond Tonalite (Oct) share a number of petrographic characteristics which distinguish these units from the Staghill Orthogneiss (Ocs). Quartz has a distinctive milky blue appearance and is typically round, anhedral and equigranular. Plagioclase has been extensively altered (50% to 80% of the mineral) to sericite and epidote or zoisite, giving the rock an overall greenish hue. Biotite content ranges up to 20% and is predominantly olive green when examined petrographically. Where present, microcline is clear though myrmekites are evident along the rims of many crystals. Titanite is a common accessory mineral which is typically euhedral with a dark orange-red rim and opaque core. Euhedral galena has grown in zones of brittle deformation. A modal analysis of samples examined petrographically is offered in Appendix 1.

The Cape Ray Granite (Brown, 1976) was distinguished within the Cape Ray Igneous Complex based on the presence of potassium-feldspar megacrysts. Along the coast, in J.T. Cheeseman Provincial Park, the Cape Ray Granite extends 2.5 km west from the Cape Ray Fault. The extent of the unit inland is obscured by the presence of the Strawberry Granite and poor exposure.

The Cape Ray Granite is a coarse grained, strongly foliated, megacrystic granite to monzogranite. The megacrysts, which range up to six centimetres in length, are salmon pink microcline. They comprise up to 40% of the modal composition of the rock and weather positively as pink laths in a coarse to medium grained matrix. These megacrysts display moderate alignment parallel to the tectonic fabric. Petrography reveals that they display local perthitic texture (with 10% or less exsolved plagioclase) differentiating this microcline from that found elsewhere in the Cape Ray Igneous Complex. Myrmekitic texture is common on the lath margins.

The strongly foliated matrix of the Cape Ray Granite is composed of blue quartz, biotite, plagioclase, microcline, epidote, muscovite and abundant accessory titanite, similar to overall composition of the Big Pond Tonalite. Magnetite, galena and local, interstitial chlorite are also present in limited amounts. The biotite content varies from 5% to 20% and is a distinctive olive green to brown-green in plane light.

The Cape Ray Granite appears to grade into the Big Pond Tonalite with a decrease in size and abundance of the microcline megacrysts over tens of metres. No intrusive contacts were observed between the tonalitic and granitic phases. The granite displays the same metamorphic and structural affects as do the adjacent tonalitic rocks. However, they are mineralogically distinct and isotopic ages reported in Dubé (1993) and Dubé *et al.* (1996) reveal a minimum absolute age difference of 11 Ma between the Cape Ray Granite and Big Pond Tonalite. In light of this large range of absolute ages, the absence of observed intrusive relationships within the complex is surprising. This could be an indication that cooling and crystallization progressed as a continuum over a protracted period.

In this work, the term Staghill Orthogneiss (Ocs) is assigned to small metamorphosed granitoid plutons and dykes within the Cape Ray Igneous Complex. These rocks were included in Brown's Long Range Gneiss (1976) and Dunning and Chorlton's Cape Ray Igneous Complex (1985). These potassium-feldspar granitic to granodioritic orthogneisses display compositional variations. Cutting other rocks of the Cape Ray Igneous Complex, this gneissic unit occupies a relatively limited part of the study area and has been identified only in the northern half of the map (pocket). Rare dykes, too small to record at the scales of mapping, have also been observed in the northern extremities of the study area.

The rocks of the Staghill Orthogneiss have poorly to moderately developed gneissic banding defined by the presence and absence of biotite. The minerals are medium to coarse grained (averaging 4 mm) and largely equigranular. Weathered outcrop surfaces are orange-pink and rusty reflecting the presence of oxidized iron. Fresh samples are largely white to light grey with a coarse, sugary texture.

Composed of plagioclase, quartz, microcline, biotite, garnet and muscovite, the Staghill Orthogneiss displays modal variations from potassium-feldspar granite to granodiorite. Quartz is orange-red on the macroscopic-scale resulting from an iron oxide film and petrographic inspection reveals that it is polygonized to recrystallized with irregular grain boundaries Up to 10% of the plagioclase has been sericitized and epidotized. Large microcline grains with myrmekitic embayments and inclusions of quartz and plagioclase comprise up to 30% of the modal composition of the potassium-feldspar granitic phases. In the granodioritic phases, the microcline grains are small and clear. Up to 25% of the granodioritic rocks are biotite in the form of large, locally chloritized books. Muscovite is present as both an accessory and a replacement mineral after the plagioclase. Both transparent and opaque titanite, zircon and local apatite are common accessory minerals. Chlorite occurs as an alteration product of biotite. Macroscopic almandine garnet is present in most exposures.

Macroscopically, the Staghill Orthogneiss (Ocs) can be distinguished from the Cape Ray Granite (Ocg) and Big Pond Tonalite (Oct) through cross-cutting relationships, the absence of mafic and other xenolithic fragments and on the basis of deformational history (Chapter 3). Petrographically, the Staghill Orthogneiss is distinguished through the degree of alteration of the plagioclase, the nature of the quartz and presence of garnet. Garnet, muscovite and biotite are present everywhere indicating a relatively complex chemical composition consistent with derivation in part from a sedimentary source. This unit of the Cape Ray Igneous Complex is interpreted to reflect renewed magmatism, where a sedimentary element has been incorporated into the melt.

Along the coast from the Cape Ray Fault northwest to Bear Cove the Cape Ray Igneous Complex displays well developed tectonic textures. These are characterized by a strong anastamosing foliation defined by mica aggregates and flattened polygonized quartz. Elongation of the xenoliths parallels this foliation on the megascopic scale. The foliation intensifies to the north and in proximity to the Cape Ray Fault, such that the rocks develop a pronounced schistosity. Farther inland, the rocks show a greater degree of metamorphism and deformation which obscure the igneous characteristics of the complex. As a result, the Cape Ray Igneous Complex is undivided in much of the northeastern region of the map (pocket). Textures range from a strong schistosity to gneissic banding defined by alternating leucocratic and melanocratic bands. Leucocratic bands are leuco-granites composed of medium grained perthite-antiperthite, sericitized plagioclase, polygonized quartz and limited muscovite. Biotite is the dominant mineral phase in the melanocratic bands. The gneissic banding is commonly folded in these more northerly exposures.

The Cape Ray Igneous Complex intrudes and surrounds the Long Range Mafic-ultramafic Complex and the Mischief Mélange. The mafic and ultramafic xenoliths are interpreted to be derived from the Long Range Mafic-ultramafic Complex. The largest bodies of the Long Range Mafic-ultramafic Complex could be considered extremely large xenoliths or roof pendants within the enveloping Cape Ray Igneous Complex.

2.4 Granites

There are four main granite bodies, the Pin Granite (Ogp), the Red Rocks Granite (OSgr), the Dragon Lake Granite (OSgd) and the Strawberry Granite (Dgs) in the southern Long Range Mountains. Figure 6 illustrates the relative positions of these plutons. Isotopic ages for two of the granite plutons have been determined through U/Pb analyses. The Pin Granite is 449 (+/- 2) Ma (Dunning and Chorlton, unpublished data) and the Strawberry Granite is 384 (+/- 2) Ma (Dubé *et al.*, 1996).

The Pin Granite

The Pin Granite was identified by Chorlton (1984) as pluton A of a suite of post-tectonic intrusive rocks. It is named the Pin Granite in this study. Located in the northern reaches of the study area the Pin Granite is a large (80 km^2), approximately oval pluton. Two well spaced joint sets can be observed on airphotos cutting the pluton trending north-

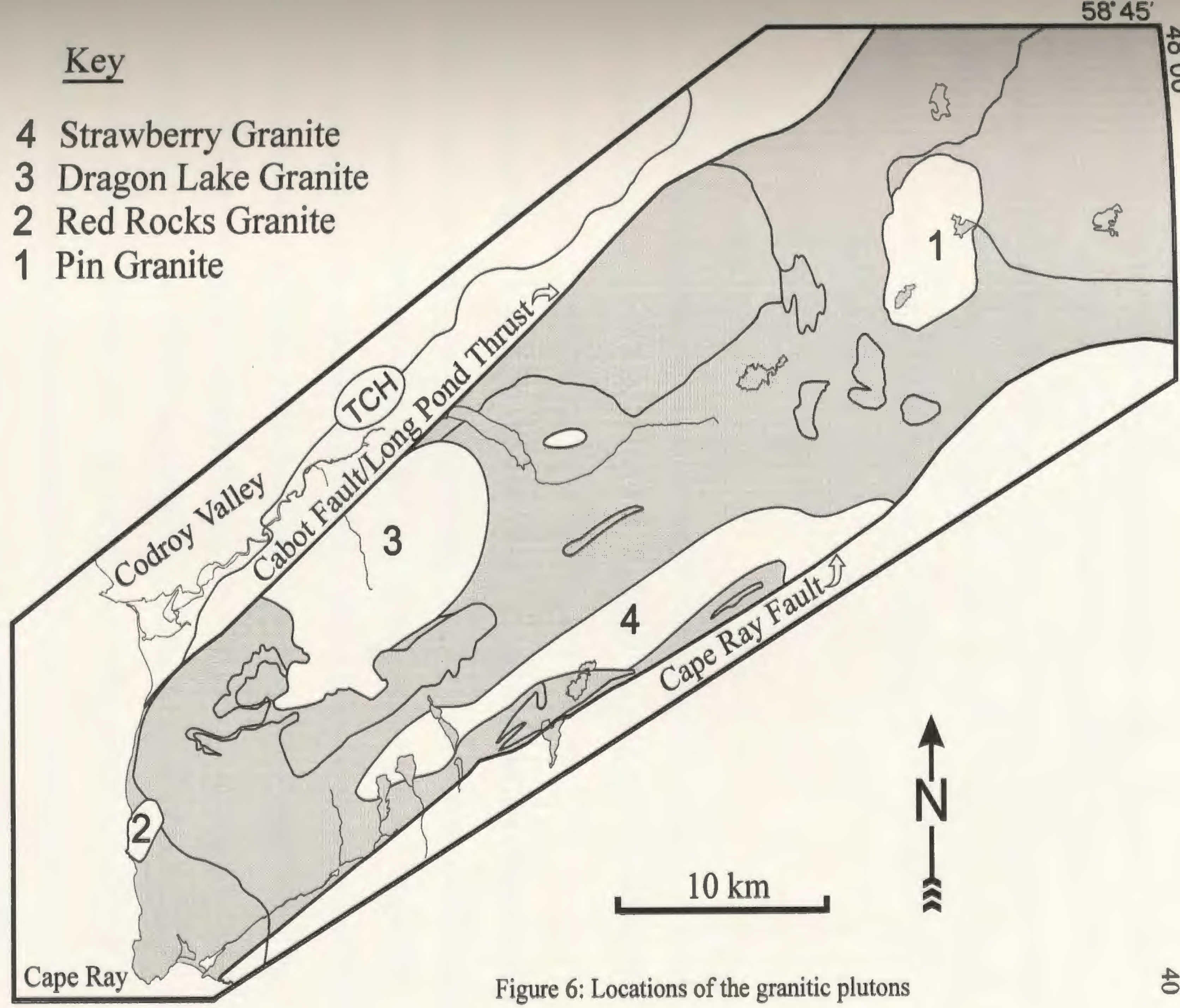


Figure 6: Locations of the granitic plutons

northeast and east. This largely coarse grained, leucocratic granite is cut by late phase feldspathic dykes, some of which extend into the host rocks of the pluton. Abundant muscovite in large books (5-20 mm in diameter) is the dominant accessory mineral. Myrmekite commonly rims perthitic microcline and occupies microcline-plagioclase contacts. Many feldspars are broken and annealed. The plagioclase mineral phase has been slightly sericitized and epidotized.

The Red Rocks Granite

The Red Rocks Granite was identified by Brown (1976) who included it in the Cape Ray Igneous Complex. This small (15 km^2), round pluton is exposed at the coast, in the vicinity of Bear Cove where it has been quarried since 1953.

The Red Rocks Granite is a two mica granite to potassium-feldspar granite which displays textural and compositional inhomogeneities. The pluton is largely equigranular, the grain size varies from fine to coarse with local microcline megacrystic phases. Pegmatitic and aplitic dykes are associated with this pluton. Muscovite and/or biotite are present throughout, but where muscovite is abundant, biotite is absent and where biotite is abundant, muscovite is rare. The gradations from a region with one species of mica to another are abrupt (0.5 m to 3 m) and the micas are small in these gradational regions. Biotite schlieren are abundant (up to 35% biotite) in elongate domains up to 10 m long and 2 m to 3 m wide. The textural and mineralogical variations are interpreted as primary igneous inhomogeneities as there are no metamorphic fabrics or mineral growth associated with them. Small brittle fault zones with apparent offsets of less than one metre and mylonites zones up to 3 m wide cut outcrops of the Red Rocks Granite.

Plagioclase, microcline and quartz are the dominant minerals. The microcline display typical cross-hatching with local untwinned cores. Titanite, zircon and fine opaque, disseminated sulphides are accessory minerals. Some sericite, chlorite, epidote and limited, local carbonate alteration minerals are present. Galena is present in some of the zones of brittle deformation.

The Dragon Lake Granite

The Dragon Lake Granite has previously been included (Brown, 1976; Brown, 1977; Chorlton 1984) as part of the Cape Ray Igneous Complex, but is interpreted to be a discrete pluton in this work. This large, irregularly shaped pluton is exposed in the south-central region of the study area and occupies up to 150 km^2. Outcrops weather white and a coarse grained, angular sand derivative characteristically collects about the outcrops. Fresh surfaces of the Dragon Lake Granite are orange-pink and display small (1 cm) microcline megacrysts. The northwestern margin of this pluton is trucated by the Long Pond Thrust. Small brittle shear zones associated with late movements on this thrust cut the periphery of the intrusion. Compositionally, the Dragon Lake Granite is a granite to monzogranite which displays mineralogical homogeneity. Both muscovite and biotite are present as primary igneous minerals. Plagioclase is partially replaced (5%) by sericite and epidote; biotite is altered to chlorite (10%). Quartz grains have polygonized rims.

The Strawberry Granite

The Strawberry Granite (Brown, 1973a; Wilton, 1983) is an elongate felsic pluton 5 km wide and at least 25 km long. It lies sub-parallel to and locally abuts much of the southeastern boundary of the study area defined by the Cape Ray Fault. This largely unfoliated biotite granite is characterized by coarse (locally >1 cm) grained to porphyritic microcline, plagioclase, quartz and biotite intergrowth. Accessory minerals include titanite, pyrite and rare molybdenite. Sericitization and saussuritization is evident in 10% of the plagioclase grains. Shear zones are extensively developed in the Strawberry Granite which is consistent to its relative proximity to the Cape Ray Fault. In proximity to shear zones chlorite is relatively abundant (<10%).

The Strawberry Granite contact with the Cape Ray Igneous Complex is gradational as in places the granite assimilated the tonalite on intrusion. In the vicinity of the contact, the Strawberry Granite is paler pink owing to a higher than typical plagioclase content. In addition, near contacts with the Strawberry Granite, the Big Pont Tonalite displays visible microcline.

The four late granitic plutons are discrete bodies and are lithologically distinct. They represent at least two different plutonic events as identified by the available age data; the Pin Granite dated at 449 Ma and the Strawberry Granite at 384 Ma. No cross-cutting relationships were observed to clarify the age relationships between these plutons and the two undated plutons which would facilitate the appropriate subdivision of this unit. The granite plutons are, therefore, treated together as a single unit as they share similar temporal relationships with the other units of the study area. Between them, the four granitoid plutons cut all of the units described above. The Strawberry and Dragon Lake granites intrude the Long Range Mafic-ultramafic Complex near the Cape Ray and Cabot faults respectively. The Pin Granite cuts the Mischief Mélange (Plate 4). They all intrude the Cape Ray Igneous Complex including the youngest phase, the Staghill Orthogneiss which is cut by dykes associated with the Pin Granite.

Porphyritic aplitic and pegmatitic dykes cut both the Red Rocks and Pin granites. These dykes are interpreted to be late stage intrusive phases associated with the two plutons.

The Strawberry and Dragon Lake granites are affected by the Cape Ray Fault and Long Pond Thrust, respectively. They both show weak fabric development which intensifies abruptly at the minor mylonitic shear zones and brittle faults which are associated with the movements on their associated faults. The Strawberry Granite is elongate parallel to the Cape Ray Fault. The Red Rocks Granite does not preserve a penetrative fabric, however it is cut by both ductile and brittle faults. The Pin Granite is the least deformed of the late granitic plutons. Though transected by two regular, widely spaced joint sets, this pluton cuts all the deformation fabrics preserved in the country rock and no other fabric is apparent within it.

Some sericite, chlorite, epidote and limited carbonate alteration minerals are present in each pluton. Wilton (1983) interpreted the presence of these minerals in the Red Rocks Granite to reflect deuteric or late magmatic mineral alteration. This interpretation is herein extended to the Pin Granite. The Dragon Lake and Strawberry granites, with the higher degree of deformation, display locally extensive development of these alteration minerals.

2.5 Fleur de Lys Supergroup

Marble and calc-silicate occurrences together with clastic metasedimentary rocks (the Mischief Mélange) were grouped together as the Metasedimentary Rocks of Terrane I by Chorlton (1984). In the present study, these are separated from this grouping since they are not clearly associated with the other lithologies. Pure white, massive marble and banded calc-silicate occur along the escarpment which defines the northwestern border of the study area. These highly deformed carbonate rocks (P€Of) are associated with the Long Pond Thrust (Chapter 3.1.2) and exist as a dismembered, steeply eastward dipping band 20 m to 50 m wide.

Massive white marble is interlayered (at a scale of 1 m to 15 m) with banded calc-silicate rocks and a single band of buff marble. Banding within the calc-silicate layers ranges from 1cm to 30cm in width. Both the lithological layering and the calc-silicate banding are considered to be the result of original bedding emphasized by metamorphic segregation.

The marble is dominated by fine grained, white calcite. Well-spaced, 5 cm to 10 cm wide, yellow, coarse grained, highly fractured bands weather positively. Medium grained muscovite, very fine disseminated graphite and flakes of hematite are impurities in this white marble. A thick band of buff marble contains minor amounts of diopside, biotite, scapolite (after plagioclase) and tourmaline.

Banding in the calc-silicate rocks is defined by a combination of grain size and modal variations. The fine grained, green-grey bands are composed of calcite, diopside and minor titanite, while the coarse grained, cream-coloured bands are predominantly calcite. Graphite is also a minor accessory mineral found in the calc-silicate rocks.

The carbonates (P€Of) are steeply dipping and strained through the movement on the Long Pond Thrust. Locally, layering has been isoclinally folded parallel to the Long Pond Thrust, structurally thickening the unit.

At two localities the carbonate rocks are underlain by a red quartzo-feldspathic gneiss with chloritized mafic enclaves (P€g). Quartz occurs as large (up to 1.5 cm long), white, enlogate blebs suggestive of quartz pebbles. Gneissic banding is fine (approximately 3 mm), penetrative and locally folded. The nature of the contact between the carbonates (P€Of) and the gneiss (P€g) is obscured by the Long Pond Thrust. This quartzo-feldspathic gneiss may be a metamorphosed arkose or arkosic quartz pebble conglomerate or a granitic orthogneiss.

The relative age relationships the carbonate rocks (P€Of) have with the other rocks of this study is unclear. This is due to their limited exposure and exclusive association with the Long Pond Thrust which obscures contact relationships with the Long Range Mafic-ultramafic Complex and the Cape Ray Igneous Complex. However, small blocks of marble and calc-silicate are present in the Mischief Mélange. These fragments, which range up to a metre in diameter, may be derived from the same source as the P€Of carbonates. If so, these carbonates are older than the Mischief Mélange and predate the emplacement of the Long Range Mafic-ultramafic Complex.

2.6 Windsor Point Complex

The Windsor Point Complex (Brown, 1973a) is an assemblage of non-marine sedimentary and volcanic rocks. Rocks of the Windsor Point Complex can be traced for 125 km inland along the Cape Ray Fault from the coast to King George IV Lake (Kean and Jayasinghe, 1981). At the coast, in J.T. Cheeseman Provincial Park, the Windsor Point Complex is approximately 1.5 km thick. The contact between the Windsor Point Complex and the rocks of the Cape Ray Igneous Complex and Long Range Mafic-ultramafic Complex is sharp and largely associated with a marked topographic lineament easily identified on the 1:50 000 topographic map sheets (11-O/11, 11-O/10 and 11-O/15). This unit is largely outside the scope of this work and the maps of Dubé and Lauzière (1996) were extensively used to augment the data acquired for this map (pocket).

The rocks or the Windsor Point Complex have long been considered Devonian on the basis of plant fossils, *Drepanophycus gaspianus*, *Taeniocrada*, *Psilophyton*, *Trimerophyton* and *Pertica* (Dorf and Cooper, 1943). However, Dubé *et al.* (1996) used U/Pb zircon analysis to date a gabbroic sill within the sedimentary package at 424 (+4/-3)Ma. This data indicates that the Windsor Point Complex also includes rocks of at least Silurian age.

The Windsor Point Complex is divided into three lithological domains (Dubé *et al.*, 1992, 1996; Dubé and Lauzière, 1996): the northern volcanic domain, the central sedimentary domain and the southern mylonite domain. The northern volcanic domain lies adjacent to the rocks of this study. It comprises approximately 700 m of bimodal volcanic rocks: felsic ignimbrites, rhyolite flows, pyroclastic and volcano/epiclastic rocks locally intercalated with pillow basalts are nearest to the Cape Ray Fault; predominantly mafic volcanic flow rocks are preserved in a southwestern belt of the northern volcanic domain. The central sedimentary domain comprises conglomerate, tuff, pebbly sandstone, shale, greywacke and siltstone. The southern mylonite domain is composed of pink mylonites and chloritic schists. Protoliths of the mylonitic rocks are unclear but probably include conglomerates similar to those of the central sedimentary domain (Dubé *et al.*, 1996), and rhyolites similar to those at the base of the Windsor Point Complex (Wilton, 1983) in the northern volcanic domain.

Rocks of the Windsor Point Complex have folds, brittle faults and mylonitization in association with the Cape Ray Fault. Contacts of the Windsor Point Complex with the Cape Ray Igneous Complex and the Long Range Mafic-ultramafic Complex are discrete mylonite zones. The movement history of the Cape Ray Fault and it's impact on the rocks of the Windsor Point Complex is described after Dubé *et al.* (1996) in Chapter 3.2.2.

Clasts of the Cape Ray Igneous Complex are common in the conglomerates of the Windsor Point Complex indicative of a topographically high source area to the NW (Wilton, 1983). Brown (1972) and Wilton (1983) claimed that the Windsor Point Complex unconformably overlies the Cape Ray Igneous Complex. At the coast, in Cheeseman Provincial Park, mylonitic Cape Ray Granite (Ocg) is in contact with a strained rhyolite containing fragments of strained Big Pond Tonalite (Oct). These fragments may either reflect an unconformity (Piasecki *et al.*, 1990) or are present through tectonic incorporation (Dubé *et al.*, 1996).

2.7 Late diabase dykes

Numerous mafic dykes have been observed throughout the study area. These intrusions are too small to be recorded on the map (pocket). These dykes are most common in the vicinity of the Cape Ray and Cabot faults and are usually 1 m to 3 m wide though one example in the southeast near the Cape Ray Fault is 10 m in width. These diabase dykes are straight, dip vertically and trend north-northeast, east-northeast or rarely northwest.

Along the coast, the diabase dykes display chilled margins and alteration at their contacts. These dykes are distinctly green and are commonly plagioclase porphyritic. The matrix is fine to medium grained plagioclase, subophitic clinopyroxene, and minor brown hornblende. Limited interstitial carbonate is present as are accessory opaques (presumed to be magnetite and pyrite). The plagioclase phenocrysts are zoned. Alteration minerals at the chilled margins include epidote and biotite, local chlorite (all after the clinopyroxene) and sericite (after plagioclase). In the southwestern highlands near the Cabot Fault and in the east near the Cape Ray Fault, the diabase dykes are green to grey, largely equigranular and fine to medium grained.

Mafic dyke occurences have been recorded in this study and by Phair (1949) and Chorlton (1984) cutting most lithologies. As such, they are interpreted to be the youngest unit in the map area. These dykes are commonly cut by faults which run along the long axis of the dykes. Phair (1949) demonstrated a relationship between the north-northeast dyke orientations and the orientations of late brittle faults and shear zones. No dykes of this nature are recorded cutting the Windsor Point Complex or other rocks east of the Cape Ray Fault.

CHAPTER 3

Deformation and Metamorphism

The rocks of the southern Long Range Mountains record a complex deformational history which involves faulting, folding and metamorphism. The relationships between the various deformational features and the lithological units provides further insight into the relative timing of both unit formation and deformational events.

3.1 Faults

Two major recognized faults bound the study area to southeast and northwest, the Cape Ray and Cabot faults, respectively. The Cape Ray Fault has received a considerable amount of attention (Gillis, 1972; Brown, 1973a; Wilton, 1983; Dubé, 1993; Dubé and Lauzière, 1996; Dubé *et al.*, 1996) since Phair (1949) first recorded thrusts in the vicinity of the town of Cape Ray. The Cabot Fault (Wilson, 1962), however, has been largely overlooked in studies conducted in southwest Newfoundland. Numerous smaller faults are present in the study area which are interpreted to be associated with the Cape Ray and Cabot faults. Although not the central focus of this study, it is recognised that both faults are profoundly significant within the framework of the tectonic development of the southern Long Range Mountains.

3.1.1 Cape Ray Fault

The Cape Ray Fault (Gillis, 1972) defines the southeast boundary of the study area. It cuts the Long Range Mafic-ultramafic Complex, Cape Ray Igneous Complex and the

Windsor Point Complex. Dubé *et al.* (1996) outline the history of the development of the Cape Ray fault zone involving southeast over northwest (sinistral) oblique thrusting followed by east-west (dextral) strike-slip motion. Isotopic dates of units within the Windsor Point Complex indicate that movements on this fault spanned a period from 415 Ma to 384 Ma. Dubé *et al.* (1996) concluded that the fault zone is the result of oblique collision between the Gander Zone (represented by the Port-aux-Basques Gneiss) in the hangingwall and a composite terrane involving both the Windsor Point Complex and the Cape Ray Igneous Complex/Long Range Mafic-ultramafic Complex in the footwall.

The rocks of the study area in the southern Long Range Mountains are in the footwall of the Cape Ray Fault. Effects of the fault on these rocks include: mylonite zones parallel to the fault which cut the Long Range Mafic-ultramafic Complex and the Cape Ray Igneous Complex, greenschist facies retrograde metamorphism (Chapter 3.3.1), intensification of the main foliation in the Long Range Mafic-ultramafic Complex and the Cape Ray Igneous Complex, and the presence of a weak foliation in and the elongation of the Strawberry Granite parallel to the fault trace. The Windsor Point Complex, however, is the most extensively deformed by the Cape Ray Fault as strain associated with its' movements is recorded throughout the unit (Dubé *et al.*, 1995).

3.1.2 Cabot Fault and Long Pond Thrust

Wilson (1962) applied the term Cabot Fault to a major topographic lineament part of which forms the northwest boundary of this study. Gillis (1972), Chorlton (1984) and Knight (1983) referred to this stucture as the Long Range Fault. As the term Cabot Fault is used more widely in the literature and to avoid confusion with the Long Range Thrust in northwest Newfoundland, this study reverts to the use of the term Cabot Fault. The Cabot Fault is a little studied and poorly understood feature that is generally associated with the escarpment which separates the Long Range Mountains from the Codroy Valley. The sense of movement on the Cabot Fault has been described as transcurrent (Wilson, 1962; Gillis, 1972; Knight, 1983), normal (Brown, 1977; Chorlton, 1984) and thrust (Colman-Sadd *et al.*, 1992).

Based on correlations between the mafic-ultramafic rocks of the Long Range Mountains with similar rocks of the Bay of Islands Complex (Buddington, 1939; Phair, 1949), Wilson (1962) proposed that the Cabot Fault is a dextral transcurrent fault responsible for a lateral displacement of rocks up to several hundred kilometers. Knight (1983) interpreted that the Carboniferous Bay St. George Basin, which includes the Codroy Valley, was formed through dextral strike-slip faulting along the Long Range Fault (Cabot Fault). However, he disagreed with the proposal that the mafic-ultramafic bodies were offset as the rocks compared are of different age and composition. The Cabot Fault was also interpreted as a major transcurrent fault adjacent to the Carboniferous Deer Lake Basin (Hyde, 1979; 1984; Hyde *et al.*, 1988).

Gillis (1972) and Chorlton (1984) described the Long Range Fault (Cabot Fault) as a steeply westward dipping normal fault. This analysis accomodates the juxtaposition of the Lower Paleozoic rocks of the southern Long Range Mountains against the Upper Paleozoic rocks of the Codroy Valley. The escarpment was interpreted to represent the face of the fault.

Interpretations of Lithoprobe East, Burgeo Transect (Colman-Sadd *et al.*, 1992) represent the Cabot Fault as a shallow, east-dipping reflector separating Dunnage Zone rocks from Grenvillian basement. As such, the Cabot Fault must be the basal thrust upon which the rocks of the southern Long Range Mountains were transported into their present position.

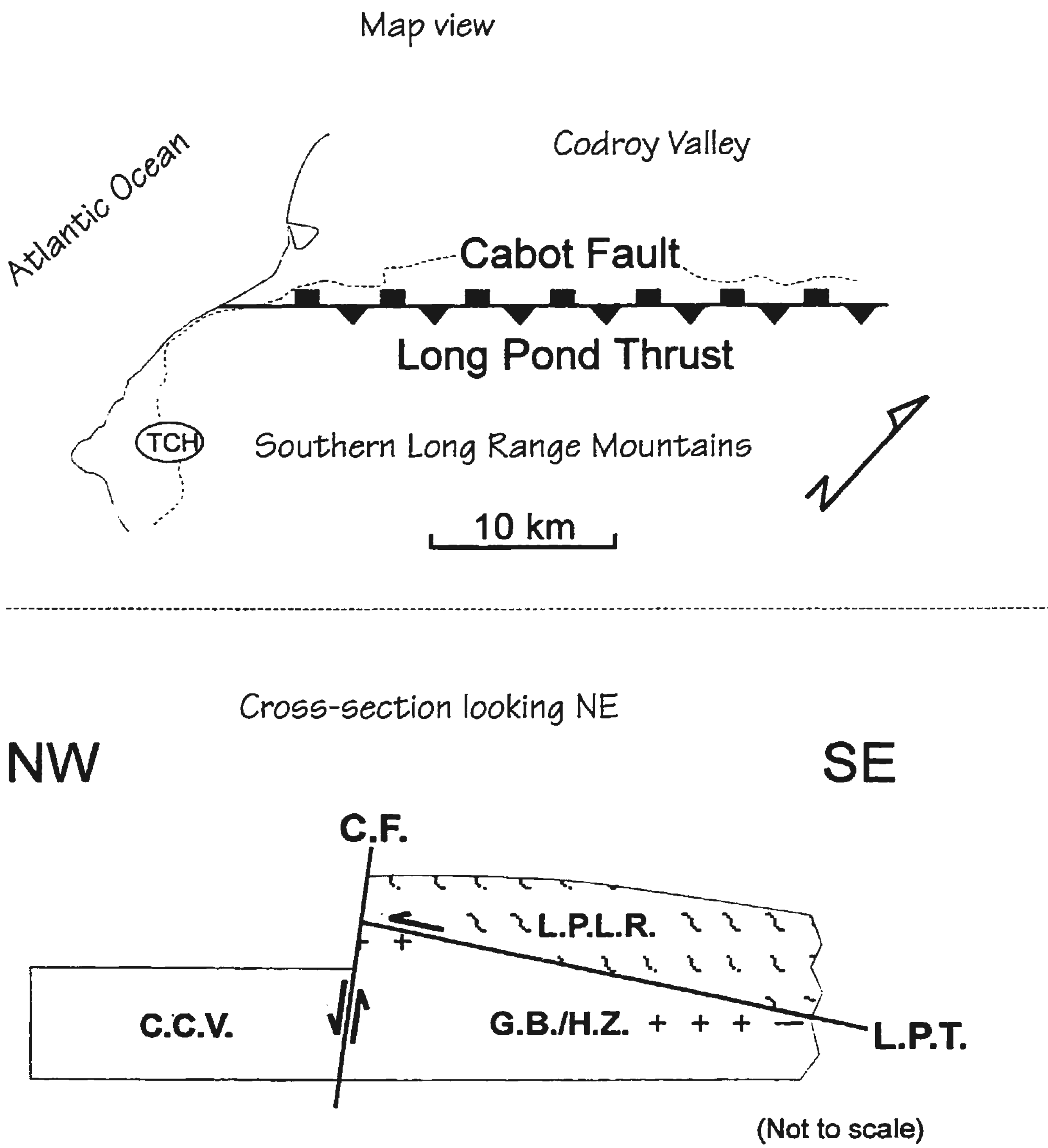
No contacts are exposed between the Carboniferous terrestrial sedimentary rocks of the Codroy Valley and the rocks of the southern Long Range Mountains. Since the Lower Paleozoic rocks of the southern Long Range Mountains are topographically higher than the Carboniferous rocks, these packages are structurally juxtaposed at the escarpment. This relationship implies that the Cabot Fault is either a west-dipping fault with a history of normal movement or an east-dipping thrust fault. This relationship implies nothing with regards to transcurrent movement.

The Long Range Mafic-ultramafic Complex, the Cape Ray Igneous Complex and the unit P€Of carbonates all record effects of thrusting. Mylonites occur within all three units at the western edge of the map area. Ductile shear zones and a series of brittle faults observed in the Long Range Mafic-ultramafic Complex, are interpreted to represent two episodes of thrust movement. The unit P€Of carbonate rocks are observed only within the high strain zone which marks the northwestern boundary of the field area. These rocks preserve kinematic indicators, including c-s fabrics and asymentrical porhyroblasts, which indicate an east-over-west thrust history. Carbonates are rheologically susceptible to strain and it is interpreted that these rocks localized thrust movement. They became caught up and transported in the thrust as a form of lubricant.

These observations support the interpretation that a major thrust fault underlies the Lower Paleozoic rocks of the southern Long Range Mountains as reported in the Lithoprobe East Transect (Colman-Sadd *et al.*, 1992). This interpretation does not adequately explain the relationship between the Lower Paleozoic rocks of the southern Long Range Mountains with the Carboniferous rocks of the Codroy Valley, as the fault represented in the seismic section juxtaposes the Lower Paleozoic rocks against older basement.

Accomodating the relationship between the rocks of the Codroy Valley and those of the southern Long Range Mountains requires a mechanism other than the basal thrust described above. As the seismic and geological evidence for a basal thrust may not be dismissed, it is herein proposed that two distinct faults have been active. An early east-dipping basal thrust fault is transected by a steeply west-dipping normal (and/or transcurrent) fault which accomodates the relationship between the Lower Paleozoic rocks of this study with the Carboniferous rocks of the Codroy Valley. As the younger fault is most similar to the original Cabot Fault of Wilson (1962), it is proposed that retains the name Cabot Fault. As such, the basal thrust fault requires a name as it is a distinct feature. It is referred to in this work as the Long Pond Thrust. Figure 7 delineates proposed geometry of the Cabot Fault and Long Pond Thrust.

Mylonite zones in amphibolitic and metagabbroic rocks of the Long Range Mafic-ultramafic Complex are largely southwest-northeast trending and steeply southeast-dipping thrusts. These faults locally juxtapose the Long Range Mafic-ultramafic Complex against the Cape Ray Igneous Complex. However, elsewhere intrusive contacts between these units and the continuation of the faults into one or both of these units show that the faults post-date



<u>Legend</u>
C.C.V. = Carboniferous sedimentary rocks of the Codroy Valley
L.P.L.R. = Lower Paleozoic rocks of the southern Long Range Mts.
G.B./H.Z. = Grenvillian Basement/Humber Zone
C.F. = Cabot Fault
L.P.T. = Long Pond Thrust

Figure7: Proposed geometry of the Cabot Fault and Long Pond Thrust

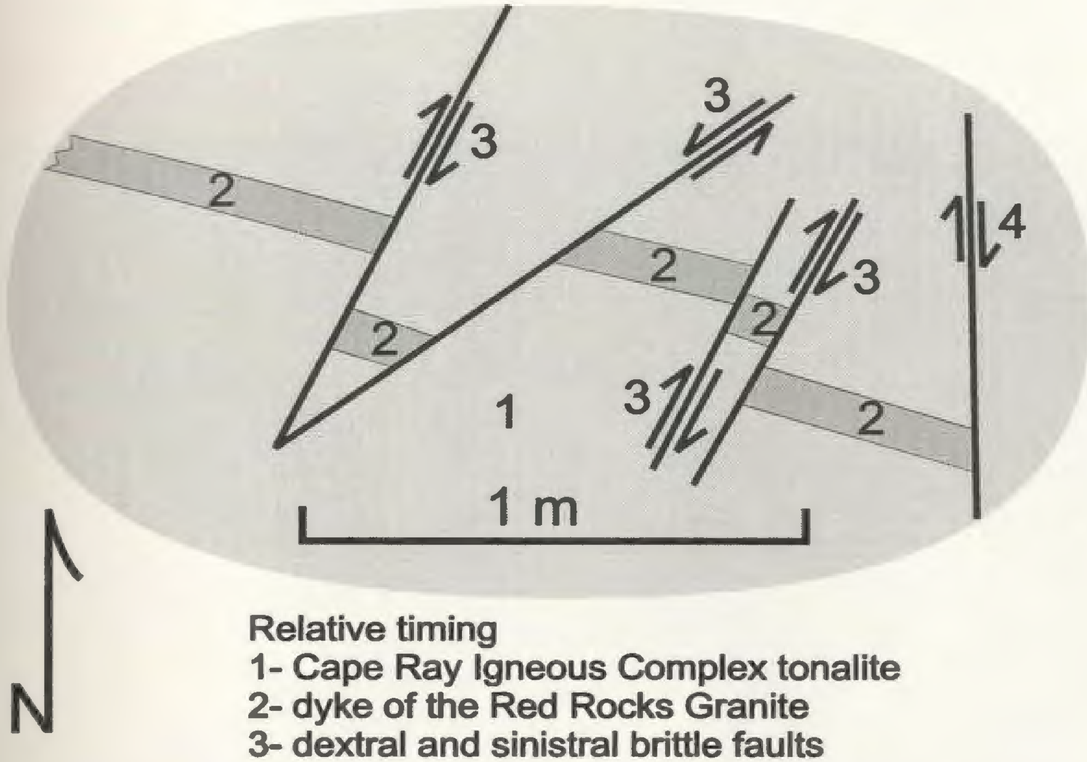
the intrusion of the Cape Ray Igneous Complex into the Long Range Mafic-ultramafic Complex. It is interpreted that the rheological contrast between the units served to localize strain along the contact. These small mylonitic thrusts are associated, through their orientation and vergence, with movements along the Cape Ray Fault and Long Pond Thrust.

Numerous small to medium scale shear zones and brittle faults cut the rocks of all units in the southern Long Range Mountains. An example of the complexities of these minor faults is illustrated in Figure 8. Both dextral and sinistral displacements are recorded in the rocks. Though both brittle and ductile faults are present throughout the study area, brittle faults are most abundant in the south and ductile faults are more prevalent in the north.

3.2 Folds

Four phases of overprinting folds, F1 to F4, are recorded in the rocks of the southern Long Range Mountains. Both the Long Range Mafic-ultramafic Complex and the Mischief Mélange show the effects of all four phases of folding. Plate 5 illustrates the complex interference pattern created by the multiple phases of folding. The Cape Ray Igneous Complex is folded by F2, F3, and F4, though only folds of the F3 and F4 phases are recorded in the Staghill Orthogneiss phase. Folding is obscured by shearing in the carbonate unit (P€Of) due to involvement in the Long Pond Thrust. All structures in the Windsor Point Complex are associated with the Cape Ray Fault. The late granitic plutons and diabase dykes are not folded.

Phase one, or F1, folds were observed at both the outcrop and the thin-section scale.



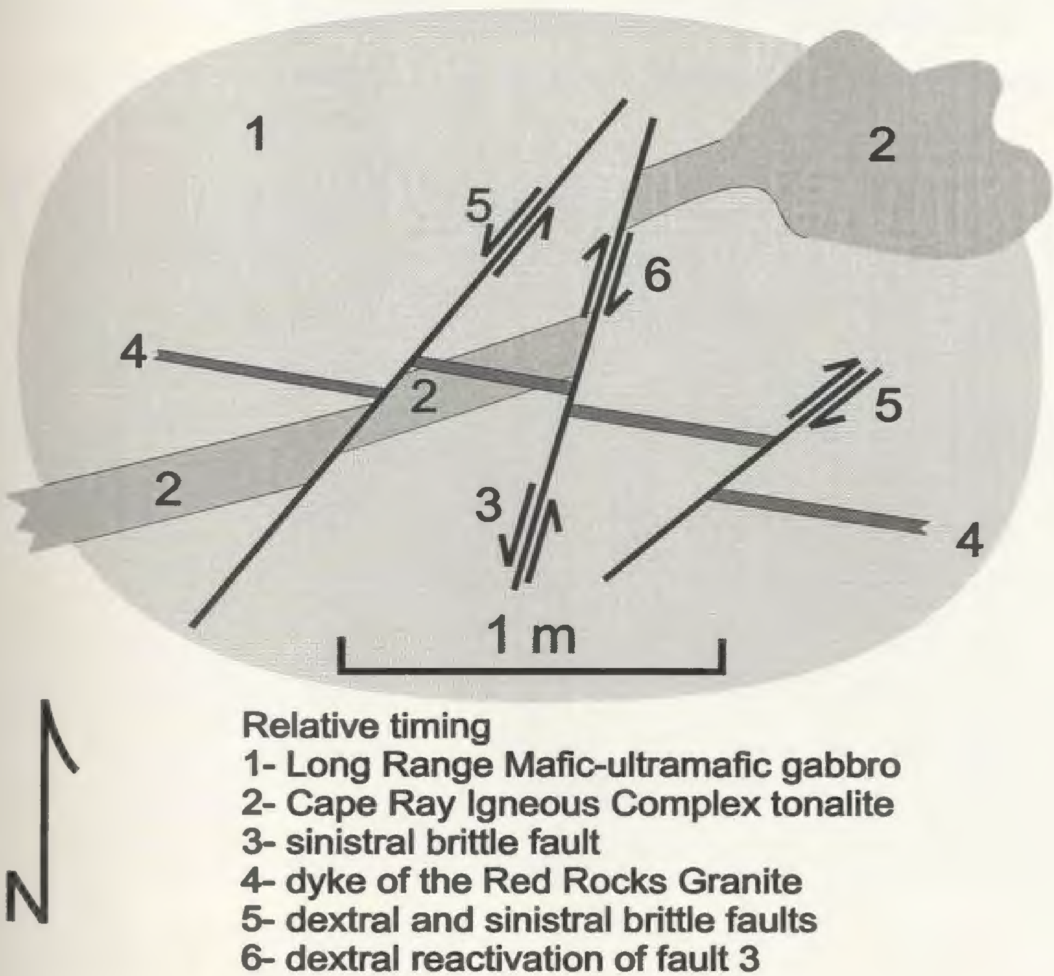


Figure 8: Two examples of the complexities of the late stage brittle faults (from field sketches)

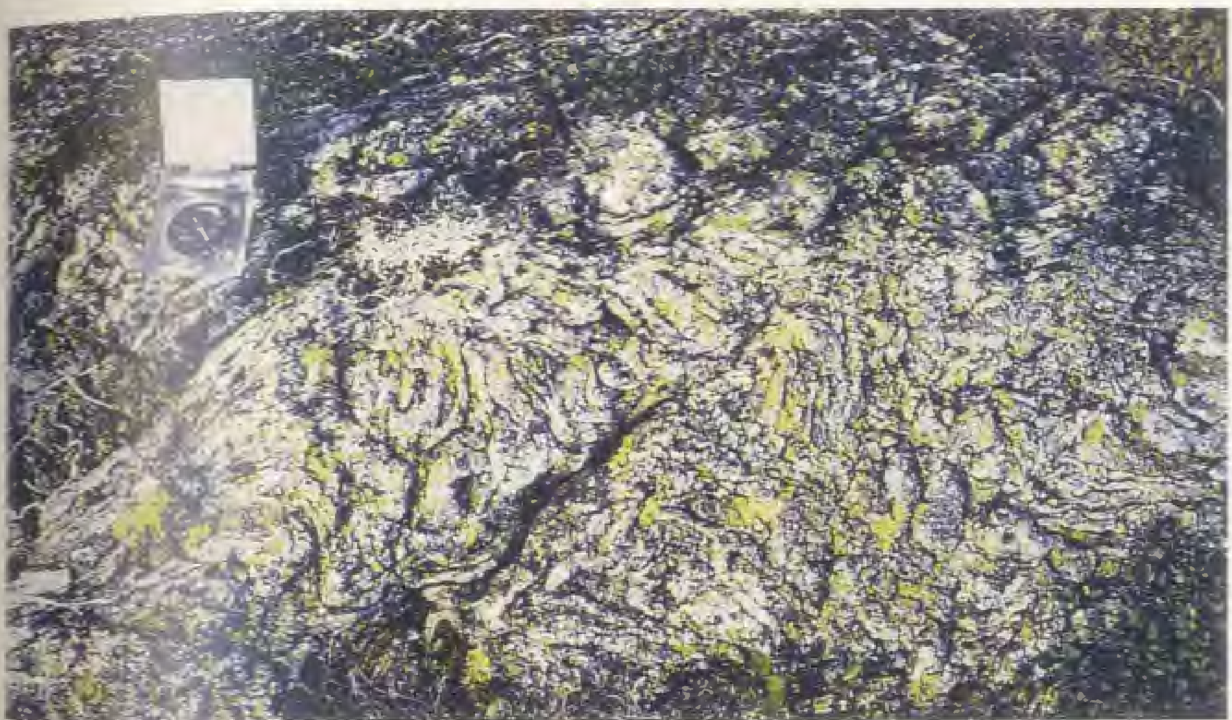


Plate 5: Fold interference pattern in the Mischief Mélange caused by the interaction of F1, F2 and F3. Compass for scale. Site 5 on Map 1.

Plate 6: F1 fold warped about the nose of an F2 fold in the Long Range Mafic-ultramafic Complex. The undeformed Pin Granite cuts the mafic rock in upper left. Flare launcher and flare for scale. Site 6 on Map 1.

The second phase of folding is recorded both on the outcrop and map scales. The overall pattern of the mafic-ultramafic bodies traces huge (amplitudes of 10's of kilometres) F2 folds (Figure 9). The effects of F3 (Figure 9), or the third phase of folding, can also be seen on both outcrop and map as the warping of major F2 fold axial surface traces as well as the warping of small (on the scale of 100's of metres) granodioritic gneiss bodies and lithological boundaries. The fourth phase folds are present at the outcrop scale but are uncommon. Their presence on the map scale is suggested by a fanning of F3 fold axial surface traces.

Folds are most easily discerned in the rocks of the Mischief Mélange. This results from the inherent inhomogeneity of these rocks. Sedimentary rocks are, in general, more susceptible to strain than plutonic rocks. As such, rocks of the Mischief Mélange have provided the greatest insights into the folds of the southern Long Range Mountains.

3.2.1 Phase one folds (F1)

The first phase of folds is represented by small scale, non-cylindrical, isoclinal, locally rootless, intrafolial folds (Plate 2) and small scale sheath folds. These are observed in the Long Range Mafic-ultramafic Complex and the Mischief Mélange. Primary igneous layering in the layered mafic and ultramafic rocks is locally affected by these folds (Plate 6). In the Mischief Mélange, F1 generally folds a compositional layering defined by variations in the abundance of garnet grains (Plate 2) which is interpreted as bedding.

A weak axial planar foliation (S1) is present. F1 folds are commonly small-scale, ranging from thin-section (Plate 14) scale up to 10's of cm in short limb length. The plunge

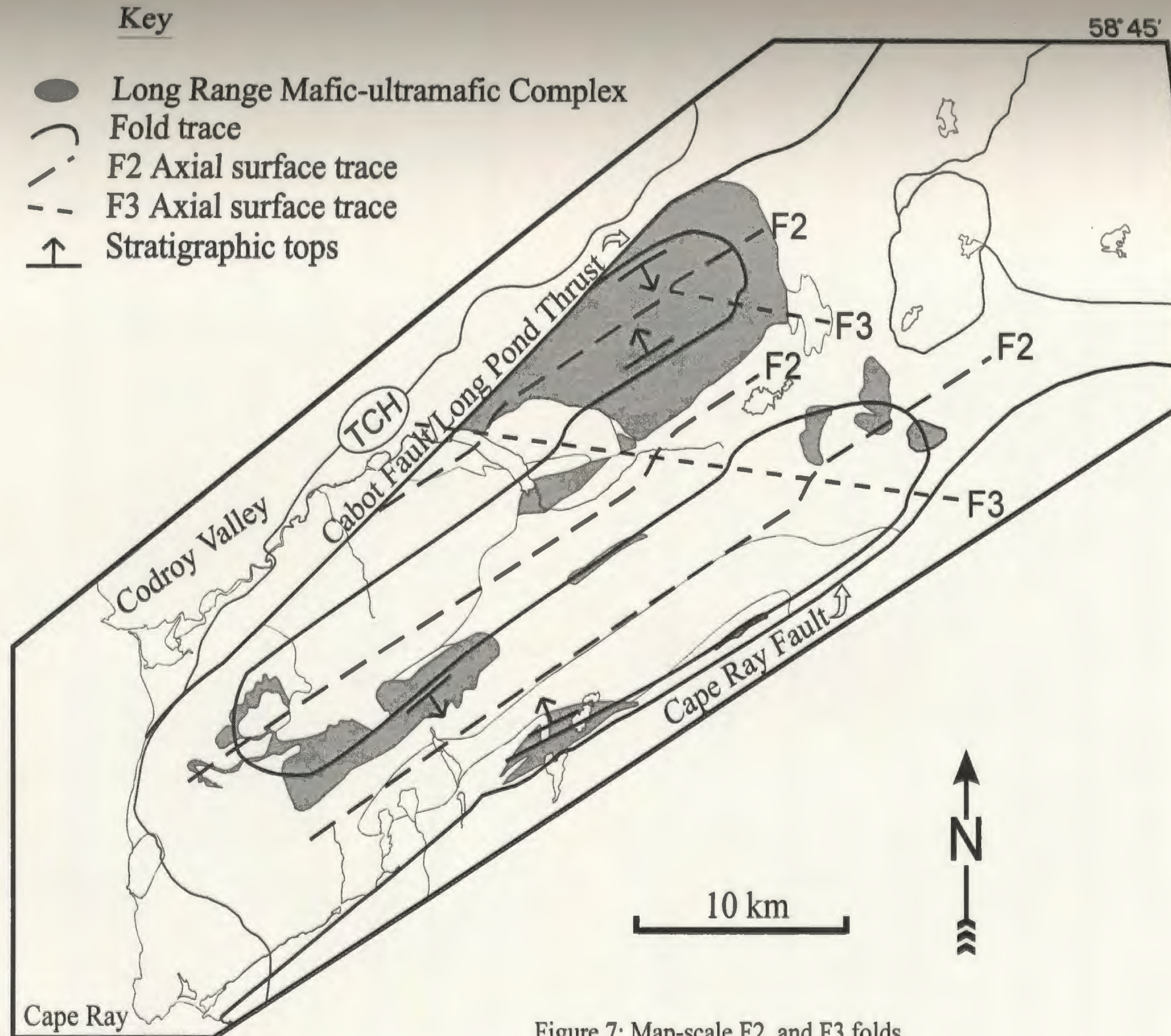


Figure 7: Map-scale F2 and F3 folds.

of F1 varies due to the overprinting of the later folds, however, they are everywhere isoclinal and recumbent. Although no F1 folds were observed in the Cape Ray Igneous Complex, the associated axial planar foliation (S1) parallels the S1 foliation in the Cape Ray Igneous Complex.

Many ophiolites record pre-obduction mantle fabrics. However, since the Mischief Mélange preserves folds which correspond to the earliest folds in the Long Range Mafic-ultramafic Complex, these F1 folds must post-date the interaction of these two rock units and must, therefore, post-date the emplacement of the Long Range Mafic-ultramafic Complex. This does not preclude early development of mantle fabrics, but, if present, these fabrics have not been identified.

3.2.2 Phase two folds (F2)

Rocks of the Long Range Mafic-ultramafic Complex, the Mischief Mélange and the Cape Ray Igneous Complex record F2. The style of the F2 folds on the outcrop scale is similar to that of the F1 folds, with both isoclinal limbs and sheath type geometries present. A weak foliation is folded by F2, distinguishing it from F1 at outcrop and thin-section scales. The folded foliation (S1) developed coevally to the F1 folds. An F2 axial planar foliation (S2) developed with the second phase of folds. S2 is coplanar with the less prominent S1 foliation in the limbs of the F2 folds. The main foliation in these rocks is, therefore, largely composite.

F2 is the dominant fold generation and is manifested on a range of scales from centimetre scale up. The Long Range Mafic-ultramafic Complex displays map-scale F2 folds (Figure 9). The discrete bodies which comprise this complex outline the trace of a single sheet of mafic and ultramafic rock which was enveloped in and subsequently folded with the younger Cape Ray Igneous Complex. The distinctive Long Range Mafic-ultramafic Complex is a marker horizon which allows the identification of the large scale F2 folds. F2 axial surface traces are curvilinear, at the map scale, as a result of subsequent folding events.

It is important to note that some of the small, elongate gneissic plutons of the Staghill Orthogneiss trend sub-parallel to the traces of F2 axial planes. The rocks of these plutons also show a non-penetrative foliation approximately parallel to the main composite foliation in the rocks that are folded by F2, though no F2 folds were observed in the Staghill Orthogneiss.

3.2.3 Phase three folds (F3)

The Long Range Mafic-ultramafic Complex, Mischief Mélange, and all phases of the Cape Ray Igneous Complex preserve third phase folds in the northern region of mapping. Phase three (F3) folds are most common and easily identifiable in the Mischief Mélange (Plate 7). The presence of F3 folds in the Staghill Orthogneiss is noteworthy, as these rocks are not folded by F1 or F2. A weakly to moderately developed gneissosity is folded by F3 in the Staghill Orthogneiss. No axial planar foliation was observed associated with this phase of folding. Over-printing the earlier isoclinal folds of F1 and F2, these F3 folds display an upright, open to tight geometry. The axial surface traces of these folds trend in a weak fan from east-northeast in the more northerly regions of Map 1 to east or east-southeast in the south. An antiform-synform pair is delineated in the northwestern part of

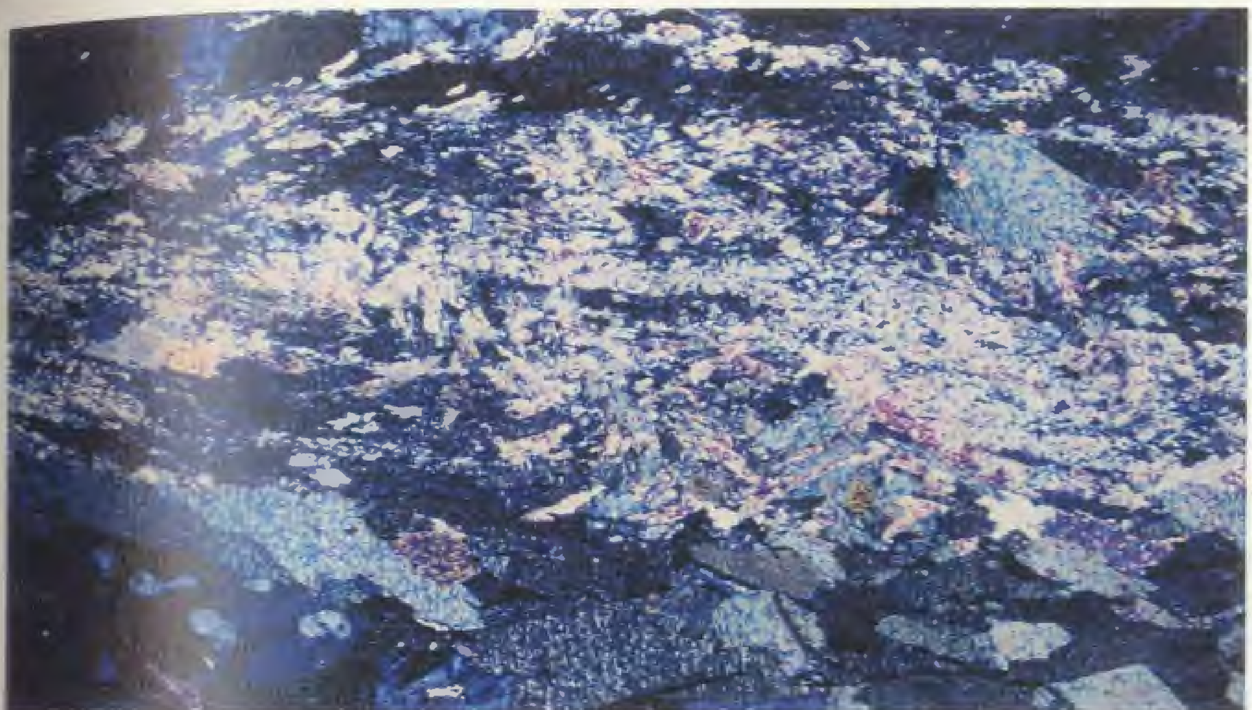


Plate 7: Photomicrograph of an F3 fold in the Mischief Mélange. View is 10 mm across. Site 7 on Map 1.

Plate 8: Photomicrograph of F4 kink folds affecting muscovite in the matrix of the Mischief Mélange. View is 10 mm across. Site 8 on Map 1.

the map (Figure 9).

3.2.4 Phase four folds (F4)

The distinctive F4 folds are preserved in the Long Range Mafic-ultramafic Complex, Mischief Mélange and Cape Ray Igneous Complex in the northwestern region of the study area. Phase four folds are open box folds or kinks observed locally at a scale of tens of centimetres on outcrops. Kink folds are also seen in a thin section of the Mischief Mélange warping a composite (S1 & S2) foliation (Plate 8). These microscopic kinks are interpreted as F4 based on their style. A slight (approximately 30°) fanning of F3 axial surface traces (Figure 9) is attributed to phase four folds.

3.2.5 Summary and interpretation

The Long Range Mafic-ultramafic Complex, Mischief Mélange and the Cape Ray Igneous Complex preserve all fold phases or their associated foliations. The absence of F1 folds in the Cape Ray Igneous Complex which displays a pre-F2 foliation (S1) suggests that the Cape Ray Igneous Complex is a late syn-F1 intrusion. The Cape Ray Igneous Complex could have been subjected to the D1 stress field (which resulted in F1 and S1 in the older Long Range Mafic-ultramafic Complex and Mischief Mélange) long enough to develop an S1 fabric but not long enough to have been folded.

The presence of sheath folds of both F1 and F2 generation, and the similarity in their styles are suggestive of progressive deformation. The over-printing of F2 over F1 and/or S1 is interpreted as the result of continued deformation within the same stress field.

The Staghill Othogneiss displays F3 folds which affect the weak F2 fabric, indicating that the Staghill Orthogneiss was emplaced in late stages of F2 deformation (Plate 9).

No folds were observed in the late stage felsic plutons. This suggests that these granitoids either intruded subsequent to the folding or that they were resistant to it.

3.3 Metamorphism

The timing of metamorphic mineral growth with respect to deformational and intrusive events was established using a combination of field and petrographic observations. This section includes a description and interpretation of the metamorphic mineral assemblages and textures observed in each unit mapped. The rocks of the Mischief Mélange are the best candidates for metamorphic study, since they are chemically complex, high aluminum rocks in which aluminosilicate and other diagnostic metamorphic minerals grow readily. However, the relative paucity and uneven distribution of the Mischief Mélange throughout the study area limits the potential for analysing the metamorphic history of the southern Long Range Mountains or mapping out metamorphic isograds.

3.3.1 Long Range Mafic-ultramafic Complex

The ultramafic rocks of the Long Range Mafic-ultramafic Complex display extensive metamorphism and/or alteration, although strong metamorphic fabrics are rare. The extensive serpentinization observed in the ultramafic rocks involves both lizardite and chrysotile varieties of serpentine which developed in at least two alteration episodes. Little was gleaned of the metamorphic conditions or timing of these alteration events since

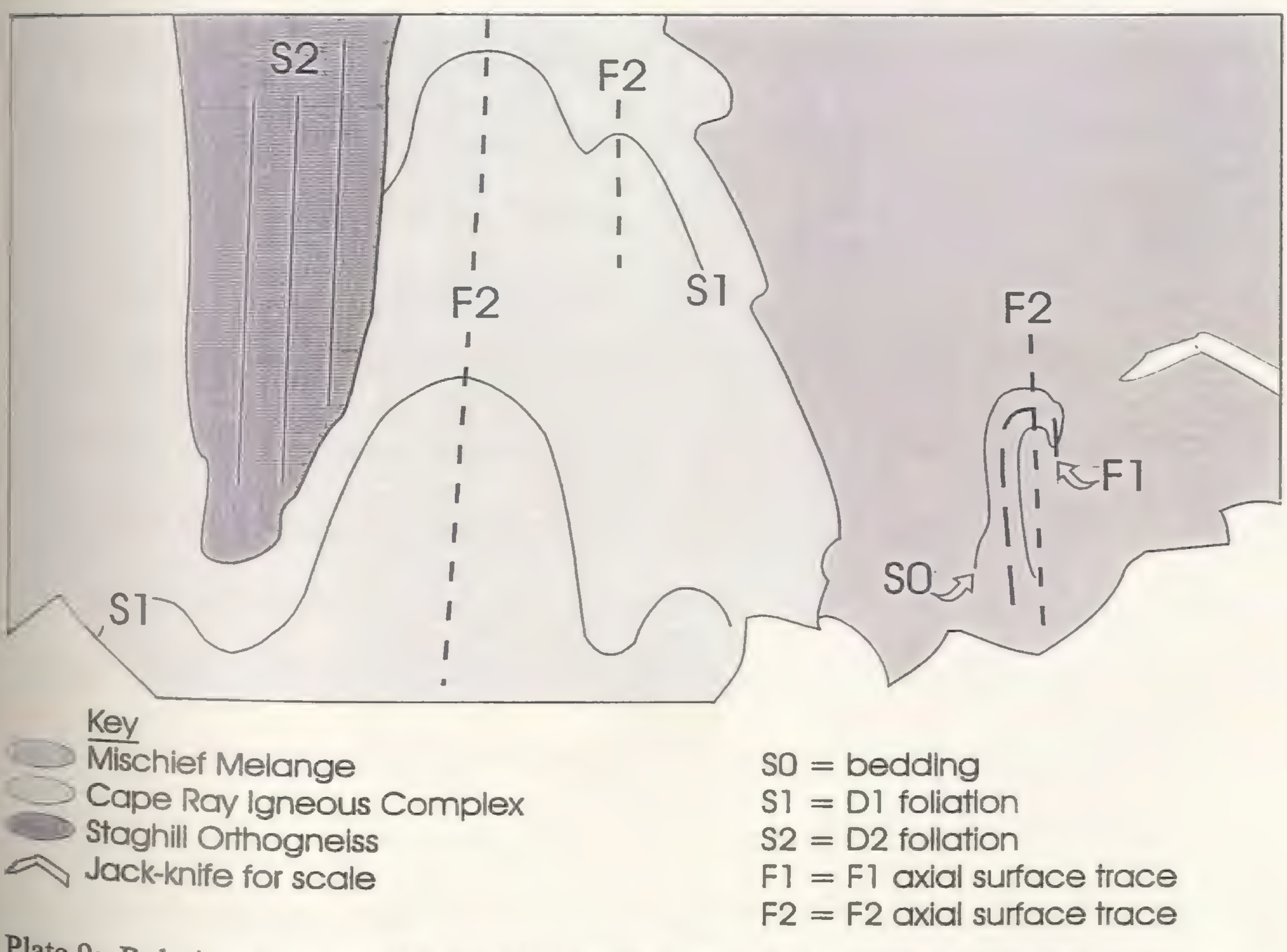


Plate 9: Relative timing of D1 and D2 in the Mischief Melange, Cape Ray Igneous Complex and Staghill Orthogneiss

ophiolitic ultramafic rocks are susceptible to serpentinization through much of their geologic history from early seafloor alteration to metamorphism during emplacement and subsequent orogenic events. The presence of actinolite and tremolite rimming olivine adjacent to plagioclase, however, is more instructive. In one thin-section, olivine displayed an inner corona of tremolite and an outer corona of actinolite. These hydrous minerals are characteristic of the greenschist and amphibolite facies in peridotites, reflecting temperatures of 400°C and higher (Winkler, 1976; p.161). Seafloor alteration was, therefore, not responsible for the development of these amphiboles and their presence must be attributed to orogenic metamorphism.

Two metamorphic episodes can be distinguished in both layered and massive metagabbroic rocks. An early, high temperature event is indicated by amphibolite facies minerals (i.e. hornblende and sillimanite). In the layered olivine-, clinopyroxene- and orthopyroxene-bearing metagabbros, the metamorphic assemblage includes green to blue-green hornblende with accessory epidote, plagioclase, titanite and rare titanite-rimmed rutile after olivine, clinopyroxene and orthopyroxene. The absence of garnet coronas between olivine and plagioclase may indicate that this metamorphic event occurred at relatively low pressure (Miyashiro, 1973, p. 312-313; Rivers and Mengel, 1988). A later lower temperature event is represented by chlorite, and locally by tremolite rimming relict olivine. In the massive metagabbro, the blue-green hornblende and minor brown biotite represent the early high temperature event, whereas clinozoisite or epidote, chlorite and limited tremolite comprise the later retrograde assemblage. Significantly, hornblende defines the mineral lineation associated with F2, indicating that the early, higher temperature metamorphic event recorded in the Long Range Mafic-ultramafic Complex is pre- or syn-F2.

In the vicinity of the Cape Ray Fault, mylonite zones associated with the fault cut the metagabbros of the Long Range Mafic-ultramafic Complex. These zones are dominantly composed of chlorite and plagioglase (greenschist facies). The adjacent rocks contain the amphibolite facies minerals over-printed by the mylonitic greenschist facies minerals. The prevailing metamorphism associated with the Cape Ray Fault was lower grade than the earlier metamorphic events which affected the Long Range Mafic-ultramafic Complex.

3.3.2 Mischief Mélange

Three distinct mineral assemblages define three metamorphic events which affected the Mischief Mélange. An early (M1) middle to upper amphibolite facies metamorphic assemblage includes sillimanite, biotite, quartz and plagioclase. M1 is partially retrograded to upper greenschist grade garnet and muscovite minerals by a second metamorphic event (M2). Late, M3 chlorite overgrows both garnet and muscovite of M2. Table 3 provides a simple outline of mineral assemblages observed in the matrix of the Mischief Mélange.

Sillimanite porphyroblasts of M1 display strong alignment within and parallel to a locally well developed gneissic banding (S1), which suggests that they grew during the development of the gneissosity. The sillimanite is also folded by F2, indicating their presence prior to the F2 event. Biotite is also folded by F2, but displays syn-F2 recrystallization in the fold noses. Biotite was, therefore, stable during the second fold event. Muscovite, which replaced sillimanite, does not display a syn-D2 fabric, but is kinked by F3. Garnet overgrows and preserves traces of F2 crenulations. Garnet also overgrows both sillimanite and muscovite replacing the sillimanite, hence it developed after the muscovite retrogression of sillimanite was initiated. The garnet is broadly fractured and fragmented and is partially replaced by chlorite. Chlorite displays kinking and recrystallization associated with the F3 deformation. One thin-section of Mischief Mélange sampled in close proximity to an exposure of Staghill Orthogneiss contains fibrolitic sillimanite associated with muscovite. Both fibrolite and muscovite in this sample are kinked by F3.

Table 3: Metamorphic mineral assemblages of Mischief Mélange matrices

SAMPLE	LH-200	LH-268	LH-278C	VL-41	VL-42	VL-71
Quartz	1, 2 & 3	1, 2 & 3	1, 2 & 3	1, 2 & 3	1, 2 & 3	1, 2 & 3
Plagioclase	1 & 2		1 & 2	1 & 2	1 & 2	1 & 2
Silimanite	1	1	1 & 2	1	1	1
Biotite	1	1	1	1	1	1
Muscovite	2	2	2	2	2	2
Garnet	2	2	2	2	2	2
Chlorite	3	3	3	3	3	3
Epidote	3		3	3	3	3
Titanite	3					

Table 3: Metamorphic minerals observed petrographically in pelitic to semi-pelitic matrices of the Mischief Mélange are assigned numbers 1, 2 and 3. Minerals designated by the same number represent equilibrium assemblages. Assemblage 1 minerals grew prior to and during D1, assemblage 2 minerals grew prior to and during D2 and assemblage 3 grew after D2.

The Mischief Mélange displays a well developed sequence of mineral growth which indicates a metamorphic sequence from amphibolite to greenschist facies. Metamorphic mineral growth in the pelitic matrices of the Mischief Mélange progressed as follows: sillimanite - biotite - muscovite - garnet - chlorite with a resurgence of fibrolitic sillimanite growth after the initiation of muscovite in proximity to exposures of the Staghill Orthogneissic intrusions. It should be noted that these timing relationships refer only to the earliest appearance of the minerals, and that overlaps in the periods of mineral growth are likely (e.g. sillimanite and biotite were stable over much the same time).

3.3.3 Cape Ray Igneous Complex

Metamorphic mineral assemblages and the intensity of metamorphic textural development in the Cape Ray Igneous Complex differ from south to north. However, due to both limited exposure in the central part of the area of study and time constraints in the field, the progression of the metamorphism and the location of any isograds were not ascertained within this unit. The metamorphic character of the southern and northern exposures of the Cape Ray Igneous Complex will be dealt with separately. The Staghill Orthogneissic phase of the Cape Ray Igneous Complex cuts the earliest fabrics observed in the Cape Ray Granite and Big Pond Tonalite. The Staghill Orthogneiss phase, therefore, also post-dates the earliest metamorphism recorded by the other phases of the Cape Ray Igneous Complex so the metamorphic features of this unit will also be described separately.

Southern exposures of the Cape Ray Igneous Complex display a strong, moderately penetrative foliation defined on the megascopic scale by weak alignment of the long axes of both xenoliths and microcline megacrysts (where present). Polygonized domains of quartz and alignment of platy minerals (muscovite, biotite, chlorite and hornblende) define the foliation on the meso- to micro-scales. From west to east along the coast the intensity of cleavage increases toward the Cape Ray Fault. Two sub-parallel cleavages can be distinguished at the fault. Dubé et al. (1996) documented these cleavages and related them to distinct episodes of movement along the Cape Ray Fault. However, since one of these cleavages is present everywhere in this unit whereas the younger over-printing cleavage is present only in proximity to the fault, it is reasonable to suggest that the older, ubiquitous cleavage is a metamorphic feature which predated the development of the Cape Ray Fault. The younger cleavage likely developed through movement along the fault.

Lower greenschist facies assemblages predominate in the southern extent of the Cape Ray Igneous Complex. Igneous, green-brown pleochroic biotite and polygonized quartz define a non-penetrative cleavage. Locally, chlorite replaces biotite with the degree of replacement increasing from a minimal background value of 5% or less to 70% in minor shear zones. Chlorite is also more abundant near the Cape Ray Fault where it defines a non-penetrative foliation overprinting and sub-parallel to the dominant cleavage. Plagioclase is extensively altered to sericite and epidote and this alteration is gradationally more intense toward crystal edges. In the Cape Ray Granite, microcline megacrysts also display saussuritization though to a lesser degree than is present in the plagioclase. Large, clear, euhedral titanite is unusually abundant in these rocks.

Metamorphic textures imposed on the Cape Ray Igneous Complex in the northern reaches of the study area are indicative of either more intense or more protracted metamorphic conditions. These include schistosities, folded and planar gneissosities, and local crenulations. Metamorphic minerals observed in the Cape Ray Igneous Complex at this location developed during two distinct events. Tremolite and biotite define the main foliation (which is a composite foliation formed by the axial planes of F1 and F2) and are folded by F2. They developed, therefore, syn-F1 and pre-F2. Locally garnet is present as small fractured porphyroblasts which do not display inclusion trails. Biotite is almost completely replaced by chlorite and rutile, whereas muscovite and chlorite partially replace tremolite and chlorite fills the cracks in the garnets. Chlorite and muscovite are largely aligned within the main foliation but locally transect it. Chlorite grains transecting the main foliation are locally fractured and kinked along a plane parallel to the main foliation, but are not bent/folded by F2 as are biotite and tremolite. Chlorite must have been stable during F2, such that it grew axial planar to it, and was later deformed by a late D2 shear event. Plagioclase, where present, is extensively sericitized and locally epidotized. Tremolite and biotite represent an early syn-F1 lower amphibolite facies subassemblage which was retrogressed to greenschist facies during F2 deformation.

A significant metamorphic gradient exists between the southern greenschist facies foliated Cape Ray Igneous Complex and the northern amphibolite facies schistose to gneissic rocks of this complex. Peak metamorphism was reached prior to the F2 event everywhere in the complex, however. It must, therefore, be concluded that the rocks of the northern reaches of the map area were at greater depth than those in the south at the time of peak metamorphism.

The rocks of the Staghill Orthogneiss display a poorly to moderately developed gneissic banding which is defined by concentrations of biotite. Biotite is present as both an igneous and metamorphic mineral as it commonly displays green-blue interiors with partial rims of brown-green pleochroism. It is also locally retrogressed to chlorite. Garnet is a common metamorphic phase and garnet porphyroblasts are fragmented and stretched into the main foliation with chlorite filling cracks. In summary, the prominent metamorphic banding is defined by the upper greenschist facies garnet-biotite zone minerals that are partially retrogressed to lower greenschist facies chlorite bearing assemblages.

3.3.4 Late Granites

The Red Rocks and Pin granites display no pervasive metamorphic fabrics or textures. However, the Red Rocks Granite is cut by several late-stage brittle faults. Orthogonal jointing is a characteristic feature of the Pin Granite and this pluton is also cut by a large brittle-ductile shear zone. The undeformed Red Rocks Granite displays relatively limited alteration of the plagioclase and biotite (i.e. <10% of the plagioclase, <5% of the biotite) to sericite-epidote and chlorite, respectively. Secondary titanite (red and transparent) and interstitial carbonate are local accessory minerals. The Pin Granite typically has minor sericite and epidote altering the plagioclase. These alteration assemblages may reflect greenschist facies metamorphism or deuteric alteration as suggested by Wilton (1983).

Both the Strawberry and Dragon Lake granites display more extensive local deformation than the other examples of this unit. This is probably a reflection of their proximity to the Cape Ray Fault and Long Pond Thrust respectively. These plutons are cut by shear zones and locally cleavages are developed parallel to and in proximity to the shear zones. These cleavages are defined by micas, and chlorite overgrows the micas in the shear zones, indicative of greenschist grade metamorphic conditions.

3.4 Synopsis

Three metamorphic events (M1, M2, M3) are identified in the Mischief Mélange of the study area, while the assemblages of the Long Range Mafic-ultramafic Complex, Cape Ray Granite and Big Pond Tonalite only preserve assemblages which correspond to the peak M1 and retrograde M3. Assemblages which are associated with M2 and M3 are present in the Staghill Orthogneiss. The late stage granites do not record these regional metamorphic events, although they locally display metamorphism associated with the Cape Ray Fault and Long Pond Thrust.

M1 is a middle amphibolite facies event which developed syn-F1. It is characterized by hornblende in the gabbros of the Long Range Mafic-ultramafic Complex, by sillimanite and biotite in the Mischief Mélange, by tremolite and biotite in the northern Cape Ray Igneous Complex.

M2 is represented by upper greenschist facies which developed after F1/D1 until sometime during F2/D2. It is characterized by muscovite and garnet in the Mischief Mélange and by biotite and garnet in the Staghill Orthogneiss.

M3 is a middle to lower greenschist facies event recorded in the Long Range Mafic-ultramafic Complex, Mischief Mélange, and all phases of the Cape Ray Igneous Complex This M3 assemblage is characterized by chlorite, muscovite and epidote in all of the above units. M3 minerals are not affected by F2/D2 but are kinked by F3. These minerals must, therefore, have developed between F2/D2 and F3/D3.

No F1 folds were observed in the Cape Ray Igneous Complex, therefore it is proposed that this suite of rocks was intruded late in the time period encompassed by the F1/M1 event. The Long Range Mafic-ultramafic Complex, the Mischief Mélange, the Cape Ray Granite and Big Pond Tonalite were affected by F2/M2. The Staghill Orthogneiss was intruded approximately parallel to the F2 axial planes and displays a gneissosity and metamorphic mineral growth consistent with M2. The Staghill Orthogneiss was therefore intruded syn-F2/M2 and locally boosted the thermal regime as is reflected by the renewal of sillimanite growth in nearby exposures of the Mischief Mélange. Dating of the Staghill Orthogneiss would define the timing of F2/M2. The F3 and limited F4 phases of folding are recorded in all of the above units, but are truncated by the dykes associated with the 449 Ma Pin Granite. All the late granitic plutons display deformation in the form of brittle and ductile shear zones and jointing related to the movement along the major bounding thrusts.

The Cape Ray Fault has been shown to be an Iapetan suture (Brown, 1976; Wilton, 1983 Dubé, 1993) which was active in the Late Silurian through Early Devonian (Dubé *et al.*, 1996). The Lower Paleozoic rocks of the southern Long Range Mountains are in the footwall of this thrust. Surprisingly, there is little of the Siluro-Devonian deformation or metamorphism that would be expected in the footwall of this major thrust. The Long Pond Thrust underlies the Lower Paleozoic rocks of the southern Long Range Mountains. This basal thrust may be a splay of the Cape Ray Fault. Such a splay would have provided a locus for strain, sparing the overlying rocks from a widespread Siluro-Devonian tectonic overprint.

CHAPTER 4

Age Relationships and Tectonic Model

Having described the physical characteristics of the rocks of the southern Long Range Mountains in Chapter 2, and interpreted their metamorphic and deformational history in Chapter 3, an attempt is made to integrate these observations and interpretations. Each unit will be dealt with first separately, then the rocks of the study area will be considered together taking into account their timing relationships, deformational and metamorphic histories. Finally, these rocks will be put into a tectonic model.

4.1 Unit Age Constraints

4.1.1 Long Range Mafic-ultramafic Complex

An ophiolite suite is a distinct association of rocks (Penrose Field Conference, 1972) which, from bottom to top, includes an ultramafic, a gabbroic, a mafic sheeted dyke and a mafic volcanic unit. Most of this critical stratigraphy is absent from the Long Range Mafic-ultramafic Complex. Limited volumes of ultramafic rock accompany the metagabbroic material of this complex. However, it is commonly held (Brown, 1976, 1977; Wilton, 1983; Chorlton, 1984; Dunning and Chorlton, 1985; van Staal *et al.*, 1992; Hall *et al.*, 1994; van Staal *et al.*; 1996) that the Long Range Mafic-ultramafic is of ophiolitic derivation. By the above definition, it should be referred to as a partial ophiolite suite.

Wilton (1983) conducted chemical analyses on the metagabbroic rocks of the Long Range Mafic-ultramafic Complex. His general conclusion was that these rocks are too altered to display typical ophiolitic chemical characteristics. However, they do display high

MgO and Ni contents and primitive compositions (on the AMF plot) all of which are expected characteristics of ophiolitic gabbros. Textures, alteration assemblages and K_2O and Ba enrichment are consistent with hydrothermal alteration typical of ophiolitic rocks. These facts combine to make a convincing argument that the Long Range Mafic-ultramafic Complex is ophiolitic.

Dunning and Krogh (1985) summarized the geochronological data which existed on Appalachian ophiolitic complexes and demonstrated that they clustered in the Upper Cambrian, Tremadocian and Arenigian periods ranging from 507 Ma to 478 Ma. Although there is no absolute age data for the Long Range Mafic-ultramafic Complex, it is reasonable to assume that it falls within this range.

Dunning and Chorlton (1985) and Fox and van Berkel (1988) correlated the Long Range Mafic-ultramafic Complex with the Annieopsquotch Complex approximately 70 km to the northeast. The Annieopsquotch Complex has been dated (using U/Pb zircon analysis) at 477.5 (+3.1, -1.8) Ma and 481.4 (+4.0, -1.9) Ma, or late Arenig (Dunning and Krogh, 1985). U/Pb zircon analyses conducted on the Cape Ray Granite (Dubé *et al.*, 1996) which intrudes the Long Range Mafic-ultramafic Complex returned an igneous crystallization age of 488 (+/- 3) Ma. The Long Range Mafic-ultramafic Complex is, therefore, older than 488 (+/-3) Ma and must be at least Tremadoc. It is significantly older than the Arenig Annieopsquotch Complex, throwing some doubt on any direct correlation between them.

Colman-Sadd *et al.* (1992) describe two belts of ophiolites (a western and an eastern) which were obducted onto the Laurentian margin during Appalachian orogenesis. The Long Range Mafic-ultramafic Complex is included in the Western Ophiolite Belt. The ophiolitic belts are distinguished through contrasting chemical characteristics and ages. The Western Ophiolite Belt is composed of Upper Cambrian to Tremadocian rocks, while the rocks of the Eastern Ophiolite Belt, of which the Annieopsquotch Complex is a part, are largely Arenigian.

Although the geochemistry of the Long Range Mafic-ultramafic Complex is inconclusive with regards to the tectonic setting (Wilton, 1983), some interpretations are possible. Oceanic crust must be relatively young and hot to be obducted. Many of the Appalachian ophiolite suites were less than 10 m.y old when they were obducted (Dunning and Krogh, 1985). Both geochemical and geochronological data indicate that most ophiolites were formed in supra-subduction zone environments (Jenner *et al.*, 1993). Those of the Western Ophiolite Belt are interpreted to have been generated in a back-arc basin setting (Colman-Sadd *et al.*, 1992). Swinden *et al.* (1997) describe two time periods of back-arc basin development recorded by the ophiolites obducted onto the Laurentian margin: 500 Ma and older, and 490 Ma to 480 Ma. The Long Range Mafic-ultramafic Complex must belong to the older age group as it had already been emplaced on the Laurentian margin by 488 (+/- 3) Ma.

4.1.2 The Mischief Mélange

The chaotic nature, extreme size of some blocks and intimate association with the ophiolitic Long Range Mafic-ultramafic Complex led to the designation of the metasedimentary rocks of the southern Long Range Mountains as the Mischief Mélange. A modifying term, such as tectonic, ophiolitic, diapiric or olististromal, can appropriately clarify the physical and genetic distinctions of a mélange. The predominant fragment lithology present in the Mischief Mélange is metagabbro, similar in nature and presumably derived from the adjacent Long Range Mafic-ultramafic Complex. Other fragments include serpentinite, chert, metabasalt and carbonate. All fragment types are consistent with ophiolitic derivation. Mélanges associated with ophiolites and bearing predominantly ophiolite derived fragments are referred to in the literature as ophiolitic mélanges (ie. Gansser, 1974). Gansser (1974) used eleven criteria to define an ophiolitic mélange. Gansser's criteria which are of significance to the Mischief Mélange are: "(2) The matrix of the mélange is ophiolitic (frequently tectonically sheared serpentinites) or sedimentary, the latter mostly of a flyschoid facies." - the matrix of the Mischief Mélange is sedimentary and consistent with a metamorphosed flysch deposit; and "(4) The base of a mélange is always a tectonic contact..." - no base to the Mischief Mélange has been identified as little of the unit remains intact after the extensive intrusion of the felsic to intermediate plutons of the Cape Ray Igneous Complex, Staghill Orthogneiss and Pin and Dragon Lake granites. It is, therefore, impossible to determine whether the base is a tectonic contact. Gansser's criteria (7) and (9) stipulate that the ophiolite and/or associated ophioitic mélange outline major plate boundaries. This may have been the case when the Long Range Mafic-ultramafic Complex and the Mischief Mélange were originally assembled, but the subsequent intrusion of the Cape Ray Igneous Complex has obscured this boundary relationship.

It is unclear whether the clastic matrix of the mélange, which still locally preserves sedimentary bedding (Chapter 2.2), was deposited prior to, contemporaneous with or after the generation of the ophiolitic rocks. However, the pelitic to semi-pelitic matrix of the

Mischief Mélange may represent deposition at the Laurentian passive margin over which the allochthonous ophiolite suite was emplaced. Clastic slope/rise sedimentary rocks associated with Laurentia in northeastern Newfoundland comprise the Fleur de Lys Supergroup. The matrix of the Mischief Mélange may be correlated with the Fleur de Lys Supergroup. However, this correlation takes the mélange matrix out of the context of the mélange.

Currie *et al.* (1992) claimed that the metasedimentary rocks of the Central Gneiss Terrane (Dashwoods Subzone) do not have a genetic association with ophiolitic rocks of the Dunnage Zone, rather they are likely metamorphosed continental slope deposits equivalent to the Fleur de Lys Supergroup of the Humber zone which is latest Precambrian to Early Ordovician in age. The southern Long Range Mountains of this study are included in their Central Gneiss Terrane. The implication of such a claim is that the Mischief Mélange should be considered the oldest unit of this study and a part of the Humber Zone. Such an hypothesis does not take into account the intimate relationship between the Mischief Mélange and the Long Range Mafic-ultramafic Complex. By definition, the ophiolitic mélange was formed subsequent to the formation of the ophiolite, therefore, the Mischief Mélange is younger than the Long Range Mafic-ultramafic Complex.

As an ophiolitic mélange is formed during emplacement of an ophiolite suite on the continental margin, the Mischief Mélange was formed during the transport and emplacement of the Long Range Mafic-ultramafic Complex onto the Laurentian margin. The Mischief Mélange is cut by the Cape Ray Igneous Complex (488 (+/-3) Ma, Dubé *et al.*, 1996) and is, therefore, Tremadocian or older. Formation of the Annieopsquotch, Betts Cove, Birchy, Avocate and Point Rousse complexes of the western Dunnage Zone are confined to

Tremadoc and Arenig stages of the Early Ordovician (Dunning and Krogh, 1985), implying that their associated mélanges are Early Ordovician or younger. Timing of the emplacement of the Humber Arm Allochthon, including the Bay of Islands and St. Anthony ophiolitic complexes, has been constrained to circa 479 Ma (Dallmeyer and Williams, 1975). The Hare Bay Allochthon was emplaced as early as 495 Ma (Dallmeyer, 1977; Jamieson, 1977; Jamieson and Vernon, 1982). Timing of the emplacement of the Long Range Mafic-ultramafic Complex and formation of the Mischief Mélange is consistant with other ophiolites and ophiolitic mélanges in western Newfoundland. As Tremadocian or older, however, it is likely to rank among the earliest Appalachian mélanges.

4.1.3 Cape Ray Igneous Complex

Intruding both the Long Range Mafic-ultramafic Complex and the Mischief Mélange, are the voluminous felsic to intermediate rocks of the Cape Ray Igneous Complex. Dubé *et al.* (1993) and Dubé *et al.* (1996) dated the Cape Ray Igneous Complex, determining igneous crystallization ages of 472 (+/- 2) Ma for the tonalitic phase, herein referred to as the Big Pond Tonalite, (1993) and 488 (+/- 3) Ma for the Cape Ray Granite (1996). These isotopic ages indicate that these phases of the Cape Ray Igneous Complex intruded over a minimum span of 11 Ma. In light of this large range of absolute ages, the absence of observed intrusive relationships within the complex is surprising. Even along the coast, where exposure approaches 100% and both dominant phases are present, no intrusive contacts were observed between the Cape Ray Granite and the Big Pond Tonalite. This could be an indication that cooling and crystallization progressed as a continuum over a protracted period. However, Paterson and Tobisch (1988, 1992) determined, through their studies of magmatic arcs the world over, that the emplacement and crystallization of plutons occur relatively rapidly ("no more than a few million years" - Paterson and Tobisch, 1992, p. 291).

The Staghill Orthogneiss cuts the other phases of the Cape Ray Igneous Complex. Where contact relationships are not exposed, it is distinguished from these other orthogneissic rocks by the absence of mafic and other xenoliths and by the absence of the early deformation (F1/S1) and metamorphic (M1) effects. Garnet, muscovite and biotite are present everywhere in this unit as metamorphic minerals, indicating a relatively complex chemical composition consistent with an S-type granite composition.

The Staghill Orthogneiss cuts F1/S1 structures and is affected by F3. The small intrusions which comprise this unit tend to show alignment with the local S2 orientation. A weak S2 foliation is present in many Staghill Orthogness dykes, although they locally truncate F2 features. The metamorphic mineral assemblages have been related to the M2 metamorphic event. Intrusion of the Staghill Orthogneiss was syn-S2. The timing of this unit is, therefore, significant in that it gives a lower limit to the F2/S2, M2 event. A sample of this rock was taken for U/Pb zircon or monazite age determination. Its age will be a test of this proposal.

Wilton (1983) and Chorlton (1984) interpreted the tonalitic phase of the complex as a product of partial melting of the ophiolitic Long Range Mafic-ultramafic Complex. Chorlton further interpreted that the rocks of this unit are synkinematic/synmetamorphic granitoids and concluded that tonalites of different mineralogic character were generated through partial melting of the Long Range Mafic-ultramafic Complex at different depths.

U/Pb zircon analysis (Dubé *et al.*, 1996) revealed that Precambrian inheritance, of 1625 (+/-65) Ma, is present in the Cape Ray Granite. The presence of inheritance in the Cape Ray Granite effectively disproves partial melting of the ophiolite as the source of the Cape Ray Igneous Complex. The only possible source of 1625 Ma ages is continental crust as any oceanic material associated with the Iapetus Ocean is, at most, 620 Ma (rift-related dyke swarms) (Williams, 1995e).

Van Staal *et al.* (1992) interpreted the Cape Ray Igneous Complex as the deep-set plutonic portion of an island arc which intrudes the oceanic crust (Long Range Mafic-ultramafic Complex). The Mischief Mélange was assembled during the obduction of the Long Range Mafic-ultramafic Complex and is intruded by the Cape Ray Igneous Complex. The intrusive relationship between the Cape Ray Igneous Complex and the Mischief Mélange and the Precambrian inheritance (Dubé *et al.*, 1996) in the Cape Ray Igneous Complex demand a continental arc.

Inheritance requires that a pluton acquires an older crustal element which contributes a distinctive isotopic signature. 1625 Ma is a Labradorian age of the Grenville Province of the North American continent (formerly part of Laurentia) exposed within a few hundred kilometres of the southern Long Range Mountains. It is, therefore, likely that the Cape Ray Igneous Complex ascended through Laurentian continental crust before intruding the Long Range Mafic-ultramafic Complex and Mischief Mélange. The Staghill Orthogneiss phase represents a late syn-orogenic intrusive suite. It reflects renewed magmatism with sedimentary material incorporated into the melt. The Cape Ray Igneous Complex represents the plutonic root-zone of a continental arc.

4.1.4 Granites

The four granitic plutons, the Red Rocks, Strawberry, Dragon Lake and Pin granites and their associated dykes intrude all other units in the study area barring the Fleur de Lys associated carbonate rocks and Windsor Point Complex rocks which flank the study area. These plutons are largely undeformed and unmetamorphosed, cutting structures present in the older rocks. However, late faults and joint sets locally cut them and limited sericitization was observed petrographically.

As described in Chapter 2.5.2, the four granitic plutons are distinct and represent different magmatic events. U/Pb isotopic ratios have been used to determine the absolute ages of the Pin Granite (Dunning and Chorlton, unpublished data) and the Strawberry Granite (Dubé *et al.*, 1996). Zircon and rutile were used to date the Pin Granite and yielded an igneous crystallization age of 449 (+1/-2) Ma. Zircon and monazite yielded an intrusive age of 384 (+/-2) Ma for the Strawberry Granite. Although no ages have been determined for the Red Rocks or Dragon Lake granites, it is clear from the existing age data that these granite bodies developed through at least two plutonic episodes.

Wilton (1983) proposed that the Strawberry Granite and Windowglass Hill Granite, present to the east of the Cape Ray Fault and outside of this study area (Figure 10), are genetically linked and represent the earliest igneous activity on both sides of the Cape Ray fault. Dubé *et al.* (1996) determined that the Windowglass Hill Granite is significantly older at 424 (+/- 2) Ma and cannot, therefore, be related to the 384 (+/-2) Ma Strawberry Granite. However, the Isle-aux-Morts Brook Granite (Figure 10) has a very similar age at 386 (+/- 3) Ma (Dubé *et al.*, 1996). Both the Strawberry and Isle-aux-Morts Brook granites postdate

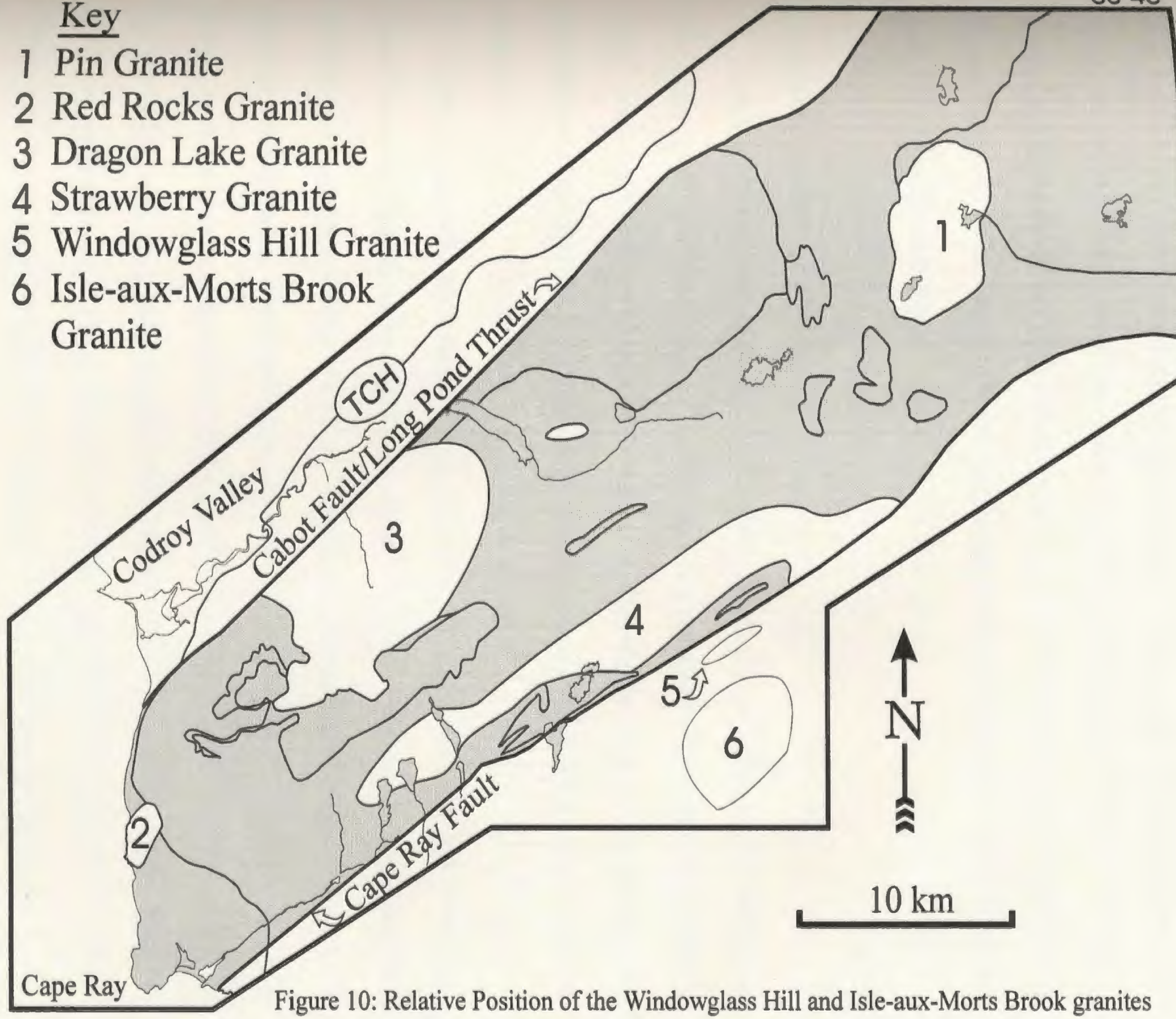


Figure 10: Relative Position of the Windowglass Hill and Isle-aux-Morts Brook granites

early mylonite development and most of the movement on the Cape Ray fault (Dubé *et al.*, 1996). It is likely that the relative positions of these granite plutons has changed little through the final movements of the Cape Ray Fault. It is reasonable, therefore, to presume that these two plutons arose during the same igneous event and represent the earliest igneous link across the Cape Ray Fault.

4.1.5 Fleur de Lys Supergroup

The marble and calc-silicate rocks of this field area are universally associated with the Long Pond Thrust. They acted as a sliding horizon for the fault and are now strung out along much of its trace. Their relative age is ambiguous as they do not display any interaction with the other rocks of the study area except as commingled units within the fault zone.

In the Corner Brook Lake map area, approximately 120 km north of this study area, metacarbonates of the Breeches Pond Formation lie along the Humber-Dunnage boundary (Cawood and van Gool, 1992). A latest Precambrian to Middle Ordovician metacarbonate sequence, the Breeches Pond formation appears to display similar relationships (ie. it is caught up in a series of thrust faults which separate the Humber and Dunnage rocks) to its neighbouring rocks as do the carbonate rocks of this study area. Cawood and van Gool (1992) ascribe the Breeches Pond formation to the Humber Zone and relate it to the Cambro-Ordovician Fleur de Lys Supergroup cover sequence. The carbonates of this study, though much less extensively exposed, are likely correlatives of the Breeches Pond Formation. It follows, therefore, that they also belong to the Fleur de Lys Supergroup.

The carbonate rocks of the Laurentian margin would have been brought into contact with the oceanic rocks of the study area through the accretion of the oceanic rocks onto the Laurentian margin during the Taconic orogenic event (Williams and Hatcher, 1983). The Taconic orogeny is widely accepted to be an Early to Middle Ordovician event (Williams, 1995e), thus constraining the timing of the interaction of the carbonates with the allochthonous rocks of the study area along the Long Pond Thrust. Subsequent remobilization of the fault has obscured the original relationship.

4.1.6 Windsor Point Complex

The Windsor Point Complex unconformably overlies the Cape Ray Igneous Complex (Brown, 1973b; Wilton, 1983; Chorlton, 1984; Dubé *et al.*, 1996) and is intimately associated with the Cape Ray Fault. The sedimentary and volcanic rocks of the group span Late Early Silurian through Devonian times and are interpreted to represent an extensional basin(s) which developed along the fault zone (Dubé *et al.*, 1996).

4.1.8 Mafic Dykes

Late mafic dykes cut the Red Rocks and Dragon Lake granites as well as the Cape Ray Igneous Complex. These relationships indicate that they are a relatively young unit. However, they were not observed cutting the Strawberry Granite which is the youngest geochronologically dated rock in the field area at 384 (+/-2) Ma. This may indicate that the dykes are older than the Strawberry Granite, though the relationship is unclear. The mafic dykes predate at least the latest movements on the Cape Ray Fault and Long Pond Thrust as they are cut by mylonitic shear zones associated with these faults. Phair (1949) demonstrated a relationship between the north-northeast dyke orientations and the orientations of late brittle faults and shear zones. This suggests a genetic link between the mafic dykes and final movements along these major faults.

4.2 History of the southern Long Range Mountains

The Long Range Mafic-ultramafic Complex developed in the late Cambrian to Tremadocian period. Obduction of the Long Range Mafic-ultramafic Complex and its associated rocks led to the generation of the Mischief Mélange. Obduction processes, including mélange generation, were initiated prior to the Arenigian intrusion of the Cape Ray Granite. Deformation initiated (D1) with the onset of obduction such that the earliest foliation development (S1) and folding (F1) are recorded in the ophiolitic and mélange rocks at this time.

The plutonic rocks of the Cape Ray Igneous Complex began intruding the Long Range Mafic-ultramafic Complex and the associated Mischief Mélange by Early Arenigian (488 +/- 3 Ma; Dubé *et al.*, 1996). Elements of the Cape Ray Igneous Complex record the earliest foliation (S1), but F1 is not recorded in this complex. Middle-upper amphibolite facies peak metamorphism (M1) is recorded in parts of the Cape Ray Igneous Complex as well as the older Long Range Mafic-ultramafic Complex and Mischief Mélange.

Progressive deformation and retrograde metamorphism continued prior to and during the renewal of magmatism marked by the intrusion of the Staghill Orthogneiss. D2 folds (F2) are recorded in the Long Range Mafic-ultramafic Complex, Mischief Mélange, Cape Ray

Granite and Big Pond Tonalite. The Staghill Orthogneiss intruded late D2/M2. These intrusions record D2 fabrics (S2), but not folds as well as M2 upper greenschist metamorphic mineral assemblages. This intrusive event post-dates peak metamorphism (M1) but caused local thermal effects such that, after M2 greenschist-grade retrogression was initiated in the older rocks, a short-term renewal of middle amphibolite mineral growth occurred in rocks close to these intrusions.

D3 and M3 occurred after intrusion of the Staghill Orthogneiss. D3 generated F3, overprinting folds in the Long Range Mafic-ultramafic Complex, the Mischief Mélange and the Cape Ray Igneous Complex. In the Staghill Orthogneiss, F3 folds affect the S2 foliation, but are the oldest folds. M3 is a lower greenschist grade metamorphism which developed syn to late D3. D4 folds (F4) overprint F3 folds in the northern parts of the map area. The 449 (+/- 2) Ma Pin Granite (Dunning and Choriton, unpublished data) cuts D4.

The Cabot Fault is re-interpreted as two faults intersecting along the escarpment which represents the western edge of this study area. The older fault is an east-dipping basal thrust fault, the Long Pond Thrust. Its hanging wall includes all the rocks of this study. The younger fault retains the name Cabot Fault. It is a steeply west-dipping post-Carboniferous, normal fault which may have also accomodated extensive transcurrent movement. The Cabot Fault juxtaposes the Ordovician and older rocks of this study against the Carboniferous rocks of the Codroy Valley.

Movement along the Cape Ray Fault was largely completed prior to the intrusion of the Strawberry Granite, however, the Pin Granite pre-dates all recorded movement on this fault (Dubé *et al.*, 1996). Movement along this fault truncates the Long Range Mafic-ultramafic Complex and the Cape Ray Igneous Complex. Both brittle and ductile faults cut the rocks of the Mischief Mélange and the Staghill Orthogneiss in discrete zones. The Windsor Point Complex developed with the Cape Ray Fault (415 Ma to 384 Ma; Dubé *et al.*, 1996).

The Cape Ray Fault has been shown to be an Iapetan suture (Brown, 1976; Wilton, 1983; Dubé, 1996), juxtaposing rocks associated with Gondwana and rocks associated with Laurentia. The Ordovician rocks of the southern Long Range Mountains are in the footwall of this thrust. Surprisingly, there is little broad-scale Siluro-Devonian deformation or metamorphism in the footwall of this major thrust. The Long Pond Thrust has the same sense of movement as the Cape Ray Fault and this basal thrust may be a splay of the Cape Ray Fault. Such a splay would have provided a locus for strain, sparing the overlying rocks of a widespread Siluro-Devonian tectonic over-print.

4.3 Tectonic Evolutionary Model

Polarity of subduction has been a concern in the efforts to understand the tectonic development of western Newfoundland. East-dipping subduction has been proposed by many workers (i.e. Searle and Stevens, 1984) as the emplacement mechanism for ophiolites on the Laurentian margin. The presence of post-obduction extensional tectonic features (i.e. high magnesian dykes which cut both Laurentian crust and obducted oceanic rocks) compelled Swinden *et al.* (1997) to propose west-dipping subduction under the Laurentian margin. No evidence regarding subduction polarity has been gleaned from the southern Long Range Mountains.

The Long Range Mafic-ultramafic Complex developed in a back-arc basin setting (Colman-Sadd *et al.*, 1992). Obduction processes were initiated as a portion of oceanic crust, encompassing the Long Range Mafic-ultramafic Complex, was thrust onto the Laurentian margin. The Mischief Mélange was generated through the obduction of the Long Range Mafic-ultramafic Complex. This marks the earliest manifestation of Taconic Orogeny in the southern Long Range Mountains.

The Cape Ray Igneous Complex was generated in a continental arc setting along the Laurentian margin. This requires west-directed subduction beneath the Laurentian margin. This major intrusive event spanned Tremadoc to Llanvirn and these rocks are interpreted as part of an Early Ordovician continental arc described elsewhere in the Newfoundland Appalachians as the Notre Dame Arc (Whalen *et al.*,1996; Jenner *et al.*, 1996).

Continued shortening across the Laurentian margin resulted in the continued obduction of the allochthonous Long Range Mafic-ultramafic Complex and the Mischief Mélange, now cut by the Cape Ray Igneous Complex. This movement accounts for early phases of metamorphism and deformation. The basal thrust which carried the entire package including the Cape Ray Igneous Complex to it final position is the Long Pond Thrust. As this fault propagated across the Laurentian passive margin, Fleur de Lys Supergroup carbonate rocks were caught up in the movement horizon.

The plutons and dykes of the Staghill Orthogneiss were intruded relatively late during the emplacement of the Long Range Mafic-ultramafic Complex and its associated rocks, though further movement resulted in the metamorphism and deformation already described for this unit. These plutons may be associated with the continued arc magmatism or magmatism related to crustal thickening as the result of shortening.

The Pin Granite (449 (+/-2) Ma (Dunning and Chorlton, unpublished data)) is the oldest, essentially undeformed rock dated in the southern Long Range Mountains. Its emplacement represents the earliest "stitching" between the allochthonous and par-allochthonous rocks of the southern Long Range Mountains and the underlying Laurentian continent.

The Cape Ray Fault juxtaposes the rocks associated with the Laurentian margin with those associated with the Gondwanan margin. As such it represents the Iapetan suture (Brown, 1976; Wilton, 1983; Chorlton, 1984; van Staal *et al.*, 1992; Dubé, 1993). The Strawberry Granite is correlated with the Isle-aux-Morts-Brook Granite across the Cape Ray Fault. Thus, they represent Devonian stitching plutons between elements of opposite sides of the Iapetus Ocean.

Chapter 5

Summary and Recommendations

5.1 Summary

Field mapping has resolved lithological relationships and timing within the previously enigmatic southern Dashwoods Subzone. Fragmental metasedimentary rocks are identified and interpreted as ophiolitic mélange, herein named the Mischief Mélange. This unit is characterized by gabbroic and ultramafic blocks and small igneous and sedimentary fragments entrained in a psammitic to pelitic matrix. The Mischief Mélange is affiliated with the Long Range Mafic-ultramafic Complex. This association lends weight to interpretation that the Long Range Mafic-ultramafic Complex is a partial ophiolite suite.

The Long Range Mafic-ultramafic Complex, Mischief Mélange and the Cape Ray Igneous Complex have all been subjected to extensive deformation and display minerals indicative of amphibolite grade metamorphism. The syn-tectonic Cape Ray Granite of the Cape Ray Igneous Complex intruded the Long Range Mafic-ultramafic Complex and Mischief Mélange as early as 488 (+/-3) Ma (Dubé *et al.*, 1996). The post-tectonic Pin Granite is dated at 449 (+2/-3) (Dunning and Chorlton, unpublished data). The rocks of the southern Long Range Mountains were not affected by the Silurian deformational and metamorphic overprint reported in rocks of other parts of the western Dunnage Zone of Newfoundland (Cawood *et al.*, 1992). The deformation recorded here, therefore, reflects the Ordovician Taconic Orogeny.

The Cabot Fault has long been considered a normal and/or dextral transcurrent fault. However, there is evidence of thrust faulting in the rocks of the southern Long Range

Mountains along the escarpment traditionally associated with the Cabot Fault. This apparently contradictory nature is resolved by the recognition of a distinct and separate feature, the Long Pond Thrust. This east-dipping thrust fault is interpreted to intersect the steeply west-dipping Cabot Fault along the escarpment. A strong, east-dipping seismic reflector was identified in the Lithoprobe East, Burgeo Transect and is correlated with the Long Pond Thrust. The Long Pond Thrust is interpreted as a basal thrust splay of the Cape Ray Fault. Such a splay would accommodate extensive strain and may have absorbed the Silurian strain, so conspicuously absent in the rocks of the southern Long Range Mountains.

5.2 Recommendations for future work in the southern Long Range Mountains

1) Geochronological analysis of the Long Range Mafic-ultramafic Complex. Knowledge of this age will provide a firm context for comparison with other Appalachian ophiolites. The pegmatitic phase of the compositionally layered metagabbro provides a likely candidate for U/Pb zircon analysis and was sampled during the course of this field work.

2) Detailed mapping of the Mischief Mélange to delineate its extent and to better understand its nature. It would be useful to investigate its extent to the northeast of the study area and to ascertain any correlation with the Keepings Gneiss to the east. The metamorphic mineral assemblage of the matrix could provide insight into the peak metamorphic conditions of the area.

3) Investigation into the Cabot Fault and Long Pond Thrust using detailed field mapping and petrographic techniques. This investigation should attempt to: a) confirm that the escarpment does represent the surface of the Cabot Fault; b) delineate the exact surface trace of the Long Pond Thrust along the escarpment; c) clarify the kinematic history of both faults; d) determine the relative and/or absolute timing of movement on both faults; e) ascertain the nature of the rocks which lie sandwiched between the Cabot Fault and the Long Pond Thrust to determine whether these rocks ought to be assigned to the Humber Zone.

4) Geochronological analysis of Staghill Orthogneiss. Knowledge of the timing of intrusion of this syn-D2/M2 unit will indicate timing for the D2 deformational (F2 and S2) and M2 metamorphic events.

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Appendix 1

Modal Analysis from Petrographic Examination

Key

Qtz = quartz

Pl = plagioclase

Pl - An% += anorthitic proportion of the plagioclase

Bt = biotite

Tr = tremolite

Hbl = horneblend

Ol = olivine

Opx = orthopyroxene

Cpx = clinopyroxene

Opq = opaque mineral

Srp = serpentine

Ttn = titanite

Tlc = talc

Dol = dolomite

Ep = epidote

Kfs = potassium feldspar

Ms = muscovite

Chl = chlorite

Tr = tremolite

Zrn = zircon

Grt = garnet

Rt = rutile

Si = sillimanite

LONG RANGE MAFIC-ULTRAMAFIC COMPLEX

Ultramafic samples

Sample #	plagio-dunite LH-93-231	amphibole gneiss LH-92-77	serpentinized wehrite LH-92-54B	serpentinized lherzolite LH-92-100	lherzolite LH-93-248B	serpentinized harzburgite LH-93-277
Pl	25	30				
Pl - An%	68	78				
Bt		3				
Tr			5			
Hbl		60				
Ol	50/*65		25/*60	*50	60	*80
Opx					15	*20
Cpx			10/*25	5/*15	5	
Opq	10	7	8	25/*35	>5	3
Srp	15		50	70	15	97
Ttn		tr.				tr.
Tlc			2			
Dol					>5	

*olivine or pyroxene mode prior to serpentinization

LONG RANGE MAFIC-ULTRAMAFIC COMPLEX

Metagabbroic samples

Sample #	metagabbro LH-92-72	metagabbro LH-93-214	metagabbro LH-93-216	metagabbro LH-93-219	metagabbro LH-93-281	metagabbro LH-93-287	metagabbro LH-93-291B
Pl	30	10	25	15	15	35	25
Pl - An%		90		78	43	36	28
Bt					20		
Tr			tr.				
Hbl	50	70	60	50	60	58	50
Chl		5	5	10		tr.	
Ep	15	10		20		5	5
Opx							>5
Cpx							8
Opq	5			5		tr.	2
Srp							
Ms	tr.	5	tr.	tr.-5		2	
Rt	tr.						
Ttn	tr.	tr.	8	5			tr.
Qtz		tr.					
Zrn					tr.		

MISCHIEF MELANGE

Sample #	mafic fragment LH-92-151A	semi-pelitic gneiss LH-93-200	semi-psammitic gneiss LH-29-203	pelitic gneiss LH-93-268	semi-pelitic gneiss LH-93-278C
Qtz	28	35	60	3	40
Pl	20	18	20		15
Bt	30	17	<5	6	<5
Ms	?	12	10	27	<5
Sil		8	7	15	15
Grt		5	3	40	20
Hbl	?				
Chl	5			6	<2
Ep	5				
Opq	2	2	tr.	3	tr.
Rt					
Ttn		tr.			
Zrn	tr.				

CAPE RAY IGNEOUS COMPLEX

Sample #	mafic xenolith LH-92-14	mafic xenolith LH-92-68	Cape Ray Granite LH-92-11	Big Pond Tonalite LH-92-116A	Big Pond Tonalite LH-93-206	Big Pond Tonalite LH-93-206"	mylonitic Big Pond Tonalite LH-93-213
Qtz		20	10	15	8	50	5
Pl	>5/*45	30	20/*30	45/*55	25/*50	10/*40	8
Pl - An%		?			30	30	20
Kfs			40				
Bt			7	25			
Ms	10		10	10	15	25	30
Hbl	50	40					
Chl					35	>5	25
Ep	35	8	3	5	10	10	
Ttn	tr.	2		tr.	tr.	tr.	
Tr							5
Zrn			tr.				
Opq	3	tr.			7	tr.	8
Rt							
Grt							

*plagioclase mode prior to muscovite/epidote alteration
'melanocratic band
"leucocratic band

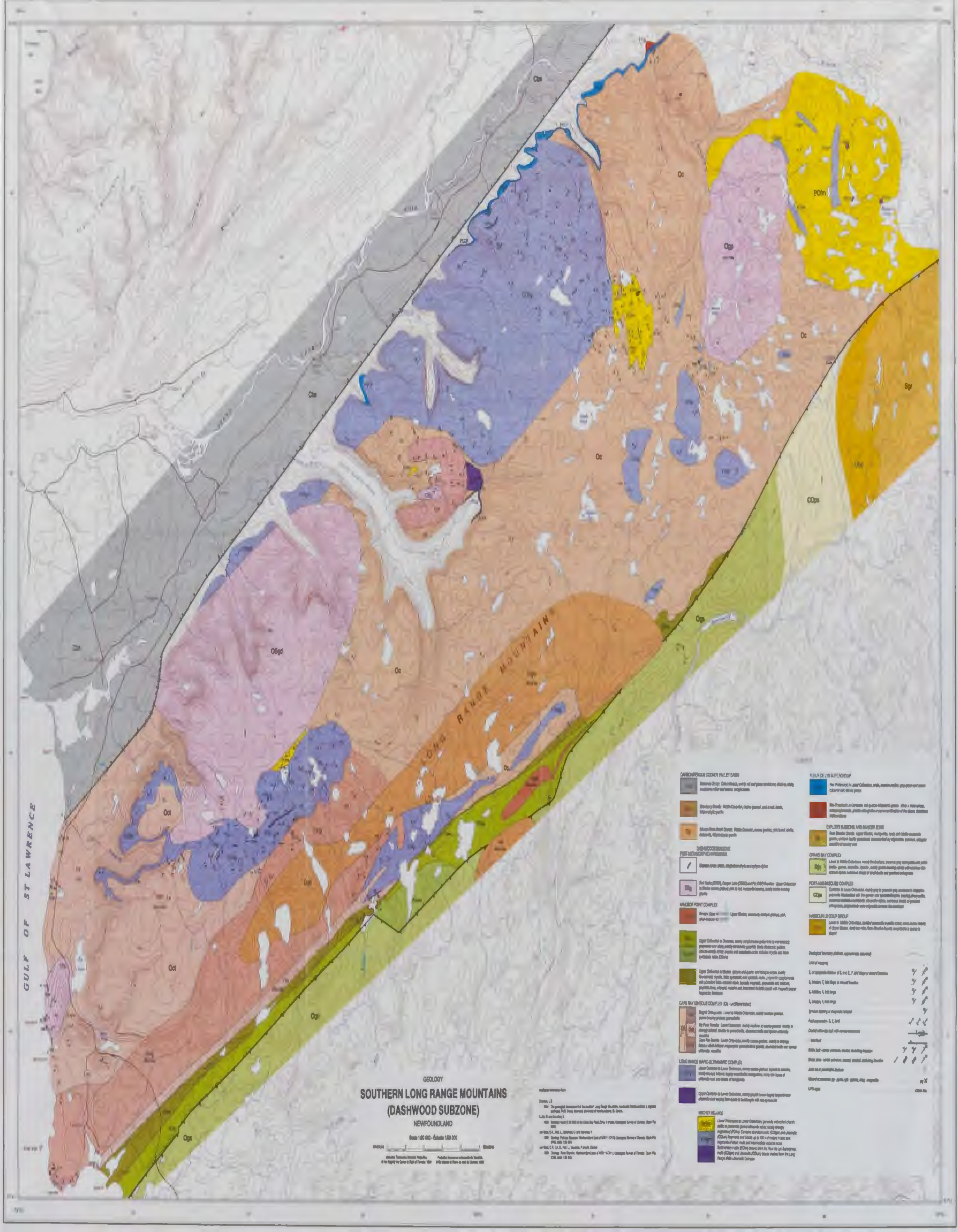
CAPE RAY IGNEOUS COMPLEX (Con't)

Sample #	Undifferentiated gneiss LH-93-223	Undifferentiated gneiss LH-93-247	Big Pond Tonalite LH-93-269A	Staghill Orthogneiss LH-93-201	Staghill Orthogneiss LH-92-269B	Staghill Orthogneiss LH-92-84	Staghill Orthogneiss LH-93-266
Qtz	20	40	40	30	20	30	40
Pl	8	5	35	22	5	10	5
Pl - An%		10					
Kfs	50	10		5	60	50	45
Bt	17	30	15	25	8	<5	5
Ms				5			<2
Hbl		5					
Chl							
Ep			8	>5		5	<2
Ttn			>2	>5	2	tr.	tr.
Tr		<5					
Zrn		tr.					
Opq	5	tr.		5	5		tr.
Rt				tr.			
Grt						5	

*plagioclase mode prior to muscovite/epidote alteration
'melanocratic band
"leucocratic band

LATE GRANITES

Sample #	Red Rocks Granite LH-92-21	Dragon Lake dyke LH-92-53	Dragon Lake Granite LH-92-64	Dragon Lake Granite LH-92-65A	Strawberry Granite LH-92-69	Strawberry Granite LH-92-81	Pin Granite LH-93-204
Qtz	20	30	40	40	25	40	30
Pl	10/*45	>5	10	5/*20	45	10	20/*25
Kfs	30	60	45	20	30	40	30
Bt	3	<5		5	5	5	
Ms	30	5	<5	10	<5	<5	15
Hbl							
Chl							
Ep	5			5	5	3	tr.
Ttn	tr.				tr.		
Tr					tr.		
Zrn	tr.			tr.			
Grt						tr.	
Opq							


GULF OF ST LAWRENCE
LONG RANGE MOUNTAIN
Cbs
Oc
Ogp
POlm
Sgl
COps
Ogs
OSgd
Ocl
CAPE RAY IGNEOUS COMPLEX
LONG RANGE MAFIC-ULTRAMAFIC COMPLEX
PORT-AUX-BASQUES COMPLEX
GRAND BAY COMPLEX
FLEUR DE LYS SUPERGROUP
GEOLOGY
SOUTHERN LONG RANGE MOUNTAINS
(DASHWOOD SUBZONE)
NEWFOUNDLAND