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PRE-CARBONIFEROUS GEOLOGY OF THE CONNAIGRE PENINSULA AND THE ADJACENT COAST OF FORTUNE BAY, SOUTHERN NEWFOUNDLAND

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ABSTRACT

One of the most complete and best exposed examples of pre-Carboniferous geology within the Avalon Zone in the Appalachian orogen is preserved on the Connaigre Peninsula and the adjacent coast of Fortune Bay, in southern Newfoundland. The oldest rocks documented in that area occur within the Tickle Point Formation, a low-grade succession of rhyolite flows and felsic pyroclastic deposits together with subordinate mafic volcanic, siliciclastic and carbonate rocks. Rhyolites from this unit have yielded U–Pb zircon ages of 682 ± 3 and 682.8 ± 1.6 Ma. Comagmatic gabbroic and granitic plutons and dykes, which together constitute the Furby's Cove intrusive suite, have been emplaced into the Tickle Point Formation. Blue-quartz-phyric, hornblende–biotite granite from this suite has been dated at 673 ± 3 Ma.

Together, these 685 to 670 Ma rocks form the uplifted basement upon which, a thick and extensive, low-grade cover succession of regionally deformed, volcano-sedimentary rocks was deposited. The redefined Connaigre Bay Group, which has been locally dated at 626 ± 3 Ma, rests with profound unconformity upon the Furby's Cove intrusive suite, unaffected by ductile shear zones in the adjacent sub-Connaigre Bay Group basement. The calc-alkaline Simmons Brook intrusive suite has been emplaced into the Connaigre Bay Group, and into mylonites, mafic gneisses and related metamorphic rocks of undetermined age. Plutons of the Simmons Brook intrusive suite, the largest of which has been dated at 621 ± 3 Ma, were deformed with their country rocks prior to emplacement of mafic intrusions between 570 and 560 Ma. Coeval mafic and felsic plutons have been intruded across boundaries between various elements of the 685 to 670 Ma basement, its cover, and pre-570 Ma plutons.

To the east of the White Horse and East Bay faults, the late Neoproterozoic Long Harbour Group embodies a thick, homoclinal to openly folded and southward-younging succession of subaerial bimodal volcanic rocks, marine siliciclastic strata, and redbeds. Rhyolites from near the base and the top of the Long Harbour Group have been dated at 568 ± 5 Ma and 552 ± 3 Ma, respectively. The younger age represents a maximum for the Neoproterozoic–Cambrian boundary, the global stratotype for which is designated (elsewhere in Fortune Bay) in shallow marine sandstones of the conformably overlying Chapel Island Formation. These Upper Cambrian strata pass upward into red sandstone and white quartzite of the Random Formation, which are disconformably overlain by fossiliferous shales of Middle and Late Cambrian age.

Regionally deformed and uplifted Neoproterozoic and Cambrian rocks are unconformably overlain by an Upper Devonian cover, composed chiefly of sub-horizontal to gently dipping coarse-grained, terrestrial sedimentary rocks. Near the northwestern margin of the Devonian basin, strata have been tilted and locally cleaved as a consequence of syn- or post-Late Devonian deformation. This tectonism has resulted in brittle reactivation of many of the major faults in the region. A suite of post-orogenic granites have been emplaced at high structural levels into the Devonian strata and their basement. These biotite granites, which locally have yielded Middle to Late Devonian ^{40}Ar–^{39}Ar cooling ages, crosscut regionally tectonized Cambrian and Neoproterozoic rocks. The largest of these granites straddles the boundary with adjacent mid-crustal plutonic and metamorphic rocks of the Appalachian mobile belt; in this area the boundary is defined by the brittle Hermitage Bay Fault.

On the Connaigre Peninsula, Neoproterozoic stratified rocks host at least two important volcanogenic sulphide showings (Winter Hill and Frenchman Head) and a number of smaller, base-metal-poor, massive pyrite occurrences. In most cases, mineralization occurs within a limited stratigraphic interval located either at or near the top of the Tickle Point Formation. In several areas, younger Neoproterozoic lavas host minor amounts of copper sulphides and/or magnetite in quartz–epidote veins or as disseminations within flows or along shear surfaces. Molybdenite, fluorite, and tin mineralization is associated principally with Devonian granites. The most extensive granophile mineralization (10^5 t of 0.3 percent MoS_2 and 10^6 t of 0.1 MoS_2) occurs along the southern margin of the Ackley Granite suite. The Devonian plutons also represent a significant source of dimension stone. One of these, the Pass Island Granite, is presently being quarried.

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INTRODUCTION

REGIONAL GEOLOGY

The Connaigre Peninsula and the adjoining coast of Fortune Bay are situated in the southwestern Avalon Zone, the easternmost of four principal tectonostratigraphic divisions of the Appalachian Orogen on the Island of Newfoundland (Williams, 1979). As classically defined, the Avalon Zone lies east of the Appalachian mobile belt, embodying the largest contiguous area of Proterozoic rocks of peri-Gondwanan affinity within the orogen (O'Brien *et al.*, 1990; *in press*). Its distinct geological character is marked by the widespread occurrence of low-grade volcanic, sedimentary and plutonic rocks of Late Neoproterozoic age, above which rests a Cambro-Ordovician shale-rich cover, containing an Acado-Baltic trilobite fauna (e.g., Hutchinson, 1962; O'Brien *et al.*, 1983; King, 1988).

In many areas, a major sub-vertical shear zone intervenes between the Avalon Zone and inboard tectonostratigraphic elements of the orogen (Blackwood and Kennedy, 1975; Holdsworth, 1994). This crustal-scale boundary has a complex history of ductile shearing, chiefly of mid- to Late Silurian age (Holdsworth, 1994; Dunning *et al.*, *in press*). Locally, however, the earlier record of ductile movement along this boundary has been excised by brittle displacements of post-Early-Devonian age. This is the case in southern Newfoundland, where the brittle Hermitage Bay Fault (White, 1939; Widmer, 1950; Blackwood and O'Driscoll, 1976) (Figure 1) separates the Avalon Zone from an amphibolite-grade, early to middle Paleozoic granite–gneiss terrane, part of the Appalachian mobile belt (Colman-Sadd *et al.*, 1979, 1990). This boundary, exposed near the head of Hermitage Bay, extends northwestward for more than 30 km, where it is ultimately truncated by mid- to Late Devonian plutons of the Ackley Granite suite (Dickson, 1983).

In the southwestern Avalon Zone, Proterozoic and early Paleozoic rocks are overlain unconformably by a cover of terrestrial clastic and subaerial volcanic rocks of Devonian age (e.g., Widmer, 1950; O'Brien *et al.*, 1990). These are of similar facies to strata deposited at about the same time in other Appalachian tectonostratigraphic zones (e.g., Chandler, 1982), and include detritus derived from inboard elements of the orogen. This Devonian cover, together with its basement, has been intruded by high-level granite plutons of established or presumed Devonian age (e.g., O'Driscoll and Strong, 1979; Furey and Strong, 1986). These are part of a larger suite of post-orogenic, high-silica granites that have been emplaced at high structural levels into the western Avalon Zone rocks and adjacent tectonostratigraphic elements of the Hermitage Flexure region (Dickson *et al.*, 1989; Kerr *et al.*, 1993).

PRESENT INVESTIGATION

This overview incorporates the results of a number of field studies of the Proterozoic, Cambrian and Devonian rocks between Hermitage Bay and Long Harbour (Fortune Bay), as well as on the offshore islands, Brunette and Sagona (Figure 1). The area described includes parts of 1:50 000-scale NTS map areas 1M/5, 6, 11 and 12 and 11P/8 and 9. More recently acquired field and geochronological data (e.g., O'Brien *et al.*, 1992a, b, 1994; O'Brien and O'Driscoll, 1994) are integrated with various earlier findings (e.g., Widmer, 1950; Williams, 1971; Greene, 1975; Greene and O'Driscoll, 1976) and are presented, together with hitherto unpublished data, in a single, comprehensive overview of the pre-Carboniferous geology of this region. Geological compilation maps of this area at various scales have been recently published (e.g., O'Brien and O'Driscoll, 1994) or are presently in preparation (S.J. O'Brien, C.F. O'Driscoll and B.A. Greene, unpublished data).

Much of the recent work on the Neoproterozoic rocks was initiated in an attempt to rationalize existing views of southwest Avalon Zone geology (e.g., O'Driscoll and Strong, 1979; Colman-Sadd *et al.*, 1979) with more recent data (Swinden and Hunt, 1991) that suggested a geological history more prolonged—if not more complex—than previously envisaged. The resultant recognition of the composite tectonic character of this region in the Neoproterozoic has important ramifications for local and regional geological development in southeastern and southern Newfoundland, including observations and implications that bear significantly on strategies of mineral exploration.

HISTORY OF GEOLOGICAL INVESTIGATIONS

PIONEERING STUDIES

During the course of their early geological surveys of insular Newfoundland, Alexander Murray and James Howley made brief visits to northern Fortune Bay (Murray, 1870; Murray and Howley, 1881 and Howley, 1888). Their most significant observation was made at Blue Pinion Cove, where Murray (1870) identified an angular relationship between red conglomerate and underlying slate and quartzite. Dale (1927) revisited the sections at Blue Pinion Cove and discovered Cambrian fossils in shales beneath Murray's unconformity. He also mapped intrusive relationships between the granite and rocks above and below the unconformity, suggesting that the redbeds could be of Devonian or Carboniferous age.

White (1939) conducted the first extensive geological study of northern Fortune Bay, mapping the area between North Bay and Femme Harbour, northward to the 'Ackley Batholith', as part of a Princeton doctoral thesis on granite-hosted molybdenite mineralization. His regional mapping led to the identification of many of the major geological elements of this region (White, 1939, 1940; Smith and White, 1954). He mapped and subdivided a very thick succession of interlayered volcanic and sedimentary rocks exposed along the north shore of Fortune Bay, east of East Bay. However he erroneously placed these rocks, which he named 'Long Harbour series', stratigraphically above fossiliferous

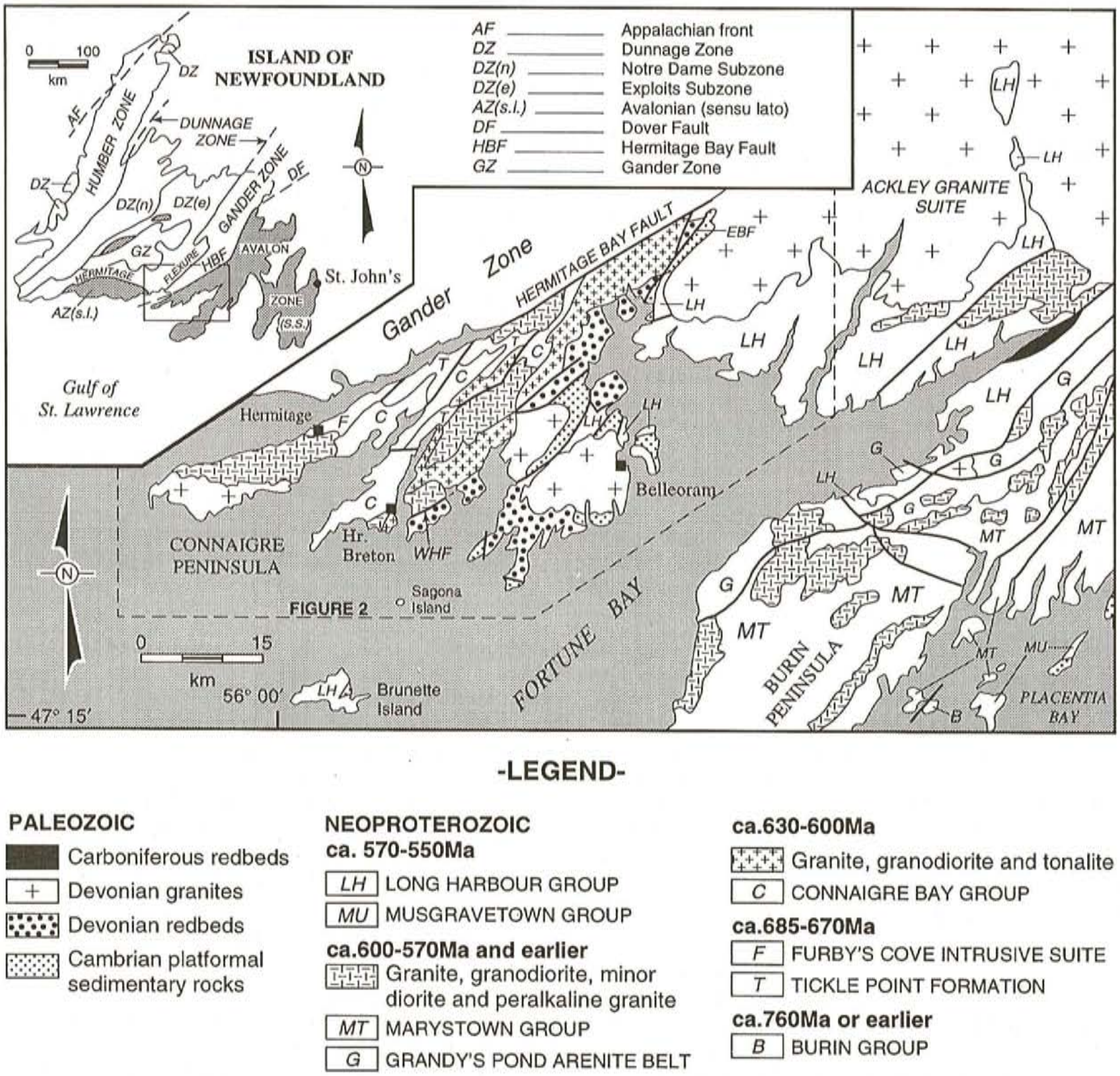

Figure 1. *Regional geology of the southwestern Avalon Zone, showing the approximate distribution of major geological units on the Connaigre Peninsula, the northern Burin Peninsula, and the intervening north coast of Fortune Bay. WHF = White Horse Fault, EBF = East Bay Fault.*

Cambrian strata (his Youngs Cove Formation), assigning them an Ordovician age. Redbeds above the uppermost Long Harbour volcanic rocks (his Rencontre Formation) were designated as Silurian[4].

White (1939) and Taylor (1940) mapped a succession of redbeds between East Bay and Corbin Bay (part of Murray's cover), identifying an unconformable relationship with a variety of basement rock units in a number of previously unrecognized sites. White (1939, 1940) locally separated these redbeds from lithologically similar strata (his Doten Cove Formation), which were subsequently shown to underlie fossiliferous Cambrian rocks (see below: Williams, 1971). He also delineated part of the large area of granite to the northwest of North Bay (his Bay du Nord Batholith), and incorrectly assumed that emplacement of these rocks postdated deposition of adjacent Devonian strata.

[4] These rocks were subsequently assigned to the Devonian by Twenhofel (1947) before Williams (1971) correctly established their Neoproterozoic age.

Widmer (1950), as part of his Princeton doctoral thesis, produced the first detailed geological map of the Connaigre Peninsula. He assigned the non-fossiliferous strata of the western part of the peninsula to a single, internally conformable lithostratigraphic unit, which he named 'Connaigre Bay volcanics', and included within it, a large adjacent area of magmatic rocks that he considered to be the local products of granitization of country rocks during emplacement of nearby Devonian plutons. The apparent lithological similarity of the volcanosedimentary succession with White's Long Harbour series compelled him to assign the Connaigre Bay rocks a similar Ordovician age.

Widmer (1950) also mapped fossiliferous Cambrian and younger successions in the eastern Connaigre Peninsula. He detailed both the nature of their external contacts and the geology and stratigraphic order of their component formations, and in the process, discovered Devonian plant fossils in the post-Cambrian cover. He established a tripartite stratigraphic division of the rocks that lay above White's (1939) Doten Cove Formation, viz., a basal unit of grey sandstones (Chapel Island Formation); an intermediate unit of quartzites (Blue Pinion—now Random—Formation); and an upper unit of fossiliferous Middle to Upper Cambrian shales. Rocks on Sagona Island, now assigned to the Chapel Island, Random and Chamberlains Brook formations, were mapped by Widmer (1950) as the Sagona Island Formation, and assigned an early Ordovician age. He also delineated the extent of major granite bodies on the Connaigre Peninsula and locally established intrusive relationships with Paleozoic strata. Although he identified several lithologically distinctive granites, he assumed all to be of Devonian or younger age.

SYSTEMATIC SURVEYS

Following Anderson's (1965) regional geological reconnaissance of the entire Belleoram (NTS 1M) area, the Geological Survey of Canada (Williams, 1971) mapped NTS map sheet 1M/11, which includes the Long Harbour type area of White (1939) and Smith and White (1954). Williams (1971) elevated the Long Harbour series to group status, recognized its true stratigraphic position beneath Cambrian rocks, and reassigned it to the late Neoproterozoic. He subdivided the Devonian strata previously surveyed by White (1939) and Widmer (1950), and expanded the area of Devonian beds to include limestones and conglomerates in the North Bay area that, previously, had been assigned to the Ordovician. He also recognized the nonconformable relationship of Devonian strata above White's Bay du Nord Batholith—which he renamed Simmons Brook—thereby discounting earlier views that all granite emplacement in this region postdated deposition of Devonian strata.

Much of the Connaigre Peninsula (parts of NTS map areas 1M/5 and 12) was systematically mapped by the Newfoundland Department of Mines and Energy in the mid-1970s (Greene, 1975; Greene and O'Driscoll, 1976; O'Driscoll, 1977; Colman-Sadd *et al.*, 1979). This work led to the elevation of the Widmer's (1950) Connaigre Bay series to group status and to its subdivision into four conformable formations. The 'granitized' rocks of Widmer (1950) were reassigned to the late Neoproterozoic Hermitage Complex, which was mapped to intrude the Connaigre Bay Group. Greene and O'Driscoll (1976) and Colman-Sadd *et al.* (1979) concurred with Widmer's correlation of Connaigre Bay and Long Harbour rocks, but following Williams (1971), assigned the new Connaigre Bay Group to the late Neoproterozoic. The calc-alkaline chemical affinities of the Connaigre Bay Group and adjacent late Neoproterozoic plutonic rocks were descibed by O'Driscoll (1977) and O'Driscoll and Strong (1979), who argued a genetic relationship amongst these various units.

Greene and O'Driscoll (1976) and, subsequently, Dickson (1988) mapped the southwestern and northeastern extensions, respectively, of Williams' (1971) Simmons Brook Batholith. O'Driscoll (1977) characterized the Simmons Brook rocks as one of two larger, petrologically distinct, magmatic assemblages. The first of these was of late Neoproterozoic age, the second, Devonian. Each was characterized by a distinctive geochemical signature and by contrasting intrusive and structural relationships with adjacent Proterozoic and Paleozoic rocks (e.g., Strong *et al.*, 1974; O'Driscoll and Strong, 1979).

One of these Neoproterozoic plutons, the Straddling Granite, was interpreted to occur on both sides of the Hermitage Bay Fault, thus stitching the original (pre-brittle) boundary between the Avalon Zone and the Central Mobile Belt (Blackwood and O'Driscoll, 1976). Elias and Strong (1982), however, abandoned the name Straddling Granite, and gave geochemical and geochronological evidence that the granites on adjacent sides of the Hermitage Bay Fault are different. The granites east and west of the fault were named Hardy's Cove intrusive suite and Indian Point granite, respectively.

The well-exposed upper Neoproterozoic to lower Paleozoic sedimentary succession on Brunette and Sagona islands was mapped and subdivided by Greene (1975), who also completed stratigraphic studies of the Cambrian rocks elsewhere in this region as part of a larger study of the Random Formation (Greene and Williams, 1974; Butler and Greene, 1976). Paleontological studies of these early Paleozoic rocks include the work of Hutchinson (1962), Greene and Williams (1974) and Anderson (1981).

RECENT THEMATIC STUDIES

Detailed sedimentological analyses of the late Neoproterozoic and earliest Cambrian rocks were completed by Hiscott (1982), Smith and Hiscott (1984) and Myrow (1987), and established specific environments in an overall evolution from alluvial to nearshore and shelf depositional regimes. Geochemical, petrological and mapping studies of the Devonian plutons and the mineralization therein were carried out in various parts of the area by Dickson (1983, 1988), Furey (1985), Furey and Strong (1986) and Tuach *et al.* (1986). More recently, chemical and isotopic studies of these and other granites in the area have been undertaken by

Kerr *et al.* 1993; *in press*. Studies of the genesis of massive sulphide showings on the Connaigre Peninsula and their host rocks were completed by Sears and O'Driscoll (1989) and Sears (1990), who presented evidence to support a Kuroko-like volcanogenic origin for the largest of these deposits.

During a lead-isotope investigation of the Frenchman Head massive sulphide occurrence by H.S. Swinden (Newfoundland Geological Survey), the age of rhyolite near the base of the Connaigre Bay Group was determined (Swinden and Hunt, 1991). The 680 Ma age for this rock prompted a renewal of interest in the Proterozoic geological evolution of the western Connaigre Peninsula, and led to the initiation of the new geochronological and geological mapping investigations in that area (O'Brien *et al.*, 1992a,b; 1994; O'Brien and O'Driscoll, 1994). This latter work led to a number of new findings, including the redefinition of the Connaigre Bay Group, the recognition of Neoproterozoic basement-cover relationships and the identification of a sub-Connaigre Bay basement terrane. In addition, the Neoproterozoic magmatic rocks of this region were divided into several discrete suites of widely differing age, sharing either depositional or intrusive boundaries with adjacent pre-Paleozoic rocks.

GEOLOGY OF THE NEOPROTEROZOIC ROCKS

INTRODUCTION

The Neoproterozoic stratified and plutonic rocks exposed in this region represent the products of a number of discrete orogenic events that span at least 140 Ma (O'Brien *et al.*, 1994; Table 1). The oldest recognized Neoproterozoic rocks are low-grade, arc-related volcanic units of the Tickle Point Formation and associated calc-alkaline plutonic and hypabbysal complexes of the Furby's Cove intrusive suite, that together form a 685 to 670 Ma basement complex. These rocks were tectonized and unroofed prior to the formation, between 630 and 620 Ma, of extensive suites of volcanic and related marine and terrestrial sedimentary rocks of the Connaigre Bay Group and broadly coeval Simmons Brook intrusive suite. Significantly, an erosional unconformity locally separates elements of 685 to 670 Ma basement from the Connaigre Bay Group. All of these rocks had been tectonized prior to onset of volcanism and plutonism related to a terminal Neoproterozoic magmatic event. The nature of deformation is typically weak and in many cases inhomogeneous. In almost all cases, it has occurred under conditions no higher than greenschist grade.

The latest Neoproterozoic tectonic events occurred between ca. 580 and ca. 545 Ma and are reflected initially by emplacement, on the western Connaigre Peninsula, of plutonic rocks of the Grole intrusive suite, the Hardy's Cove intrusive suite, and parts of the Harbour Breton Granite. This magmatism is coeval with the onset of volcanism in the Long Harbour Group, a low-grade and little-deformed volcano-sedimentary succession best preserved in an open synclinorium between the Connaigre and Burin peninsulas. Long Harbour volcanism (Belle Bay and Mooring Cove formations) continued for at least 20 Ma, interrupted by deposition of marine sandstones and shales (Andersons Cove Formation). The upper terrestrial clastic division of the Long Harbour Group (Rencontre Formation) grades into the overlying Chapel Island Formation, a shallow marine unit that includes strata that record the Neoproterozoic–Paleozoic boundary.

Presented below is a brief characterization of the Neoproterozoic rocks including descriptions of their internal and external contact relationships. The overview is ordered within a tripartite tectonic framework: 685 to 670 Ma, 630 to 620 Ma and 570 to 550 Ma.

685 to 670 Ma Basement Rocks

The oldest known rocks in the southwestern Avalon Zone lie west of the Devonian sedimentary basins of the Connaigre Peninsula (Figure 2). This basement, which yields precise U–Pb zircon ages between 685 and 670 Ma, lies unconformably beneath strata of the Neoproterozoic Connaigre Bay Group, intruded by rocks of varied Neoproterozoic ages. Smaller areas of higher grade, ductilely foliated metamorphic rocks may represent relicts of additional basement components, although the absolute age of these rocks is unresolved. The northwestern limit of the 685 to 670 Ma basement in this area is the Hermitage Bay Fault.

Tickle Point Formation

The oldest dated lithostratigraphic unit in the area is a stratified sequence composed primarily of calc-alkaline felsic volcanic rocks. These strata were named Tickle Point Formation by O'Driscoll (1977) and were originally included within the Connaigre Bay Group as its basal component (cf., Colman-Sadd *et al.*, 1979). The subsequent recognition of depositional contacts between higher stratigraphic levels of the Connaigre Bay Group and granites that are intrusive into the Tickle Point Formation necessitated the removal of the formation from the group (O'Brien *et al.*, 1992a; O'Brien and O'Driscoll, 1994).

The most characteristic rock types within the Tickle Point Formation are massive rhyolite flows and their less extensively developed flow-banded and autobrecciated variants. Locally associated with the flows are fine-grained, silicic pyroclastic rocks, including welded and non-welded ash-flow tuffs. In the Tickle Point Formation as presently defined, volcanic rocks of mafic composition are present but not extensively developed. Minor units of clastic sedimentary rocks, and a distinctive unit of intricately laminated to banded and internally brecciated carbonate rocks, are locally preserved at or near the top of the formation. In several areas on the western Connaigre Peninsula, these carbonates and related chemical sediments are either host to, or are closely associated with, significant zinc- and copper-rich VMS-style mineralization (Sears, 1990; O'Brien and O'Driscoll, 1994;

Table 1. Table of formations, Avalon Zone, northern Fortune Bay

AGE	UNIT	AGE CONTROL	OTHER CONTACT RELATIONS WITH OLDER UNITS	DIAGNOSTIC LITHOLOGY
	BELLEORAM GRANITE	intrusive relationship with fossiliferous strata	intrusive into Long Harbour Group, Youngs Cove Group and Cinq Isles Formation	grey quartz monzonite and granodiorite; red microgranite
	intrusive contact			
DEVONIAN	**GREAT BAY DE L'EAU FORMATION**	upper Devonian fossils	angular unconformity with Long Harbour and Youngs Cove groups	red to buff pebble to boulder conglomerate; black shale
	not in contact			
	ACKLEY GRANITE SUITE	several $^{40}Ar/^{39}Ar$ cooling ages from elsewhere in suite	intrusive contacts with Long Harbour Group, Youngs Cove Group and Cinq Isles Formation	coarse-grained porphyritic to equigranular biotite granite; microgranite and aplite
	not in contact			
	OLD WOMANS STOCK	intrudes rocks correlated with fossiliferous Devonian	intrusive and faulted contacts with Long Harbour Group, Youngs Cove Group and Pools Cove Formation; intrusive into Cinq Isles Formation	K-feldspar and plagioclase porphyritic granite; biotite ± hornblende granite; microgranite and felsite
	not in contact			
DEVONIAN ?	**PASS ISLAND GRANITE**	lithological and geochemical correlation	intrusive into Grole Intrusive Suite	coarse-grained equigranular to porphyritic biotite granite
	not in contact			
	POOLS COVE FORMATION	lithological correlation; similar stratigraphic position as fossiliferous strata	unconformable on Simmons Brook Intrusive Suite	red boulder conglomerate and arkose
	disconformable contact			
	CINQ ISLES FORMATION	lithological correlation	unconformable on Simmons Brook Intrusive Suite	red shale, sandstone and conglomerate with limestone
	unconformable contact			
LATE NEOPROTEROZOIC AND CAMBRIAN	**YOUNGS COVE GROUP** Salmonier Cove Formation Chamberlains Brook Formation Random Formation Chapel Island Formation	lower to upper Cambrian fossils	faulted with Simmons Brook Intrusive Suite and Long Harbour Group	grey shallow-marine sandstone; white quartzarenite and red sandstone; black and grey shale
	conformable contact			
	LONG HARBOUR GROUP Rencontre Formation Mooring Cove Formation Andersons Cove Formation Belle Bay Formation	552 ± 3 Ma (U/Pb zircon): Mooring Cove Formation 568 ± 5 Ma (U/Pb zircon): Belle Bay Formation	contacts with older units not exposed	subaerial bimodal volcanic rocks; marine sandstones and shales, red conglomerate and related terrigenous rocks
	not in contact			
	HARDYS COVE GRANITE	unpublished U/Pb data 568 ± 2 Ma G.R. Dunning, written communication, 1994	intrusive into Tickle Point Formation, Connaigre Bay Group and Simmons Brook Intrusive Suite; faulted contacts with Tickle Point Formation	biotite granite, granodiorite and diorite
	not in contact			
	HARBOUR BRETON GRANITE	unpublished U/Pb data 570 ± 3 Ma G.R. Dunning, written communication, 1994	intrusive and faulted contacts with Tickle Point Formation, Simmons Brook Intrusive Suite and Connaigre Bay Group	biotite granite; minor porphyritic granite and microgranite
	not in contact			
LATE NEOPROTEROZOIC	**GROLE INTRUSIVE SUITE**	567 ± 3 Ma (U/Pb zircon)	intrusive into and faulted with Tickle Point Formation, Furby's Cove Intrusive Suite and Connaigre Bay Group; coeval gabbros intrude Simmons Brook Intrusive Suite posttectonically	quartz diorite, diorite and gabbro
	not in contact			
	SIMMONS BROOK INTRUSIVE SUITE	621 ± 3 Ma (U/Pb zircon)	intrusive and faulted contacts with Tickle Point Formation, Connaigre Bay Group and metamorphic rocks of uncertain affiliation	hornblende-biotite granodiorite tonalite and granite; diorite
	intrusive contact			
	CONNAIGRE BAY GROUP Downs Point Formation Doughball Point Formation Sam Head Formation	626 ± 3 Ma (U/Pb zircon)	unconformable on Tickle Point Formation; faulted with Tickle Point Formation and Furbys Cove Intrusive Suite	marine siliciclastic sediments; mafic flows and pyroclastics; variegated terrigenous clastic and volcanic rocks
	unconformable contact			
	FURBY'S COVE INTRUSIVE SUITE	673 ± 3 Ma (U/Pb zircon)	faulted contacts with Tickle Point Formation	blue quartz granite; diorite; bimodal dyke swarm
	intrusive contact			
	TICKLE POINT FORMATION	682 ± 3 Ma (U/Pb zircon)		rhyolite; mafic flows; siliciclastics; chemical sediments
	base not exposed			

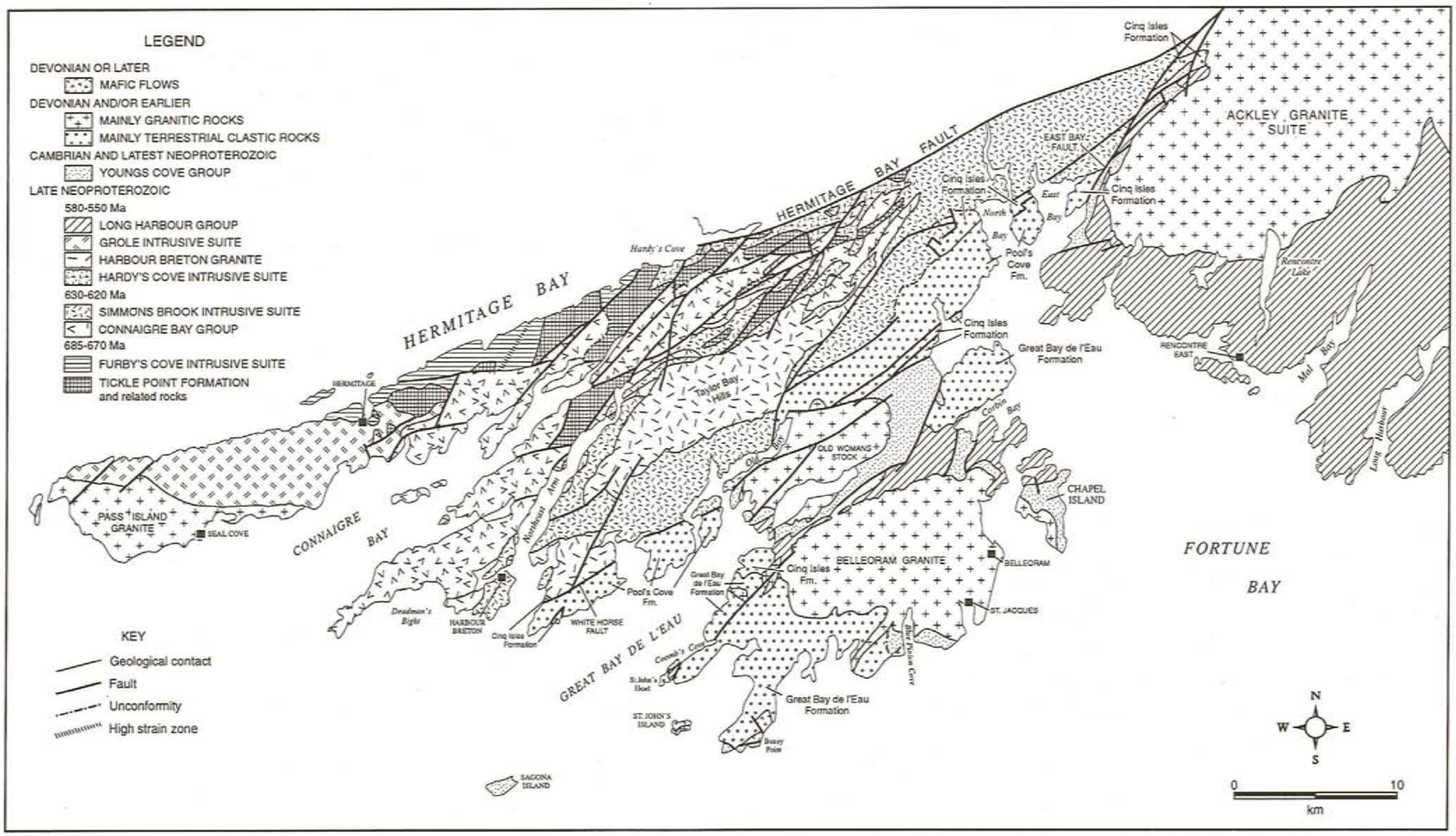

Figure 2. *Simplified geological map of the Connaigre Peninsula and the adjacent coast of Fortune Bay.*

Plate 1). The maximum exposed thickness of the Tickle Point Formation has been estimated at 500 m (O'Driscoll, 1977). Rhyolite flows from the type section near Tickle Point have yielded U–Pb zircon ages of 682 ± 3 Ma (O'Brien *et al.*, 1994; R.D. Tucker, unpublished data) and 682.8 ± 1.6 Ma (Swinden and Hunt, 1991).

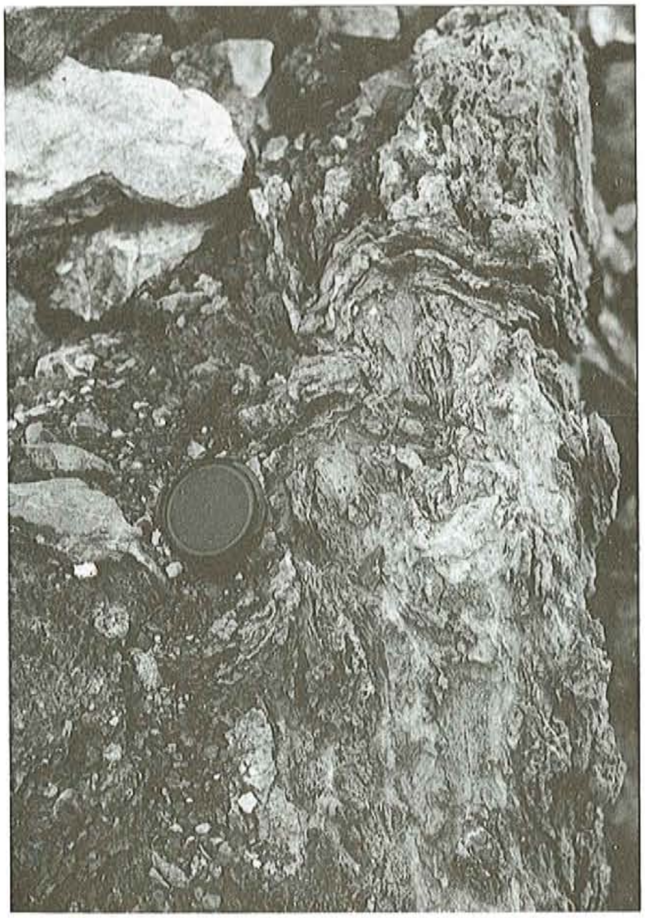

Plate 1. *Mineralized (Zn–Pb–Cu) calc-silicate and carbonate rocks near the top of Tickle Point Formation, Winter Hill.*

Furby's Cove Intrusive Suite

The Furby's Cove intrusive suite (O'Brien *et al.*, 1992a), situated in the west-central Hermitage Peninsula, was emplaced into the Tickle Point Formation prior to the deposition of the (redefined) Connaigre Bay Group. The suite includes both granite and gabbro phases that locally take the form of narrow sheet-like intrusions. The most diagnostic felsic rock types are pink to white, equigranular, blue-quartz granite and granodiorite. Blue-quartz granite porphyry also occurs, mainly in a separate pluton situated several kilometres from the main complex. Typically, the mafic rocks of the Furby's Cove intrusive suite are variably altered, medium-grained, green to dark-grey gabbro and hornblende porphyry. Locally, the felsic and mafic phases are extensively mixed, and are probably comagmatic. Near the contact with the Tickle Point Formation, granite of the suite is affected by a zone of intense ductile shearing (Plate 2). In this zone, which varies in width from several tens to more than a hundred metres, granite is deformed into moderately to steeply dipping protomylonite and mylonite, with associated down-dip stretching lineation.

Plate 2. *High-strain zone in granite of the Furby's Cove intrusive suite, south shore of Hermitage Bay.*

The Furby's Cove intrusive suite also contains a bimodal dyke swarm, which includes many hundreds of diabasic, granitic and felsitic dykes that have been emplaced into granite and gabbro of the suite and into their country rocks (Plate 3). The granite dykes, like the Tickle Point Formation rhyolites, are in places garnetiferous (O'Driscoll, 1977). These and other dykes are represented in clasts in the basal conglomerate of the cover. It is unlikely, however, that all dykes in this zone are of one age; some may be related to one or more significantly younger Neoproterozoic or Paleozoic magmatic events.

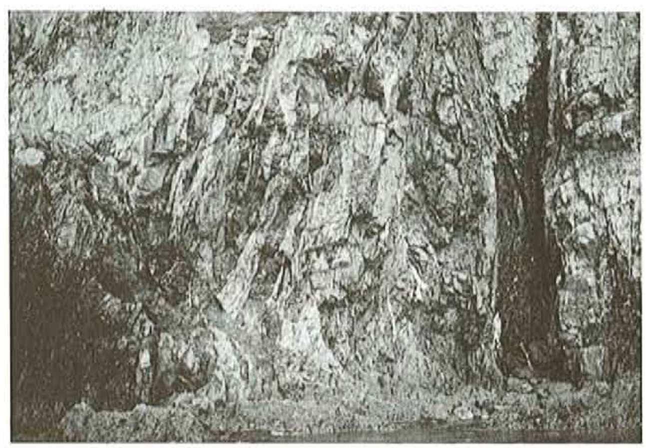

Plate 3. *Diabase and felsite dykes, part of the major dyke swarm in the Furby's Cove intrusive suite near Hermitage. Field of view approximately 20 m.*

Other Possible Basement Components

Small areas of amphibolitic gneiss, migmatite and mylonite occur together with metasedimentary and metavolcanic rocks near the western margin of the Simmons Brook intrusive suite in the north-central part of the Connaigre Peninsula. Pre-625 Ma Simmons Brook diorites have been emplaced posttectonically into these amphibolite-grade rocks. It is uncertain if the metamorphic rocks represent further elements of the 685 to 670 Ma basement, relicts of a more ancient terrane, or the higher grade metamorphic equivalents of a Neoproterozoic cover. These rocks contain pre-620 Ma ductile high-strain zones that may represent the remains of early tectonic boundaries within the southwestern Avalon Zone, variably masked by emplacement of younger Neoproterozoic granite (see below).

630 to 620 Ma Stratified and Magmatic Rocks

The stratigraphic and plutonic history of the Connaigre Peninsula in the interval between 630 and 620 Ma generally parallels that recorded in partly coeval successions elsewhere in southeastern Newfoundland (e.g., King, 1990). The Connaigre Peninsula is unique, however, in that stratified rocks (Connaigre Bay Group) formed during this period were deposited directly upon a substrate of 685 to 670 Ma intrusive and extrusive rocks, thereby establishing a primary stratigraphic linkage between these two Neoproterozoic tectonic events. A similar linkage with basement is provided by the coeval plutonic rocks of the Simmons Brook intrusive suite. Compositional ranges within these plutonic suites broadly parallels that of the volcanic rocks, a relationship seen elsewhere in the Avalon Zone (e.g., Strong and Minatides, 1975). The felsic and intermediate phases contain both hornblende and biotite and, like the extrusive rocks, have a variable to strongly calc-alkaline chemical signature (O'Driscoll, 1977; O'Driscoll and Strong, 1979; Sears, 1990; C. O'Driscoll, unpublished data).

Connaigre Bay Group

The Connaigre Bay Group as redefined by O'Brien *et al.*, (1992a) corresponds to the upper three units of the group as originally mapped by Greene and O'Driscoll (1976) and O'Driscoll (1977), and subsequently published on the 1:50 000-scale map of Colman-Sadd *et al.* (1979). The group lies unconformably on various levels of the 685 to 670 Ma basement, although in most cases, this contact is faulted or obscured by younger intrusions. The Connaigre Bay Group is also intruded by several plutons of the 620 and 580 Ma magmatic suites (see below). Its external boundaries with these rocks are tectonic in many areas (Figure 2).

Sam Head Formation

The basal division of the Connaigre Bay Group is a thick succession of fine-grained, green and grey, marine siliciclastic rocks, named Sam Head Formation[5] by Colman-Sadd *et al.* (1979; Figure 3). With the exception of the basal strata, such as those described below, the unit is characterized by fine-grained, graded sandstones and argillites. These are locally crossbedded and rippled (O'Driscoll, 1977). However, mafic tuff and interlayered thin-bedded to massive tuffaceous sandstone exposed in the north-central part of the Connaigre Peninsula, have also been assigned to the Sam Head Formation (cf. Subunit 5a of Colman-Sadd *et al.*, 1979). These strata, which are atypical of the group in the type area around Connaigre Bay, are also associated with hornfels of mafic tuffaceous protolith. It is assumed that these rocks represent facies equivalents of the Sam Head Formation farther south but it remains conceivable that part of this succession may be related to the 685 to 670 Ma basement complex.

The Sam Head Formation rests with profound unconformity upon granite of the Furby's Cove intrusive suite. At the contact in Hermitage, coarse-grained cobble conglomerate and breccia lie directly upon blue quartz granite, and contain variably rounded cobbles and granules of the underlying granite (Plate 4). The conglomerate also contains fragments of fine-grained mafic and felsic dykes and various rhyolitic volcanic detritus. Where the basal Connaigre Bay Group is in contact with Tickle Point Formation rhyolite, its base is locally marked by a thick, purple to red conglomerate or by well-rounded quartz-pebble and quartz-cobble conglomerate (O'Driscoll, 1977; Plate 5).

Doughball Point Formation

The lower siliciclastic unit of the Connaigre Bay Group is conformably overlain by mafic volcanic rocks of the Doughball Point Formation (O'Driscoll, 1977; Figure 3). The sequence includes thick massive flows and coarse-grained agglomerates of both andesitic and basaltic composition. A distinctive feature of the basalts is the presence of locally coarse-grained augite euhedra. In several areas, mafic rocks are interlayered with rhyolite flows and felsic fragmental rocks. Zircon separated from one such rhyolite flow, located several hundred metres from the base of the formation, has been dated at 626 $\pm$ 3 Ma (R.D. Tucker, unpublished data; O'Brien *et al.*, 1994). The basalts of the Sam Head Formation are typically tholeiitic, contrasting with the more strongly calc-alkaline signatures of the basement volcanic sequence (Sears, 1990).

Downs Point Formation

The top of the Connaigre Bay Group is represented by a ca. 1-km-thick succession of fine- to coarse-grained, red to grey, terrestrial clastic rocks that constitute the Downs Point Formation (O'Driscoll, 1977; Colman-Sadd *et al.*, 1979; Figure 3). The boundary of this formation with underlying volcanic rocks is gradational. The clastic rocks contain an extensive felsic pyroclastic unit located several hundred metres above its base (O'Driscoll, 1977). A unique characteristic of the formation is the presence of layers and lenses of fine-grained magnetite (O'Driscoll, 1977).

[5] Previously named Great Island Formation by O'Driscoll (1977).

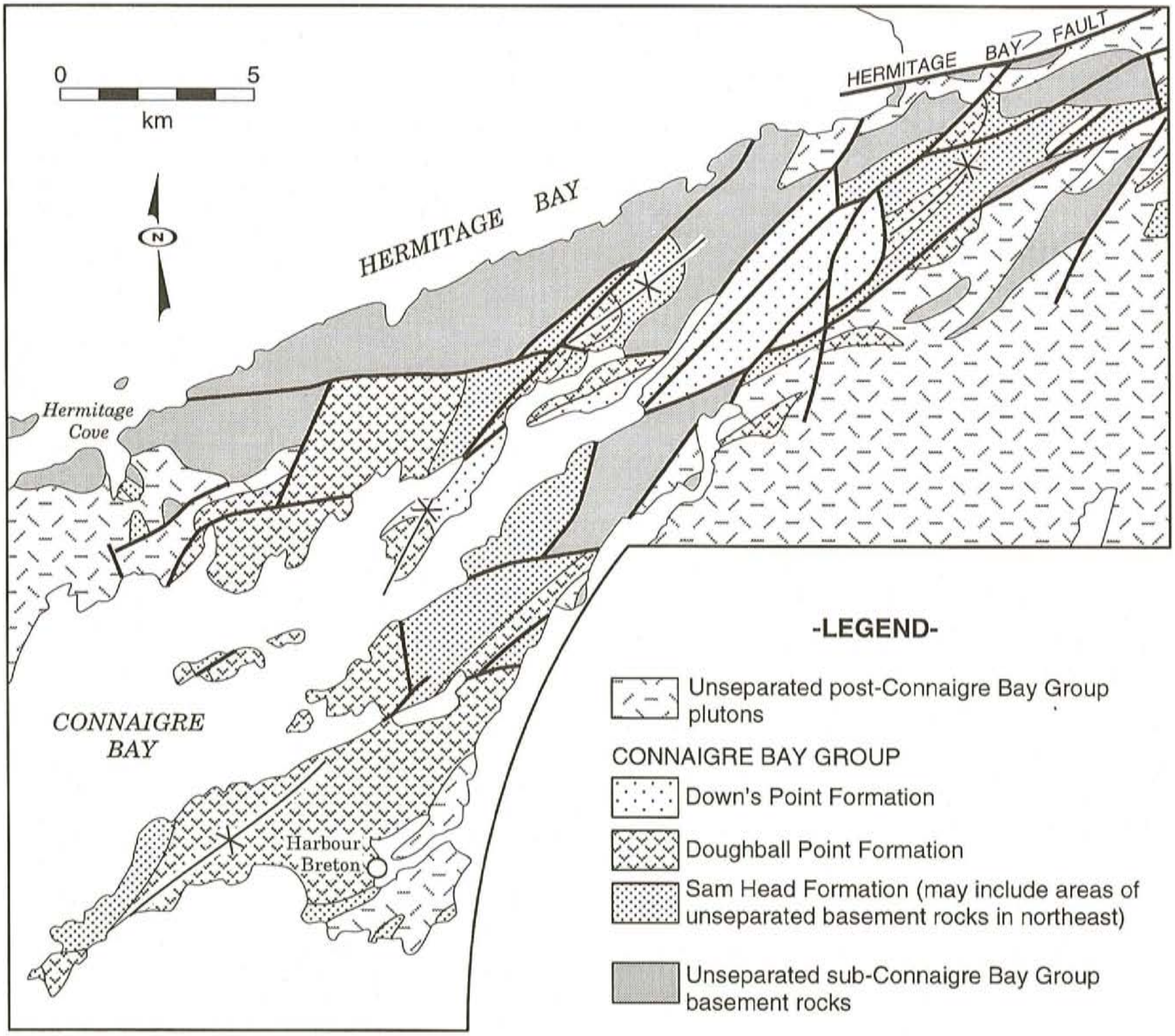

Figure 3. *Geological map of the main outcrop area of the Connaigre Bay Group, showing the distribution of its component formations (after O'Brien and O'Driscoll, 1994.)*

Simmons Brook Intrusive Suite

Hornblende ± biotite-bearing felsic, intermediate and mafic intrusive rocks that together comprise the Simmons Brook intrusive suite extend in a broad, 5- to 10-km-wide band, from Harbour Breton in the south, northeastward across the entire area (Figure 2). Its eastern limit is marked by its unconformable contact, or faulted equivalent, with overlying Devonian strata.

The most diagnostic rocks of the Simmons Brook intrusive suite are medium- to coarse-grained, pale grey to black-and-white, hornblende–biotite granodiorite and tonalite. Minor amounts of pink to red, alaskitic granite and granite porphyry are very locally developed. The more intermediate compositions contain variously digested mafic xenoliths of probable cognate origin. They commonly host mafic dykes (Plate 6), at least some of which are comagmatic with the enclosing felsic and intermediate rocks. The intermediate compositions, in particular, readily display a pervasive foliation of weak to locally moderate intensity. Foliated granodiorite from the Simmons Brook intrusive suite near the contact with overlying Devonian strata has been dated at 621 ± 3 Ma (R.D. Tucker, unpublished data; O'Brien *et al.*, 1994).

The earlier mafic intrusions typically take the form of elongate, thick sheet intrusions, generally less than 1 km

Plate 4. *Basal conglomerate of the Connaigre Bay Group, Hermitage Cove, at the contact with the Furby's Cove intrusive suite.*

Plate 5. *Quartz-bearing conglomerate from the base of the Sam Head Formation, Connaigre Bay Group, at the contact with the Tickle Point Formation.*

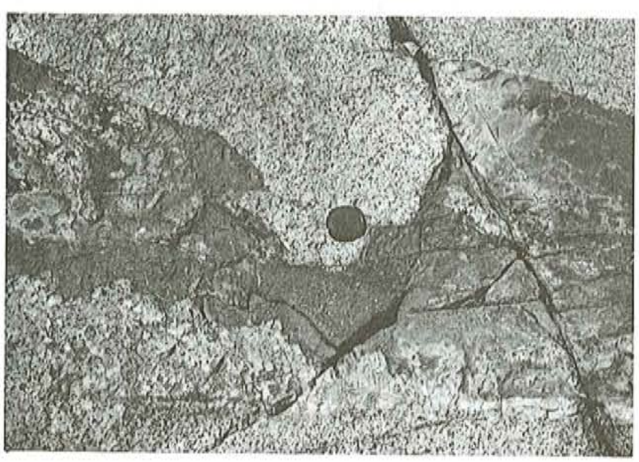

Plate 6. *Early mafic dykes, intruding into granodiorite, Simmons Brook intrusive suite, Old Bay.*

wide; these are situated along the western side of the suite. Mafic rocks may have been as volumetrically extensive elsewhere in the suite, although this is uncertain, as much of this area has since been disrupted extensively by younger Neoproterozoic plutons or masked by overlying Devonian strata. Mafic units typically include dark green and black, medium- to coarse-grained gabbro and fine- to medium-grained diorite. Similar mafic rocks are more extensive in the northeastern part of the suite, again intruded by more felsic members (Williams, 1971; Dickson, 1988). The Simmons Brook intrusive suite has strong calc-alkaline affinities (O'Driscoll, 1977; O'Driscoll and Strong, 1979; C.F. O'Driscoll, unpublished data).

The Simmons Brook intrusive suite has intruded the Tickle Point Formation and the overlying Connaigre Bay Group and is itself intruded by the Harbour Breton Granite. Felsic and mafic members of the suite have also been emplaced, posttectonically, into amphibolites, mafic gneisses and mylonites exposed in the north-central part of the Connaigre Peninsula. The Simmons Brook intrusive suite is unconformably overlain by Devonian strata of the Pools Cove Formation in several areas southwest of North Bay (e.g., Williams, 1971). The suite is in tectonic contact with Cambrian strata along the East Bay Fault; a number of brittle faults that lie parallel to or splay from that fault have juxtaposed down-faulted Cambrian and Devonian strata with various Simmons Brook rocks. Its northwestern limit in much of the area is the Hermitage Bay Fault, which separates it from Siluro-Devonian granites of the Gander Zone (Dickson, 1988).

Latest Neoproterozoic (580 to 550 Ma) Rocks

In this part of northern Fortune Bay, the East Bay–White Horse fault system separates latest Neoproterozoic intrusive rocks in the west from coeval stratified rocks to the east (Figure 2). On a more regional scale, intrusive rocks of this age crosscut older rocks in uplifted horsts or anticlinoria on the Connaigre and Burin peninsulas; these flank an intervening synclinorium occupied by the coeval extrusive rocks (Figure 1). On the Connaigre Peninsula, ca. 580 Ma intrusive rocks have been emplaced across the basement-cover contact between 685 to 670 Ma and 630 to 620 Ma rocks. Coeval latest Neoproterozoic rocks have been emplaced into the Simmons Brook intrusive suite posttectonically.

The discussion of the latest Neoproterozoic (580 to 550 Ma) geology of this region is divided into two parts. The first part outlines the geology of the intrusive rocks, most of which have been emplaced early in this final stage of Proterozoic tectonic evolution. Locally, these yield radiometric ages between about 580 and 570 Ma (O'Brien *et al.*, 1992b, 1994; R.D. Tucker, unpublished data). The second part describes the stratified rocks. These are, in part, coeval with the intrusions, but their deposition continued, apparently without significant hiatus, across the Proterozoic–Paleozoic boundary.

Intrusive Rocks

Grole Intrusive Suite

The Grole intrusive suite (O'Brien *et al.*, 1992a) is located between Connaigre and Hermitage bays on the southwestern Hermitage Peninsula (Figure 2). It consists of black and dark-green to grey, medium- to coarse-grained gabbro that is associated with dark-grey, medium-grained quartz diorite and diorite. A distinctive coarse-grained, black gabbro phase, characterized by large euhedra of largely unaltered amphibole together with pyroxene, biotite and plagioclase, forms a subunit within the suite. The diorite–quartz diorite phase is net-veined by granite, which locally coalesces to form small bosses. In several localities, the quartz diorite displays an incipient, centimetre-scale, gneissic banding, the result of syn-intrusion deformation. Contact migmatites are locally developed at the suite's margin (Plate 7).

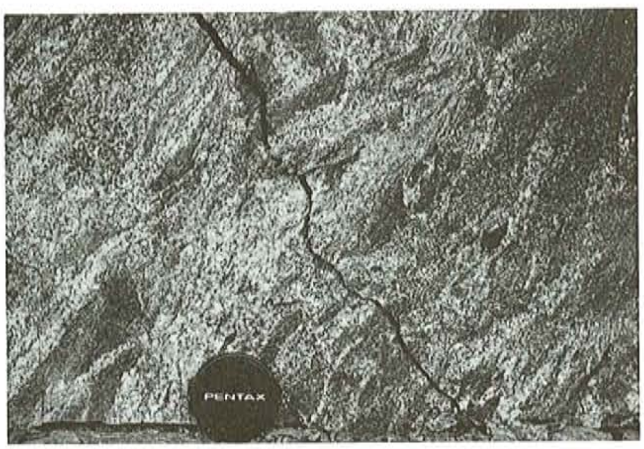

Plate 7. *Late Neoproterozoic migmatites, near Hermitage.*

The Grole intrusive suite has been emplaced into both the 685 to 670 Ma basement (Tickle Point Formation, Furby's Cove intrusive suite) and its 630 to 620 Ma cover (Sam Head and Doughball Point formations), crosscutting the intervening unconformity (Figure 2). The timing of the intrusion with respect to some of the larger regional structures in the region is not entirely clear. Nevertheless, the Grole intrusive suite crosscuts moderately dipping strata above the unconformity, indicating that early deformation of the cover may have occurred prior to its intrusion. Quartz diorite of the Grole intrusive suite has been dated at 567 ± 3 Ma (O'Brien *et al.*, 1994; R.D. Tucker, unpublished data). Coeval and lithologically similar gabbroic plugs have been emplaced into the Simmons Brook intrusive suite, crosscutting solid-state fabrics in the latter pluton.

Hardy's Cove Intrusive Suite

The Hardy's Cove intrusive suite (Elias and Strong, 1982) denotes the granitic rocks mapped by Widmer (1950) and O'Driscoll (1977) as intruding the Connaigre Bay Group and its basement near the head of Hermitage Bay. These rocks had previously been included with granite north of the Hermitage Bay Fault in the larger Straddling Granite (O'Driscoll, 1977; Colman-Sadd *et al.*, 1979). Subsequent geochemical (Elias and Strong, 1982) and geochronological investigations (G. Dunning, written communication, 1994) have indicated that adjacent granites on opposing sides of the Hermitage Bay Fault, although lithologically similar, are unrelated. Most of the northwestern boundary of the Hardy's Cove intrusive suite coincides with the Hermitage Bay Fault.

The Hardy's Cove intrusive suite is an elongate, northeast-trending pluton that consists of three regionally extensive and contiguous phases, all with similar northeast orientation. The most characteristic of these is a pink to orange, medium-grained equigranular granite, which contains some biotite; in many localities the granite is alaskitic. A second, less widely developed phase consists primarily of buff to grey, medium-grained granodiorite, locally associated with felsite. Grey to green, medium-grained diorite represents the third and least widespread Hardy's Cove component.

Harbour Breton Granite

The Harbour Breton Granite as defined by Widmer (1950) and mapped by Greene (1975) and Greene and O'Driscoll (1976), includes those felsic magmatic rocks that have been emplaced into the Simmons Brook intrusive suite, its varied country rocks, and its cover in the area north and west of Great Bay de l'Eau. Previously, this intrusion had been described as embodying two main plutons and several smaller bodies that lay either peripheral to or widely separate from the main plutons. Only one component of the Harbour Breton Granite, however, can be shown to intrude Paleozoic rocks, viz., the Old Womans Stock of Greene and O'Driscoll (1976); (Old Woman's Cove Stock of Widmer, 1946)[6]. There is substantial evidence to indicate that significant parts—or perhaps all—of the remaining area of Harbour Breton Granite is of pre-Devonian age (see below).

The main body of Harbour Breton Granite in the Taylor Bay Hills (Taylor Brook Stock of Widmer, 1946) has been divided by Furey and Strong (1986) into several sub-phases. The latter authors reassigned most of the northeastern part of this pluton, initially to the Simmons Brook intrusive suite and, subsequently, to a separate Cambrian granite (Furey and Strong, 1986). Their divisions are here viewed to represent variants of two major phases—and a third less extensive

[6] This granite is described with other Devonian or younger plutons elsewhere in the text (see: Geology of the mid-Paleozoic rocks)

one—of a single pluton (cf., Greene and O'Driscoll, 1976). The first and most extensive of these is fine- to medium-grained, red and orange alaskite and biotite (± hornblende) granite. Furey and Strong (1986) describe areas of plagiophyric monzogranite associated with these granites. A second regionally mappable phase, situated in the northwest part of the pluton, consists of medium-grained, porphyritic granite. A third phase of microgranite and felsite occurs along the margin of the main pluton in the Taylor Bay Hills. The smaller bodies of the Harbour Breton Granite resemble the most extensive phase of the main Taylor Brook Stock, although they have been more tectonized and altered, at least locally. These medium-grained granites are, in places, associated with diorite that may be related to Harbour Breton magmatism.

With the exception of the Old Womans Stock, the Harbour Breton Granite, as originally defined, is in contact with Devonian strata in one area, and in that case, the boundary is marked by the White Horse Fault. There, Devonian conglomerates are rich in very large boulders identical to the Harbour Breton Granite outcropping immediately northwest. It is presumed that these boulders have been derived from a Harbour Breton Granite source, and that the fault represents a remobilized basement-cover contact. It follows then, that the granite in that area was intruded and uplifted prior to deposition of the Devonian Pools Cove Formation, and must predate (significantly) emplacement of the Old Womans Stock, which intrudes the same rocks. In addition, the Harbour Breton Granite in Northeast Arm is host to a major pretectonic mafic dyke swarm (Plate 8); emplacement of pretectonic mafic dykes on such a scale is not seen in known Devonian rocks in this region. Finally, and most convincingly, a sample of granite from the Harbour Breton Granite type area has yielded a late Neoproterozoic crystallization age (570±3 Ma, U–Pb zircon date; G. Dunning, written communication, 1994).

Until further data become available, the Harbour Breton Granite is tentatively redefined to denote those granite bodies that are exposed, in part, along the shores of Northeast Arm (or Harbour Breton Bay), and thence northeastward, for at least 20 km, as a series of discontinuous northeasterly elongate bodies. Its outcrop area includes granites exposed between Harbour Breton and the east shore of Deadman's Bight—its type area. The status of Widmer's Taylor Brook Stock is less clear but is here assumed to be coeval with granite in the Harbour Breton type area.

Stratified Rocks: Long Harbour Group

Late Neoproterozoic (post-580 Ma) stratified rocks are known to occur only in the area east of the White Horse–East Bay fault system, where they comprise the Long Harbour Group (Figure 2). This succession has been divided into four formations (Belle Bay, Andersons Cove, Mooring Cove and Rencontre), which were first mapped by White (1939) and subsequently refined by Williams (1971). Rhyolites from near the base and the top of the group have been dated at 568 ± 5 Ma and 552 ± 3 Ma, respectively (O'Brien *et al.*, 1994; R.D. Tucker, unpublished data). Thick and continuous sections through the Long Harbour Group outcrop east of the Connaigre Peninsula on the north shore of Fortune Bay (Figure 4); elsewhere the group is exposed in small fault blocks, that in many instances, have been thermally metamorphosed in the aureoles of Devonian granites.

Plate 8. *Pretectonic diabase dyke swarm in the Harbour Breton Granite, Jerseyman's Head; second author as scale.*

The Long Harbour Group is unconformably overlain by the Devonian Pools Cove Group. Its contact with the overlying Cambrian Youngs Cove Formation on Chapel Island and Brunette Island is conformable; elsewhere this contact is tectonized. The Long Harbour Group is intruded posttectonically by the Belleoram Granite and the Ackley Granite suite.

Belle Bay Formation

The Belle Bay Formation, the stratigraphically lowest division of the Long Harbour Group, includes a vast thickness of bimodal subaerial volcanic rocks. The formation's true thickness is unknown, but has been estimated at between 4.5 and 6 km (White, 1939; Williams, 1971). Thick, massive and banded rhyolite flows and thick units of variably welded, fine-grained ash-flow tuffs and massive to vesicular basalts are

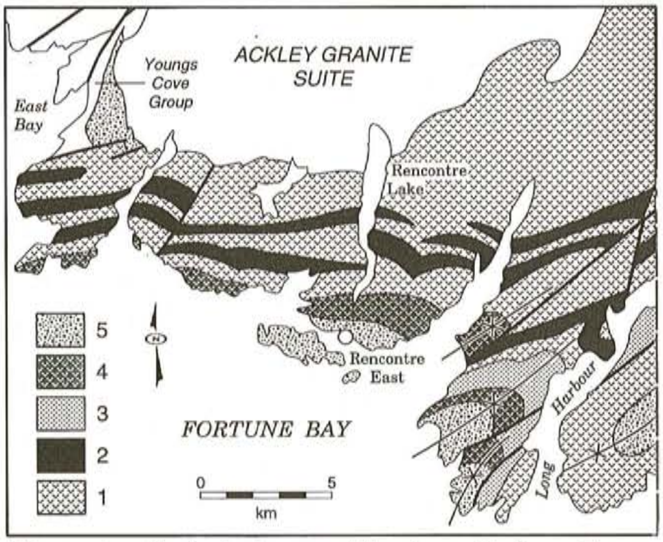

Figure 4. *Geological map of the Long Harbour Group between East Bay and Long Harbour, Fortune Bay, showing the distribution of its component formations (after Williams, 1971). 1–Belle Bay Formation felsic rocks; 2–Belle Bay Formation mafic rocks; 3–Andersons Cove Formation; 4–Mooring Cove Formation; 5–Rencontre Formation.*

characteristic rock types; these occur interlayered as individual flows or composite mafic and felsic units (Plate 9). Epiclastic sedimentary rocks are less extensively developed. Hornfels of Long Harbour Group protolith is extensively developed in the aureole of the Belleoram Granite. A narrow zone of hornfels is developed in Belle Bay Formation rhyolite along the southern margin of the Ackley Granite suite; local development of andalusite has been described within this aureole (Dickson, 1982). Along much of its northwestern margin, the Belle Bay Formation is faulted against the Youngs Cove Group (Williams, 1971; Greene and O'Driscoll, 1976). Rhyolite and ash-flow tuffs of the Belle Bay Formation have pronounced alkaline to mildly peralkaline chemical affinities (S.J. O'Brien, unpublished data).

Andersons Cove and Mooring Cove Formations

The two intermediate formations of the Long Harbour Group are well exposed in the easternmost part of this region. The fine-grained, siliciclastic Andersons Cove Formation, which outcrops extensively east and northeast of Long Harbour, does not occur west of Mal Bay. In the type area between Long Harbour and Mal Bay, rhyolitic flows of the Belle Bay Formation are conformably overlain by a thin unit consisting of red and purple sandstone and green mafic agglomerate; these represent the basal beds of the Andersons Cove Formation (Williams, 1971). These rocks pass directly upward into at least 350 m of fine-grained, grey and green sandstones, siltstones and shale. These are thin to medium bedded and have irregular, wavy bedforms (Williams, 1971). Basalt at the base of the Mooring Cove Formation overlies the Andersons Cove Formation conformably and is, in turn, overlain by a mixed succession of rhyolites and variegated coarse- to fine-grained, epiclastic rocks (Williams, 1971). Where the Andersons Cove Formation is missing, either basalts, rhyolites or volcanogenic sandstones of the Mooring

Plate 9. *Banded rhyolite of the Belle Bay Formation, Long Harbour Group, Long Harbour.*

Cove Formation lie directly and disconformably on the Belle Bay Formation (Williams, 1971; Figure 4). The absence of the Andersons Cove Formation suggests the presence of a regional disconformity at this contact (Williams, *ibid.*).

Rencontre Formation

The Rencontre Formation conformably overlies the Mooring Cove Formation in several localities east and west of Mal Bay (Williams, 1971). East of Long Harbour, however, Williams (*ibid.*) has mapped the Rencontre Formation to directly overlie the Belle Bay Formation, with no angular discordance at the contact. The Rencontre Formation is well exposed on Brunette Island (Greene, 1975; Smith, 1984), where more than 1000 m of variegated siliciclastic rocks overlie silicic and mafic rocks of either Belle Bay or Mooring Cove affiliation.

Pronounced north-to-south facies variations occur in the lower part of the Rencontre Formation in this region (cf., Greene, 1975 and Williams, 1971; see also, Smith and Hiscott, 1984). A succession of green, grey and red sandstones and siltstones overlies black argillites that lie directly upon the Long Harbour Group basalts on Brunette Island (Greene, 1975). A thinner sequence of similar rocks also occurs within the Rencontre Formation along the north shore of Fortune Bay but there, it overlies several hundred metres of red conglomerate and coarse-grained sandstone. These lie conformably upon the Mooring Cove Formation (Williams, 1971; Smith, 1984). In both cases, the basal contact of the Rencontre Formation is sharp, and no interdigitation of clastic and volcanic rocks is observed. The upper part of the Rencontre Formation is similar in both areas, where coarse-grained sandstones and granular conglomerate are overlain by quartz-rich sandstone and red siltstone that in turn pass conformably into the overlying Chapel Island Formation.

GEOLOGY OF THE CAMBRIAN ROCKS

INTRODUCTION

Shales and associated fine-grained siliciclastic rocks, here assigned to the Youngs Cove Group (cf., White, 1939), conformably overlie the Long Harbour Group. The Youngs Cove Group comprises four lithostratigraphically and biostratigraphically distinctive divisions, which in order of increasing stratigraphic position, are the (uppermost Neoproterozoic to Lower Cambrian) Chapel Island Formation, the (Lower Cambrian) Random Formation, the (lower Middle Cambrian) Chamberlains Brook Formation and the (Upper Cambrian) Salmonier Cove Formation. Structural complexities preclude accurate thickness estimates for the entire succession but at least 1000 m of Youngs Cove strata are preserved in northern Fortune Bay.

As is the case elsewhere in Fortune Bay, the Chapel Island Formation contains both latest Neoproterozoic and earliest Cambrian rocks (e.g., Myrow, 1987; Narbonne *et al.*, 1987). Its Neoproterozoic rocks conformably overlie the Rencontre Formation of the Long Harbour Group. The top of the Youngs Cove Group is unexposed. An angular unconformity separates Youngs Cove strata from upper Devonian strata of the Great Bay de l'Eau Formation. Cambrian rocks have been intruded by the Belleoram Granite, the Old Womans Stock and the Ackley Granite suite, and have been thermally metamorphosed in the aureoles of these plutons. In most areas, however, the external contacts of various Cambrian rocks are faults.

Youngs Cove Group

Latest Neoproterozoic–Early Cambrian Rocks

The latest Neoproterozoic–Early Cambrian Chapel Island Formation transitionally overlies shallow-marine siliciclastic facies rocks at the top of the Rencontre Formation (Long Harbour Group) on Brunette Island (Greene, 1975; Smith and Hiscott, 1984). The same contact is also exposed on the northern end of Chapel Island, where it is likewise gradational and conformable (Williams, 1971). In its type section at Chapel Island, the formation is about 600 m thick. Approximately 300 m of the lower part of the formation are exposed on Brunette Island, whereas about 200 m of its upper part outcrop on Sagona Island (Greene, 1975). Elsewhere in Fortune Bay, thicknesses up to 1000 m for the Chapel Island Formation have been reported (Myrow, 1987).

In northern Fortune Bay, the Chapel Island Formation includes, at or near the base, red argillite and pink quartz-rich sandstone succeeded by grey and black shale. These are overlain by thin- to medium-bedded graded and rippled sandstone and siltstone, which are locally capped by red and green siltstone (Greene, 1975; Myrow, 1987). Grey limestone lenses occur within the Chapel Island section on Brunette Island (Greene, 1975).

Earliest Cambrian trace fossils are commonplace within Chapel Island Formation strata beneath the Random Formation on Sagona Island as well as on the western tip of the nearby Burin Peninsula (Crimes and Anderson, 1985; Myrow, 1987; Narbonne *et al.*, 1987). The section on Chapel Island includes parts of members 1 and 2 of the Chapel Island Formation as defined by Myrow (1987) and thus should include the Proterozoic–Paleozoic boundary (cf. Narbonne *et al.*, 1987).

The overlying Random Formation (Blue Pinion Formation and part of the Sagona Island Formation of Widmer, 1950) is well exposed on Sagona Island; it also outcrops below the sub-Devonian unconformity at Blue Pinion Cove and in small fault-bounded inliers in the vicinity of Boxey Point (Figure 2). In each case, thin quartzite and interbedded grey sandstone of the basal Random Formation overlie the Chapel Island Formation conformably and transitionally (Greene, 1975).

Within the Random Formation, the thin, basal unit of white to grey orthoquartzite and interbedded red and green sandstone passes up into a middle unit of thick-bedded, red micaceous sandstones. These are in turn overlain by thick-bedded and trough- to planar-crossbedded, mature white quartzarenite and white-weathering quartz-rich sandstones. The redbed succession is most extensively developed on Sagona Island, where it is between 190 and 210 m thick (Greene *in* Butler and Greene, 1976; Hiscott, 1982); 12 m of this facies are exposed at Blue Pinion Cove. The upper quartzite unit attains thicknesses of 38 m on Sagona Island and 196 m at Blue Pinion Cove (Greene, *ibid.*). On Sagona Island, the upper quartzite contains a 10-m-thick unit of red and green micaceous sandstone.

The age of the Random Formation, long the subject of debate (see Anderson, 1981 and references therein), is generally fixed as Early Cambrian (Tommotian, Anderson, 1981; Bengston and Fletcher, 1983). Sandstone beds containing inarticulate brachiopods on Sagona Island, formerly placed in the Random Formation (Butler and Greene, 1976), are now considered to be part of the overlying Chamberlains Brook Formation.

Middle Cambrian Rocks

The early Middle Cambrian rocks that are here assigned to the Chamberlains Brook Formation disconformably overlie the Random Formation at Blue Pinion Cove, Sagona Island and St. John's Island; the formation also occurs in fault-bounded blocks at St. John's Head. The Middle Cambrian succession is composed chiefly of thin- to medium-bedded, dark-grey micaceous quartzites and slates, and black shales containing grey limestone nodules. Red and green shale and sandstone are present at the base of the formation at Blue Pinion Cove and St. John's Head. At least 60 m of Chamberlains Brook Formation are preserved on Sagona Island.

Early Middle Cambrian grey shales containing *Paradoxides lamellatus* fauna (see Appendix 1) disconformably overlie the uppermost strata of the Random Formation on Sagona Island and St. John's Island (Hutchinson, 1962; Greene, 1975). In the sub-Devonian basement at Blue Pinion Cove, a similar disconformity occurs at the base of the Middle Cambrian succession, which in that locality, contains *Paradoxides eteminicus* Matthew (Hutchinson, 1962). There, the disconformity is marked by 1 to 1.5 m of pebble conglomerate and glauconitic sandstone developed above the uppermost Random quartzite bed. The surface of the disconformity, locally marked by phosphatic nodules, has less than 1 m of relief.

In addition to *Paradoxides lamellatus,* Hutchinson (1962) has also reported the presence of *Paradoxides bennetti* Salter, *Bailiella ornata* Resser, *Liostracus ouangondianus* (Hartt) and *Liostracus tener* (Hartt) within the Chamberlains Brook Formation in this part of northern Fortune Bay.

Upper Cambrian Rocks

Exposures of Upper Cambrian strata are known to occur in only three areas around Fortune Bay; all are situated along the shore of Great Bay de l'Eau and in each case, the fossiliferous strata are either unconformably overlain by, faulted with, or intruded by rocks of Devonian or assumed Devonian age (Plate 10). These Upper Cambrian beds, named Salmonier Cove Formation by Widmer (1950), are mainly black pyritiferous shales and grey micaceous sandstone and argillite. These rocks contain *Agnostis pisiformis, Olenus* and *Peltura* zone fauna, as well as inarticulate brachiopods (Widmer, 1950; Hutchinson, 1962; Greene, 1975). The bottom of the Upper Cambrian succession is not exposed. The lack of fossiliferous upper Middle Cambrian strata (post-*bennetti)* in the Fortune Bay area, could reflect the presence of a disconformity at the base of the Upper Cambrian. A maximum thickness of approximately 60 m of this formation has been preserved in this region (Hutchinson, 1962).

GEOLOGY OF THE MID-PALEOZOIC ROCKS

Extensive outliers of terrestrial sedimentary rocks of known or suspected mid-Paleozoic age are preserved on the southeastern Connaigre Peninsula (Figure 2). These rocks, assigned to the Cinq Isles, Pools Cove and Great Bay de l'Eau formations, form a 1500-m-thick-cover sequence that has been deposited on the Neoproterozoic to lower Paleozoic basement described above. Unconformable contacts between the mid-Paleozoic strata and the Simmons Brook intrusive suite, the Long Harbour Group and the Youngs Cove Group are preserved locally; elsewhere original basement-cover relationships are either unexposed or structurally reactivated.

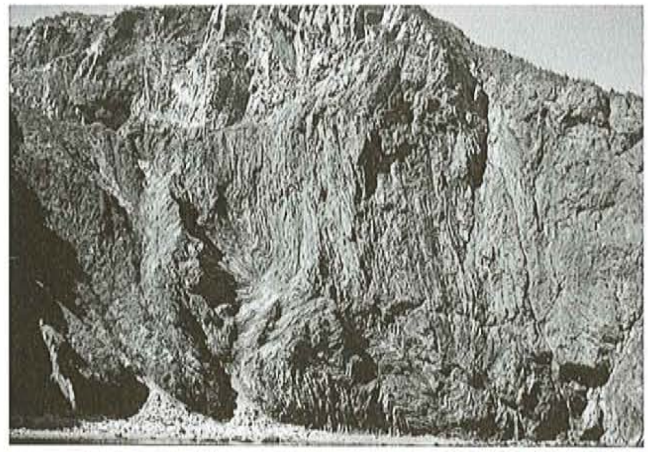

Plate 10. *Dyke of Belleoram Granite intruded into Upper Cambrian rocks, St. John's Head, Great Bay de l'Eau (height of cliff is approximately 100 m).*

The mid-Paleozoic cover and its basement have been intruded by a variety of felsic magmatic rocks. These comprise four separate high level plutons: Pass Island Granite, Old Womans Stock, Ackley Granite suite and Belleoram Granite; all but the last pluton consist almost entirely of homogeneous biotite granite. The mid-Paleozoic country rocks locally contain clasts that resemble at least some of these granites, a possible indication that plutonism was continuous throughout the period of formation of the Devonian basins (cf. Williams, 1971).

STRATIFIED ROCKS

The mid-Paleozoic stratified succession has been divided into three regional lithostratigraphic components. Fossils have been found only in the Great Bay de l'Eau Formation, which contains Upper Devonian flora (Widmer, 1950). The Pools Cove Formation (White, 1939) has been interpreted as the lithostratigraphic facies equivalent of the Great Bay de l'Eau Formation; both lie disconformably above the Cinq Isles Formation (Williams, 1971; Greene, 1975) without angular discordance. Neither the top of the Pools Cove Formation nor the top of the Great Bay de l'Eau Formation has been identified. All three formations are intruded by Devonian or younger granites.

Cinq Isles Formation

The Devonian or earlier(?) Cinq Isles Formation consists of more than 360 m of red micaceous sandstone, quartz-pebble conglomerate, red shale, and fine-grained, unfossiliferous red and grey limestone (Williams, 1971;

Calcutt, 1973; Greene, 1975). The carbonate rocks, which are diagnostic of this unit, occur as massive beds, up to 12 m thick, and as thin, hardpan-like layers (Chandler, 1982). The base of the Cinq Isles Formation is defined by either boulder conglomerate or, as is the case at its nonconformable contact with the Simmons Brook intrusive suite, by arkosic granite wash (Williams, 1971).

Pools Cove Formation

The Pools Cove Formation consists of three regionally mappable units (Williams, 1971; Greene, 1975) having a cumulative thickness that varies from 800 m (in the southwest) to 1500 m (in the northeast). A sequence of red, coarse-grained boulder conglomerates occurs at the base of the formation (Plate 11). These are rich in rounded clasts of various plutonic rock types that have been eroded from the 620 and 580 Ma intrusive suites. Large rounded clasts of Cinq Isles limestone are also present. These conglomerates rest nonconformably upon the Simmons Brook intrusive suite (Williams, 1971) and disconformably upon the Cinq Isles Formation (Greene and O'Driscoll, 1976). The basal conglomerate member passes upward into thick- to very-thick-bedded units of buff to orange arkosic sandstone and conglomerate.

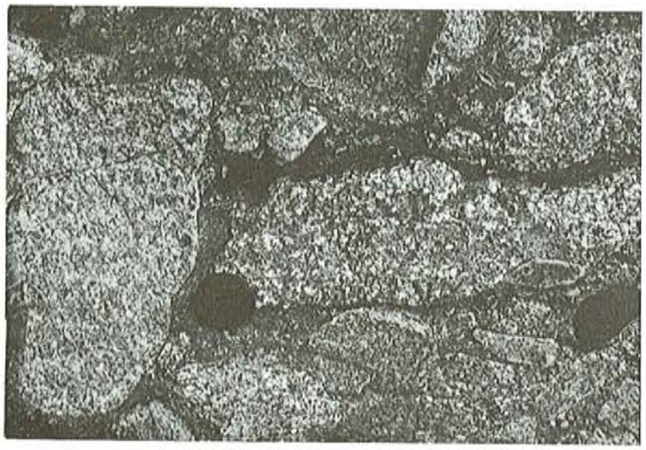

Plate 11. *Coarse-grained boulder conglomerate of the Pools Cove Formation containing clasts of Harbour Breton Granite, near White Horse Fault, east shore of Northeast Arm.*

The most extensive member also forms the uppermost portion of the formation, and consists of boulder conglomerate interlayered with arkosic sandstone. The conglomerates include detritus eroded from various underlying Proterozoic, Cambrian and Devonian(?) units, as well as boulders of banded gneiss, amphibolite, megacrystic granite and muscovite granite. The distinctive nature of the latter detrital assemblage—typical of the southeastern crystalline margin of the Appalachian mobile belt—implies that the source area for the Pools Cove Formation includes mid-crustal rocks that are now exposed west of the Hermitage Fault.

Great Bay de l'Eau Formation

The Great Bay de l'Eau Formation (Widmer, 1950) consists of approximately 300 m of red to buff, pebble to boulder conglomerate and lesser amounts of green conglomerate and red and black shales (Williams, 1971; Greene, 1975). The coarse-grained rocks are poorly bedded, variably indurated and gently dipping to subhorizontal. Basaltic flows, interbedded with red arkosic sandstone and conglomerate, overlie conglomerate at or near the top of the formation at Boxey Point (Boxey Point Basalt of Greene, 1977; Smith, 1976). A wide thermal aureole is developed in the Great Bay de l'Eau rocks adjacent to the Belleoram Granite, where, garnet and biotite are locally developed in the matrix of the conglomerates (Furey, 1985). The detrital assemblage of the Great Bay de l'Eau Formation, in any one area, closely reflects the nature of the local sub-Devonian basement (Plate 12). Additional detritus includes a variety of granitoid rocks, most of which are exposed locally. A notable exception is the presence of clasts of muscovite granite, presumably derived from an area west of the Hermitage Bay Fault.

Plate 12. *Quartzite clasts derived from underlying Random Formation in basal conglomerate of the Great Bay de l'Eau Formation, Blue Pinion Cove.*

An angular unconformity separates the Great Bay de l'Eau Formation from the underlying Youngs Cove, Random and Rencontre formations. The basal relationship with the Cinq Isles Formation, exposed along the west shore on Great Bay de l'Eau, is a disconformity (Calcutt, 1973; Greene, 1975).

Black bituminous shale and grey siltstone of the Great Bay de l'Eau Formation exposed near Coomb's Cove contain the Upper Devonian flora *Protolepidodendron* sp. and *Eospermatopteris* sp. (Widmer, 1950). Remains of unidentified plant species are also present in red shales farther east, along the eastern shore of Boxey Point (Greene, 1975).

PLUTONIC ROCKS

Ackley Granite Suite

The large area of granite exposed to the east of the East Bay Fault and north of the Long Harbour Group constitutes the southwestern lobe of the ca. 3000 km^2 Ackley Granite suite (Dickson, 1982, 1983). In much of this area, the suite consists of mostly homogeneous, pink, massive, biotite granite. It is medium to coarse grained, leucocratic and varies texturally from mostly K-feldspar porphyritic in the north to equigranular in the south (Williams, 1971; Dickson, 1988). Miarolitic and alaskitic granite, together with microgranite and aplite are widespread along its southern margin with the Long Harbour Group, where they host important molybdenite mineralization (White, 1939 and later authors; see below). Locally, coarse-grained granite porphyry and pegmatite are developed at or near the contact; the latter also contains molybdenite. Unlike other Devonian granites in the region, the Ackley Granite suite is virtually devoid of mafic dykes.

Granite of this suite intrudes the Long Harbour and Youngs Cove groups; its emplacement occurred after regional deformation of the stratified rocks. The Ackley Granite suite does not come in contact with fossiliferous upper Devonian strata, and its age relative to these strata remains unclear. An unconformable relationship, as inferred by Williams (1971), cannot be discounted.

Pass Island Granite

The Pass Island Granite (Strong *et al.*, 1974), first mapped by Widmer (1950) and later extended by O'Driscoll (1977), lies at the southwestern tip of the peninsula between Hermitage and Connaigre bays, where it has been emplaced into the late Neoproterozoic Grole intrusive suite. Most of the Pass Island Granite is a homogeneous (on a regional scale) orange and pink, medium- and coarse-grained equigranular rock, containing hornblende and biotite. The granite is locally inhomogeneous, with diffusely bounded fine-grained variants containing hornblende schleiren. K-feldspar-bearing porphyritic to sub-porhyritic variants are also locally developed. Intrusive breccia and faint syn-magmatic fabrics are preserved in the fine-grained margin of the granite near Pass Island (O'Driscoll, 1977). The granite locally hosts a large number of rectilinear diabase and felsite dykes, which appear to be unrelated to Pass Island magmatism.

Old Womans Stock

Much of the area between Old Bay and Salmonier Pond is underlain by an elliptical body of granite that has intruded Neoproterozoic, Cambrian and Devonian rocks. Widmer (1946) named these rocks "Old Woman's Cove Stock", and assigned them to the Ackley Granite (cf. Widmer, 1950). This pluton was later included in the Harbour Breton Granite by Greene and O'Driscoll (1976), who modified the name to "Old Womans Stock". This name was again modified (to Old Woman Stock) by Furey and Strong (1986), who viewed it as one of two component plutons of their Harbour Breton Complex. For reasons outlined above, however, (see: Harbour Breton Granite) this pluton is here interpreted to be a significantly younger intrusion, separate from the Harbour Breton Granite.

In the northernmost exposure area of the Old Womans Stock, narrow granite veinlets emanating from the pluton are intrusive into the Pools Cove Formation, which in that area is represented by arkosic granite wash and conglomerate rich in granitic detritus. In Old Bay, the granite is intrusive into the Cinq Isles Formation (Plate 13). Furey and Strong (1986) have subdivided the pluton into a number of phases. It consists of a central core of homogeneous plagiophyric granite, locally cut by K-feldspar porphyritic granite and microgranite. Much of the remainder of the pluton consists of fine- to medium-grained, hornblende–biotite granite and alaskite. A narrow unit of orange to red microgranite and aplite is developed along its eastern margin, where extensive hydrothermal alteration and associated granophile mineralization occurs.

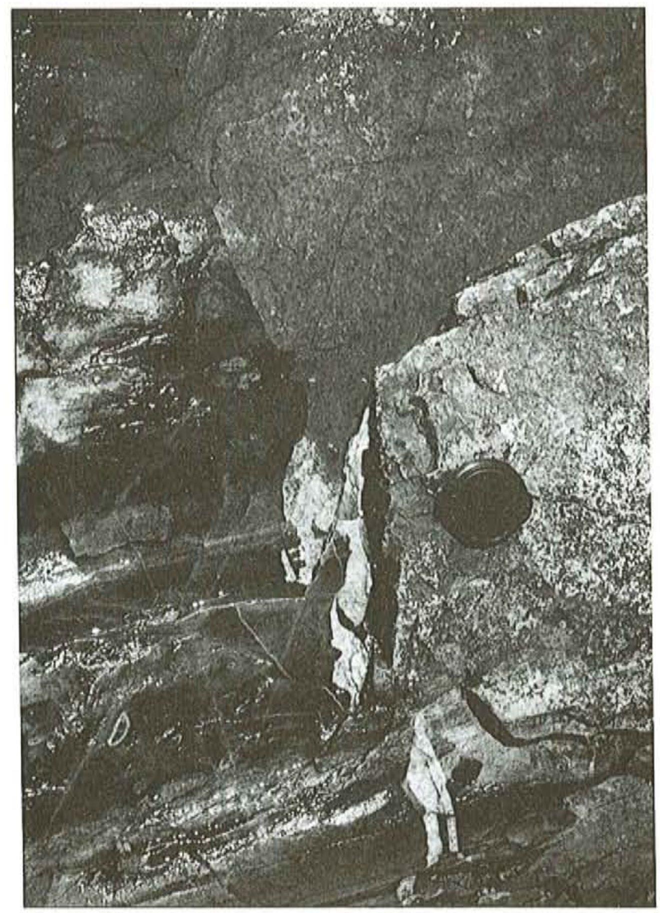

Plate 13. *Intrusive contact between the Old Womans Stock and the Cinq Isles Formation, Old Bay.*

Belleoram Granite

The circular body of granite and adamellite that has intruded the Long Harbour and Youngs Cove groups and their Devonian cover in the southeastern Connaigre Peninsula is known by various names: e.g., Belleoram Granite (Widmer, 1950); Belleoram Stock (Williams, 1971); Belleoram pluton (Furey, 1985). This intrusion is, in part, atypical of Devonian plutons elsewhere in this region. Widmer's (1950) original usage is retained here to denote these rocks; his Carboniferous age designation remains unproven.

Two major rock units comprise most of the Belleoram Granite. These are equigranular grey to pink, quartz monzonite to granodiorite and red, feldsparphyric microgranite. A number of subdivisions for the pluton has been proposed by Furey (1985; see also Furey and Strong, 1986). A distinctive feature of the intrusion is the widespread occurrence of mafic magmatic enclaves and country rock xenoliths; the latter are of widely variable dimension and rock type. The xenoliths are restricted mostly to the pluton margins, whereas, the enclaves are developed throughout the intrusion (Ermanovics *et al.*, 1967; Furey, 1985). Dykes of quartz-feldspar porphyry, as well as diabase and bimodal rhyolite–basalt dykes, are emplaced into country rocks adjacent to the Belloram Granite; the largest of these are mapped as emanating from the main intrusion (B. Greene, unpublished data).

MINERALIZATION

HISTORY OF MINERAL EXPLORATION

The region contains many mineral showings, some of which have been the target of mineral exploration programs. At present, exploration for volcanic-hosted sulphide deposits on the Connaigre Peninsula is ongoing.

The earliest exploration for mineral deposits in the area focussed on the molybdenite occurrences near Rencontre East. A molybdenite discovery was recorded in the vicinity of Rencontre Lake in 1882 (Smith, 1936; Whalen, 1976) and this and other prospects were examined at various times during the early 1900s. In 1934, the Rencontre East deposit was examined by C.K. Howse of the Department of Natural Resources (Quinn, 1944) and the first comprehensive exploratory program was conducted by Dana and Company Incorporated between 1935 and 1937 (Smith, 1936; Whalen, 1976); this resulted in the identification of four areas with possibilities for economic development. These were the Motu, Rencontre (now called Ackley City) Crow Cliff and Wylie Hill deposits (Quinn, 1944). Development work included trenching, drifting, crosscutting and shaft sinking on the Rencontre deposit and trenching on the other deposits. The area was surveyed by D.E. White in 1937 and the mineral deposits were studied in extensive detail (White, 1939, 1940).

In 1943-44, the Government of Newfoundland commenced a diamond-drilling program on the Ackley City (Rencontre) prospect in an attempt to establish a larger tonnage of molybdenite in the Rencontre East area (Quinn, 1944). Six holes totalling 226.4 m were drilled but failed to add to the previously proven ore reserves. The property was initially considered for production by the Canadian government during World War II, but its location and low proven reserves, together with subsequent availability of molybdenite from other sources ended plans for further development.

In 1953, NALCO acquired the properties as a mineral concession from the Government of Newfoundland and Labrador. Caledon Mineral Company Limited received an option on the property in 1958 and completed nineteen short holes in 1959. These included eleven holes at Wylie Hill, three at Ackley City and five at Motu. Also an induced potential, resistivity, and biogeochemical survey was completed at Wylie Hill. A resistivity survey and metallurgical tests were made at Ackley City (Whalen, 1976).

In 1968, Canadian Javelin acquired an interest in the property and granted an option to Norlex Mines Limited. A diamond-drilling program was completed in 1969. Eleven holes totalling 1221.5 m were drilled at Ackley City and fourteen holes totalling 1434.9 m were drilled at Wylie Hill. No further work was done on the properties and NALCO dropped their claim in 1975.

Work was done by Whalen (1976, 1980) on the molybdenite deposits of the Rencontre East area as part of an M.Sc. program at Memorial University of Newfoundland. The geology, geochemistry and mineral potential of the Ackley granite, including studies of greisen-hosted lithophile mineralization along it southern contact, was also the subject of several studies undertaken or sponsored by the Government of Newfoundland and Labrador (Dickson *et al.*, 1980; Dickson, 1982; Dickson and Howse, 1982; Dickson, 1983; Tuach *et al.*, 1986).

Two volcanogenic sulphide deposits occur in stratified rocks on the Connaigre Peninsula: Frenchman Head and Winter Hill. The Frenchman Head prospect was discovered during the mid-1950s by NALCO geologists while carrying out reconnaissance work on part of their extensive concession in eastern Newfoundland (McKenzie, 1984). During the early 1960s, geochemical and geophysical anomalies were discovered, and this led to an extensive stripping and trenching program. In 1964 and 1965, Pickands Mather and Company (1965), on behalf of NALCO, drilled 19 holes having an aggregate length of 1226.4 m. Their best intersection was 18.6 m of 2.2 percent Zn, including 2 m of 7.46 percent Zn.

In 1982 and 1983, Noranda staked the Frenchman Head prospect and surrounding area. Geophysical and geochemical work were done in the area, and a drillhole in 1986 at Frenchman Head tested coincident geophysical and soil geochemical anomalies along strike from the original showing. The best values were 8 m of 2.26 percent Zn, which included 2 m of 6.49 percent Zn (Graves, 1986). The property was dropped by Noranda in the early 1990s and restaked by Vinland Resources shortly afterwards. Cominco carried out geophysical and geochemical investigations (Willett, 1989) in the areas northeast and southwest of Frenchman Head but eventually dropped the properties with no further work done. The area dropped by Cominco was also restaked by Vinland Resources. Work is currently ongoing in the area.

The Winter Hill prospect was discovered in late July 1984 by Noranda (Graves, 1985a) during follow-up work to an airborne survey flown the previous year. This survey was done to cover favourable geology along strike from the Frenchman Head prospect as well as lake-bottom geochemical anomalies located by the provincial Department of Mines and Energy (Butler and Davenport, 1978). Initial work included detailed mapping, trenching and prospecting. During this time, several new showings were located along strike to the northeast and southwest of the main showing.

Nine holes were drilled on the property in 1985 and 1986 for a total length of 1817.0 m (Graves, 1985b, 1986). A further six holes were drilled in 1990 totalling 1557.6 m (Simpson, 1990). Although it was found that the mineralized area contains numerous shallow-dipping felsic and mafic dykes, which in some cases, hampered drilling, results were encouraging. The best intersection encountered was 11.0 m of 6.17 percent Zn including 4.0 m of 10.1 percent Zn. In 1991 further drilling and geophysical work were carried out to test a strong geophysical anomaly and also for increased mineralization down dip and along strike (Perry and Graves, 1991). Three holes were drilled for a total of 606.2 m. The results were disappointing and no further work was recommended at that time. Noranda reduced its property to 18 claims in October 1991 and still hold the mineral rights under Extended Licence 2474.

Other significant activity on the Connaigre Peninsula includes work involving dimension stone. Granite was quarried at Old Bay between 1910 and 1914. The quarry is approximately 5 m high, 12 m long and 27 m wide and was worked by two stiff-leg derricks (Widmer, 1950). It was connected to a 20-m granite pier in Old Bay by a narrow-gauge railroad. It is not known how much granite was shipped from the site. Another small quarry was developed in similar granite near the eastern end of Harbour Breton. This was used as foundation stone in local buildings (Widmer, 1950).

Recent development work has been done in granite on the Hermitage Peninsula near Seal Cove. A trial quarry was opened in 1990 by Mr. J. Kealey of Mount Peyton Granite Company and twenty-seven blocks of granite were removed. In 1992, Classic Stone Incorporated was formed to pursue the establishment of a granite processing plant in Buchans. In 1993, the company opened a second quarry near Seal Cove and started commercial production (Meyer and Howse, 1994). In the fall of 1994, Classic Stone and Kenney's Marble Works joined forces to form North Atlantic Stone Incorporated and to set up a dimension-stone fabrication plant at Buchans. This plant will focus on producing granite monuments and other granite products for commercial and domestic use (Murphy, 1994). They will use granite quarried at Seal Cove as well as a number of other sites in central Newfoundland.

MINERAL OCCURRENCES IN PROTEROZOIC ROCKS

In addition to the Winter Hill and Frenchman Head prospects, Neoproterozoic stratified rocks host a number of smaller, base-metal-poor massive pyrite occurrences (Figure 5; Sears, 1990). In most cases, mineralization occurs within a limited stratigraphic interval located either at or near the top of the Tickle Point Formation. Although the absolute age of the mineralization has not been determined, the similarity of lead isotope ratios in the Winter Hill and Frenchman Head showings indicate that these deposits, at least, formed during the same mineralizing event (S. Swinden, unpublished data) and that lead, in both cases, is derived from the same source.

At Winter Hill (Figure 5), disseminated to massive and banded, sphalerite, galena, pyrite, pyrrhotite and chalcopyrite stratabound mineralization occurs in calcareous chemical sediments and calc-silicate rocks that overlie a copper-rich (chalcopyrite, pyrite, pyrrhotite) alteration zone in felsic volcanic breccias (Simpson, 1990). The carbonate–calc-silicate layer, which is up to 30 m thick in places, extends discontinuously along strike for approximately 3.5 km, and is everywhere mineralized (Simpson, 1990). The most notable drill intersection from the area contains 6.17 percent Zn over a width of 11 m, including a 4-m-wide zone of 10.1 percent Zn (Simpson, 1990).

Correlative Ca-Mg-carbonate–silicate rocks have been mapped in several areas around the western Connaigre Peninsula, and in all cases they are either mineralized or spatially associated with mineralized rocks. Perhaps the most important of these is situated in the vicinity of Frenchman Cove, where carbonate–calc-silicate rocks, containing thin, pyrite-rich bands, lie along the strike of an extensive rhyolite-hosted alteration zone, containing massive pyrite and pyrite–sphalerite stringer-type mineralization (A. Chislett, personal communication, 1993; O'Brien and O'Driscoll, 1993; Figure 5). This alteration zone lies approximately 1 km west of the well-known Frenchman Head prospect (Sears and O'Driscoll, 1989). The latter showing consists of disseminated pyrite, sphalerite, chalcopyrite and galena mineralization in silicified rhyolites of the Tickle Point Formation near the contact with the overlying Connaigre Bay Group. Drill intersections of 18.6 m of 2.2 percent Zn (including 2 m of 7.46 percent Zn) and 8 m of 2.26 percent Zn (including 2 m of 6.49 percent Zn) from the Frenchman Head prospect have been reported by Pickands Mather and Company (1965) and Noranda Exploration Company Limited (Graves, 1986), respectively.

Smaller occurrences of carbonate and/or calc-silicate rocks occur along the coast of Hermitage Bay, northeast of Hardy's Cove and on the west shore of Northeast Arm at Harvey Hill (Figure 5). In the first case, pyrite-rich limestone–dolostone breccia occurs in tectonic contact with Neoproterozoic Hardy's Cove intrusive suite. At Harvey Hill, white calc-silicate-like rocks are spatially associated with at least two massive pyrite bands in rhyolite. These rocks lie along strike from two other massive pyrite occurrences that are situated to the north and northeast of the head of Northeast Arm, within rhyolite of the Tickle Point Formation.

Late Neoproterozoic rocks of the Connaigre Bay Group host several small copper sulphide occurrences. These have been found mainly in mafic volcanic rocks of the Doughball Point Formation, where mineralization occurs either in calcite–epidote veins, as disseminations in flows and agglomerates, or along fracture or shear planes (Greene and O'Driscoll, 1976). Mafic flows and overlying clastic

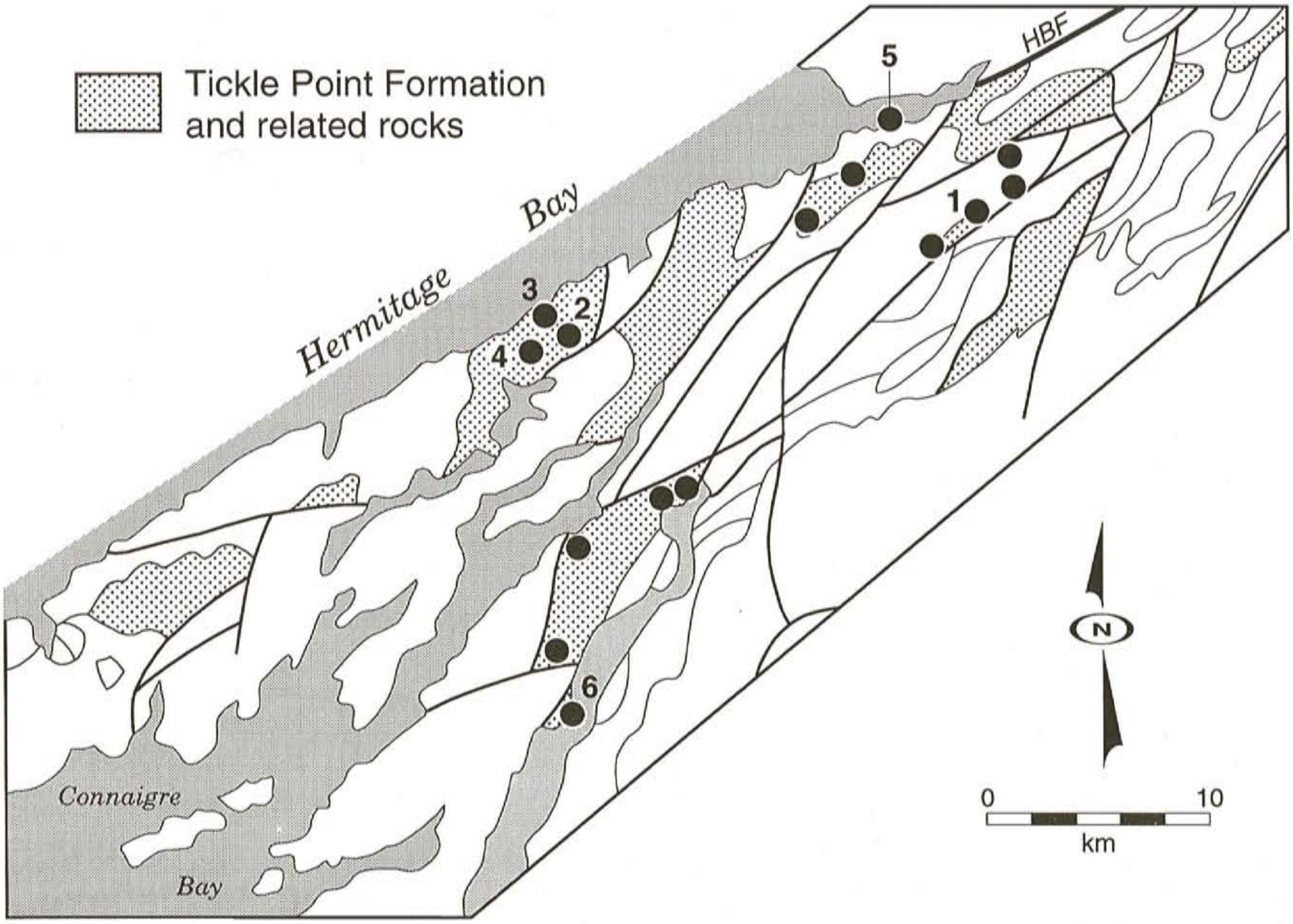

Figure 5. *Location of principal massive sulphide occurrences (solid circles) in the western Connaigre Peninsula, showing the distribution of the Tickle Point Formation and related rocks. 1 = Winter Hill; 2 = Frenchman Head; 3 = Frenchman Cove; 4 and 5 = mineralized carbonate–calc-silicate occurrences; 6 = Harvey Hill.*

sedimentary rocks in the Connaigre Bay Group southwest of Winter Hill locally contain magnetite, which occurs, in the first case, as veins and disseminations, and in the second case, as a detrital phase forming laminae and thin lenses.

The youngest Neoproterozoic rocks in the region are known to contain only minor base-metal mineralization. Covellite, magnetite and hematite, together with fluorite, occur within quartz veins and along fractures in mafic and felsic volcanic rocks of the Long Harbour Group near the head of Great Bay de l'eau. Williams (1971) reported the presence of disseminated galena and chalcopyrite in mafic volcanic rocks of the Long Harbour Group west of Mal Bay. The northern exposures of the Rencontre Formation in the area between the Ackley Granite suite and the Hermitage Bay Fault, host locally extensive gossans that carry fine-grained disseminated pyrite (Dickson, 1988). Immediately east of this area, the uppermost alkaline to peralkaline volcanic rocks of the upper Long Harbour Group, and nearly subvolcanic granite of the same age, both contain showings and significantly elevated values of Zr, Nb and Y (S.J. O'Brien, unpublished data; Miller, 1991). A number of small occurrences of fluorite and barite are situated in the Belle Bay Formation rhyolites near the mouth of Long Harbour (Smith, 1953; Williams, 1971). Significant brecciation and an influx of silica are evident within the Hardy's Cove intrusive suite near the Hermitage Bay Fault and associated splays from it. Very localized pyrophyllitization occurs in rhyolite of the Tickle Point Formation at the contact with the Hardy's Cove intrusive suite. Minor molybdenite occurrences are hosted by microgranite at the margin of the Taylor Bay Hills pluton of the Harbour Breton Granite.

MINERAL OCCURRENCES IN PALEOZOIC ROCKS

Several small aplite and pegmatite-hosted molybdenite deposits occur within the marginal phase of the Ackley Granite suite at its contact with the Belle Bay Formation of the Long Harbour Group at, and near, Rencontre Lake (White, 1940; Whalen, 1976, 1980; Figure 4). The two largest of these deposits contain approximately 125 000 tons, grading 0.31 percent MoS_2 and 1 000 000 tons of 0.1 percent MoS_2 (Tuach *et al.*, 1986; also see Nolan, 1969, and above section

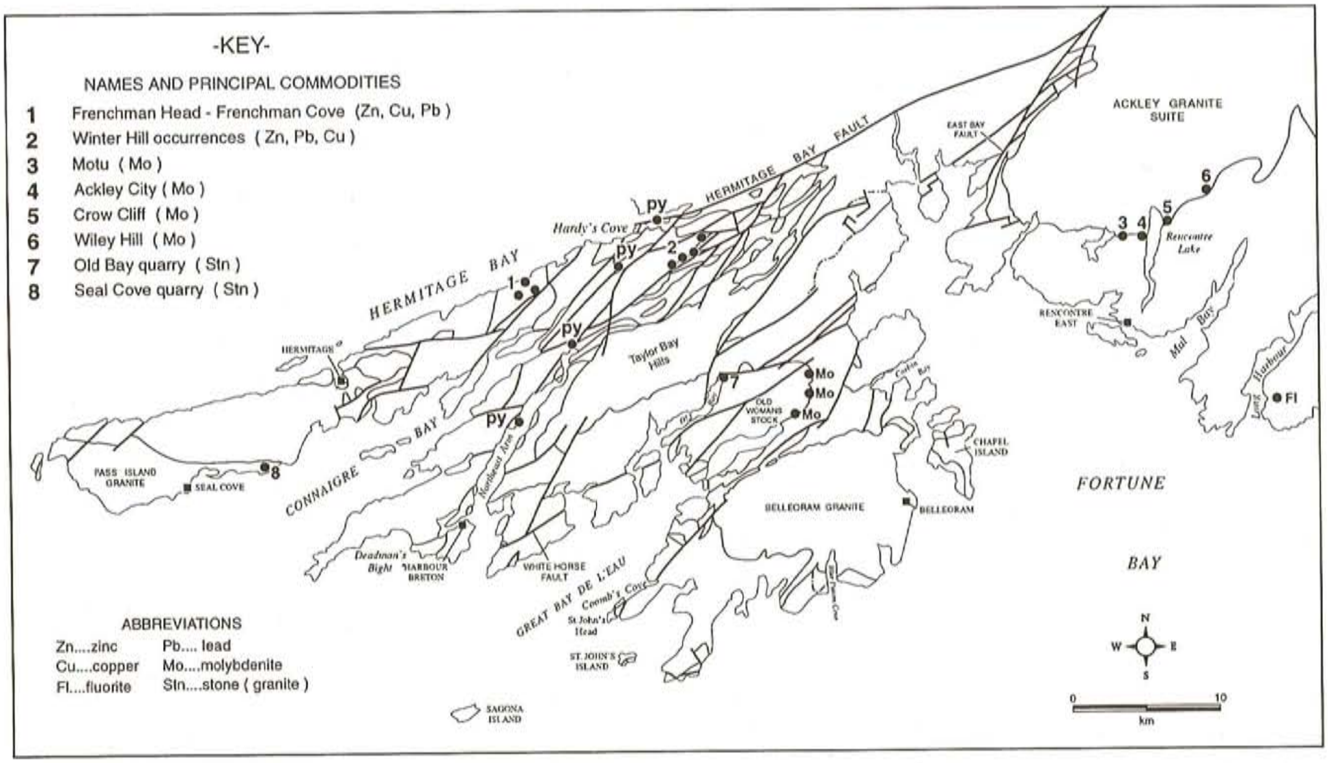

Figure 6. *Principal mineral occurrences in the study area (boundaries as in Figure 2).*

on History of Mineral Exploration). Molybdenite occurs as disseminations mainly in altered aplite (Ackley City and Wiley Hill deposits), in fine-grained alaskitic granite together with aplite (Wiley Hill showing) and in pegmatite (Crow Cliff and Motu showings; Figure 6). A summary of White's (1939, 1940) work is given in Williams (1971); the reader is also referred to Whalen (1976, 1980) and Dickson (1983) for additional accounts of this mineralization. Along the same contact, east of Long Harbour, the Ackley Granite suite hosts pods of pyritic greisens that locally contain molybdenite and wolframite (Dickson, 1983). Small molybdenite and tin occurrences are reported from several localities elsewhere in the southeastern lobe of the Ackley Granite suite (Dickson, 1983).

The Old Womans Stock contains several small occurrences of fluorite ± molybdenite ± bornite ± chalcopyrite in quartz veins, locally up to 10 cm wide, situated in hydrothermally altered zones along the margins of the intrusion (Widmer, 1950; Colman-Sadd *et al.*, 1979; Furey and Strong, 1986). Fluorite, galena and sphalerite have been described from the Belleoram Granite on Chapel Island (Furey, 1985). Minor fluorite also occurs in microgranite of the Belleoram Granite along its northwestern contact.

White to buff and pink, medum- to coarse-grained granite of the Devonian Pass Island Granite is presently being quarried near Seal Cove by Classic Stone Incorporated. A lithologically similar granite, part of the Old Womans Stock, had been quarried for use as building stone from a site at Old Bay in the early part of this century; operations there ceased in 1914 (Plate 14).

Plate 14. *Granite blocks in the abandoned building-stone quarry in the Old Womans Stock at Old Bay.*

The Paleozoic stratified rocks contain little known mineralization. Several areas of pyritiferous gossan are developed in the Chapel Island Formation and other associated strata of the Youngs Cove Group within the aureole of Devonian granites. Minor amounts of galena, sphalerite, chalcopyrite and fluorite occur in thin calcite veins within Devonian conglomerate of the Great Bay de l'eau Formation, north of Coomb's Cove, on the east shore of Great Bay de l'Eau (Greene, 1975).

DISCUSSION OF DEPOSITIONAL AND TECTONIC HISTORY

Between 685 and 670 Ma, arc-related felsic volcanic rocks and an associated arc-root plutonic complex of felsic and mafic composition (Tickle Point Formation and Furby's Cove intrusive suite) developed in what is assumed to be an overall compressional tectonic environment. Trace-element and rare-earth-element studies of these rocks (Sears, 1990) concur, in part, with earlier geochemical investigations (O'Driscoll and Strong, 1979) and confirm the calc-alkaline and transitional calc-alkaline to tholeiitic nature of these early volcanic rocks. Sears (*ibid.*) has argued for their arc origin within a collisional oceanic environment. The lithology and overall depositional character of the component lithofacies of the 680 Ma stratified sequence supports this model and is consistent with deposition in a marine environment.

A relatively late-stage extensional phase within the evolution of the 685 to 670 Ma basement is illustrated by widespread emplacement of diabase, felsite and granite dykes. These rocks form dyke complexes or swarms, primarily composed of rocks cogenetic with Furby's Cove intrusive suite; these have been intruded into both that suite and the Tickle Point Formation. Elements of the dyke swarm have shed detritus in basal conglomerate of the overlying Neoproterozoic cover succession. That the main dyke swarm borders and parallels the Hermitage Bay Fault is considered significant, and may indicate that the post-lower Devonian brittle structure is sited on a much older, tectonically weakened zone in the 685 to 670 Ma basement.

A unique feature of the 685 to 670 Ma basement is the presence of major ductile shear zones. The most extensive of these occurs within the Furby's Cove intrusive suite, where granite hosts a major steeply dipping zone of mylonite and protomylonite, several tens to hundreds of metres in width. Ductile fabrics are not developed along strike in the adjacent Connaigre Bay Group, and although the absolute age of ductile shearing has not been established, it likely predates deposition of that 630 to 620 Ma cover. Elsewhere, ductilely foliated to mylonitic rocks assigned to the basement are intruded by massive diorite and granodiorite of the 621 ± 3 Ma Simmons Brook intrusive suite. Although lower age limits for metamorphism and ductile deformation are unavailable, the geochronology and contact relationships, coupled with other regional considerations, are consistent with the high strain being related to the 685 to 670 Ma tectonism. Ductile shearing in this case, unlike that in the Furby's Cove intrusive suite, affects rocks of contrasting lithology. These shear zones, which have been disrupted by younger Neoproterozoic plutons, potentially represent relicts of an early juncture between discrete, pre-620 Ma tectonic entities. Like the aforementioned dyke swarm, these tectonically weakened zones may have had an important influence on subsequent Neoproterozoic and Paleozoic tectonic development.

Varied crustal levels of the 685 to 670 Ma basement were uplifted prior to the onset a second period of volcanism and marine sedimentation, which is recorded in the ca. 630 to 620 Ma Connaigre Bay Group. The unconformity between the Connaigre Bay Group and 685 to 670 Ma rocks establishes a unique stratigraphic linkage between the two tectonic events and precludes the possibility that the older rocks were structurally emplaced into the western Avalon Zone (for the first time) during Paleozoic tectonism. A similar linkage is provided by the coeval Simmons Brook intrusive suite, which crosscuts elements of the basement and the Connaigre Bay Group cover.

Plutonic rocks formed between 630 and 620 Ma display a continuum of compositions from granite to diorite and have strong calc-alkaline chemical affinities; both features are compatible with evolution in an arc setting. Coeval mafic volcanic rocks of this age are primarily island-arc tholeiites consistent with an arc-rift tectonic setting (Sears, 1990). Similar tectonic environments have been proposed for coeval rocks elsewhere in the western Avalon Zone (Knight and O'Brien, 1988). On the Connaigre Peninsula, such a setting is also supported, in a general way, by the presence and nature of associated marine siliciclastic rocks (Sam Head Formation). Finally, lutetium–hafnium isotopic signatures from plutons generated at this time argue for the presence of much more ancient continental crust in the source region of the magmas (O'Brien *et al.*, 1994; R.D. Tucker, unpublished data).

Locally, pre-600 Ma rocks have been inhomogeneously deformed prior to the onset of a complex tectono-magmatic event, or series of events, that began at approximately 580 Ma and continued until the end of the Proterozoic. On the Connaigre Peninsula, plutonic rocks formed in this later period locally crosscut tectonic fabrics in the earlier (ca. 620 Ma) plutons of the Simmons Brook intrusive suite. Elsewhere on the peninsula, plutonic rocks of this age (e.g., Grole intrusive suite) cut across the sub-Connaigre Bay unconformity, and intrude steeply dipping and weakly cleaved Connaigre Bay Group rocks. Locally, the 580 Ma plutonic rocks display evidence of synmagmatic deformation.

Volcanic rocks formed in this interval, viz., the Long Harbour Group, lie east of the East Bay Fault and are not in contact with older units. The youngest Long Harbour Group volcanism displays alkaline to mildly peralkaline affinities, in marked contrast with the chemical signatures of 620 Ma and older volcanism. The upper volcanic rocks of the Long Harbour Group lie immediately below redbeds of the Rencontre Formation that were deposited in pull-apart basins (cf. Smith and Hiscott, 1984). This association, coupled with the composition of the volcanic rocks, argues convincingly for their formation in an extensional tectonic regime, at least in the terminal Neoproterozoic (ca. 550 Ma onward). Coeval felsic magmas emplaced into the Long Harbour Group rocks east of this region share the alkaline to peralkaline chemical affinities of the younger statified rocks (O'Brien *et al.*, 1984). The relationship of 580 Ma magmatism as recorded on the Connaigre Peninsula to the onset of volcanism east of the East Bay Fault remains equivocal. Those plutons may represent, in part, the magmatic roots of the early Long Harbour Group volcanism.

The internal stratigraphic conformity that is exhibited on a regional scale by the Long Harbour Group suggests that much of the region east of the East Bay Fault had escaped significant deformation between ca. 570 and 550 Ma. A possible exception may be local block faulting and body rotation of Long Harbour units prior to deposition of the Mooring Cove Formation and again prior to that of the Rencontre Formation. This would allow for the locally disconformable nature of those formations' basal boundary in parts of this area and elsewhere around Fortune Bay.

In the latest Neoproterozoic, alluvial sedimentation in pull-apart basins (lower Rencontre Formation) gave way to near-shore and open-shelf marine siliciclastic deposition (Chapel Island Formation) in a tectonically stable region (Smith and Hiscott, 1984). In the Early Cambrian, the quartz arenite-dominated, transgressive Random Formation was deposited in a high energy, tidally dominant, nearshore environment, conformably above shoreline deposits of the upper Chapel Island Formation (Hiscott, 1982). A period of non-deposition followed, but this was not accompanied by significant tectonism. Subsequent to this, shales and minor siliciclastic and carbonate rocks accumulated in a quiescent platformal setting through the early Middle Cambrian, and again in the Late Cambrian.

At least two periods of post-Cambrian tectonism have affected the region, but precise controls on the timing of both are lacking. A profound angular unconformity (Plate 15) separates upper Devonian conglomerates from moderately dipping (at Blue Pinion Cove) to overturned (at St. John's Island) greenschist- to sub-greenschist-facies, middle Cambrian strata. This relationship, coupled with the paraconformity between Middle and Upper Cambrian rocks, indicates that Early Paleozoic strata were first deformed and metamorphosed (under greenschist conditions) sometime between the Late Cambrian and the Late Devonian. The regionally conformable nature of the Rencontre–Chapel Island–Youngs Cove succession further implies that major folds of Long Harbour strata in the eastern part of the region also formed in this time interval. Many of the major northeast-trending reverse faults on the Connaigre Peninsula were formed or signicantly reactivated by tectonism of this age.

The Devonian cover sequence typically displays little evidence of post-accumulation tectonism, other than that related to granite emplacement. Notable exceptions, however, occur along the basin margins, where earlier basement-cover relationships have been obliterated by normal faulting. The most notable of these faults form part of the White Horse–East Bay fault system, which locally juxtapose various late Neoprotoerozoic intrusions with the Pools Cove Formation (Plate 16). Zones of penetrative cleavage of Devonian or younger age are associated with this deformation, and are developed both in basement and cover rocks. The relationship and timing of late deformation along these structures affecting Devonian strata to displacements along the Hermitage Bay Fault are unclear. Unpublished geochronological data from the Hermitage Bay area indicates that the main brittle displacements along that fault are of post-Early Devonian age (G. Dunning, written communication, 1994).

Plate 15. *Angular unconformity between overlying Great Bay de l'Eau Formation (Upper Devonian) and underlying Cambrian Youngs Cove Group, Blue Pinion Cove (height of cliff is approximately 120 m).*

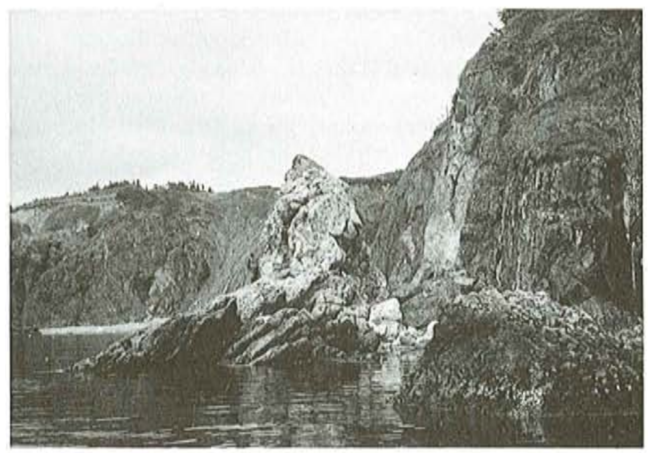

Plate 16. *White Horse Fault. Pools Cove Formation in foreground in fault contact with limestone of the Cinq Isles Formation (the White Horse), in turn, faulted with Connaigre Bay Group.*

The absolute time span of Devonian plutonic activity in this region is unresolved, and it is not clear if all magmas were emplaced subsequent to the accumulation of the Devonian cover succession. Some intrusions, such as the Belleoram Granite, clearly intrude upper Devonian rocks. In other cases, such as the Ackley Granite suite, contact relationships with fossiliferous upper Devonian rocks are not established, and their relative ages are unresolved. Williams' (1971) earlier report of clasts of the Ackley Granite suite in Devonian strata has not been refuted. This observation may be evidence that an early pulse of Devonian magmatism either accompanied or preceeded the opening of terrestrial Devonian basins, whereas Late Devonian (or younger) magmatism followed deposition, basin closure and mild deformation of the basin fill.

SOME REGIONAL IMPLICATIONS

Earlier concepts of the Neoproterozoic stratigraphic development of the Avalon Zone have envisaged widespread and essentially uninterrupted deposition of a regionally homogeneous tripartite succession of low-grade volcanic and marine to terrestrial siliciclastic rocks (e.g., Williams, 1979). Minor tilting and extensional block faulting related to the Avalonian Orogeny (Lilly, 1966; Rogers, 1967, 1972) were seen as the only tectonic events of regional significance to have affected these rocks prior to the deposition of an early Paleozoic platformal succession, widely viewed as the hallmark of the Avalonian cycle. The most profound tectonism of Avalonian rocks was viewed to be of post-Cambrian, pre-Late Devonian age, related to the assumed, initial accretion of the Avalon Zone to inboard Appalachian elements during early- to mid-Devonian Acadian orogenesis (e.g., Dallmeyer *et al.*, 1983).

The emergence of an extensive geological and precise geochronologic database across the Avalon Zone provides new insight into the stratigraphic and tectonic development of Avalonian rocks, highlighting the role of late Neoproterozoic tectonism. Data from the northern Fortune Bay region reveal a protracted and episodic late Proterozoic geological history, which is significantly more complex than previously envisaged anywhere within the Avalon Zone. A number of individual tectonic entities formed in a variety of contrasting tectonic environments, at widely differing times, over a period of more than 140 Ma. The earliest of these, a metallogenically important arc sequence, was intruded, deformed and uplifted together with its plutonic roots, and together with these magmatic rocks, served as depositional substrate to the first of two widely separate and unrelated periods of volcanism, marine sedimentation and coeval plutonism. Various Neoproterozoic elements were amalgamated, tectonized and thus variably dispersed, significantly earlier than the formation of the latest Neoproterozoic to Cambrian siliciclastic and shale-rich cover. Documentation of the absolute chronology and field relationships that illustrate this protracted geological history establishes conclusively the complex and composite nature of the Newfoundland Avalon Zone in the late Neoproterozoic.

This work further highlights both the uniqueness and economic significance of the Tickle Point Formation volcanic rocks, in general, and its carbonate and calc-silicate facies in particular. All of these rocks represent a highly prospective environment for volcanogenic massive sulphide mineralization within the Avalon Zone (cf. Sears, 1990). Whereas Tickle Point rocks are unique relative to the remainder of the Newfoundland Avalon Zone, they are not restricted to this region. Coeval successions of similar rocks form an integral part of the Avalon Zone elsewhere in Atlantic Canada, where they are spatially associated with ca. 620 and ca. 570 Ma rocks (Barr *et al.*, 1991). Significantly, in southern Cape Breton Island, a volcano-sedimentary succession, analogous to the Tickle Point Formation (Stirling Belt) and dated at 681 $^{+6}_{-2}$ Ma, hosts base-metal-rich massive sulphides (e.g., the abandoned Mindamar mine; Macdonald and Barr, 1993; Bevier *et al.*, 1993).

The unique and relatively complete geological record from the late Neoproterozoic through to the Middle and Late Cambrian is preserved within the Long Harbour and overlying Youngs Cove groups. The conformable nature of the succession, as seen in this part of Fortune Bay, argues against the existence of a significant regional deformational event anytime in the period between the onset of Long Harbour volcanism and culmination of Youngs Cove sedimentation (excluding minor faulting; see above). A maximum age for this period is provided by the 568 ± 5 Ma zircon date from the lower Belle Bay Formation. Notwithstanding the local basal disconformities due to non-deposition (cf. Williams, 1971), no significant regional hiatus is recorded prior to the uplift and widespread resultant disconformity at the base of the early Middle Cambrian. In that case, deposition of the remainder of the Cambrian succession resumed without any intervening deformation of pre-Middle Cambrian rocks.

Late Neoproterozoic strata that comprise the Long Harbour Group include rocks as young as 552 ± 3 Ma. This date represents the maximum age for the Proterozoic–Paleozoic boundary[7] (Tucker and McKerrow, in press), which occurs in the overlying Chapel Island Formation. The Long Harbour Group is the time stratigraphic, and in part, lithostratigraphic equivalent of much of the classic Ediacaran-bearing Neoproterozoic succession of the Avalon Peninsula, in particular, the Mistaken Point Formation (and perhaps younger units) of the Conception Group, and the overlying St. John's and Signal Hill groups. These sequences and the Long Harbour Group may have once shared a similar basal relationship (e.g., unconformity) with 620 Ma and older magmatic rocks, represented by the Holyrood and Simmons Brook intrusive suites, respectively.

Finally, recognition of the composite nature of the type Avalon Zone and the protracted nature of its orogenic history has ramifications for the regional tectonostratigraphic setting of mineralized Neoproterozoic rocks within the larger eastern (or peri-Gondwanan) margin of the Newfoundland Appalachians. Confirmation of the composite nature of the Avalon Zone type area allows for a less restrictive 'Avalonian' orogenic signature and challenges the importance of the early

[7] The global stratotype for this boundary has been designated in the Chapel Island Formation exposed on the southern Burin Peninsula (Narbonne *et al.*, 1987).

Paleozoic cover as a prerequisite for an Avalonian tectonic affinity. The results indirectly heighten the probability that coeval Neoproterozoic rocks in the Hermitage Flexure region formed together with those in eastern Newfoundland in a similar tectonic setting, thus strengthening earlier correlations of the Avalon Zone (s.s.) with auriferous Neoproterozoic successions west of the area of Cambrian cover (e.g., Hope Brook Mine; Dunning and O'Brien, 1989; Dubé *et al.*, 1994). In doing so, the Avalon Zone is further highlighted as an important area for gold exploration in the Newfoundland Appalachians.

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Note: Geological Survey file numbers are included in square brackets.

APPENDIX 1

Revised taxonomic nomenclature for Cambrian trilobites from the study area.

Paradoxides lamellatus, Hartt *in* Dawson, 1868; now *Eccaparadoxides lamellatus*

Paradoxides eteminicus Matthew, now *Eccaparadoxides eteminicus*

Paradoxides bennetti Salter, 1859 now *Eccaparadoxides bennetti*

Liostracus ouangondianus (Hartt *in* Dawson, 1868) now *Braintreella ouangondianus*

Liostracus tener (Hartt *in* Dawson, 1868) now *Badulesia tenera*