GEOLOGICAL ASSOCIATION OF CANADA
NEWFOUNDLAND SECTION

MINERALIZING ENVIRONMENTS AND LATE NEOPROTEROZOIC LITHOFACIES OF CONCEPTION BAY AND NORTHEAST TRINITY BAY

FALL FIELD TRIP GUIDEBOOK

AVALON PENINSULA
OCTOBER 3 and 4, 1998

CONTENTS

INTRODUCTION

Regional Setting of the Avalon Zone

The Avalon Peninsula lies at the eastern edge of the Appalachian Orogen on the Island of Newfoundland. The peninsula is situated within the larger Avalon Zone, the easternmost of the four principal tectonostratigraphic divisions of the Newfoundland Appalachians (Williams, 1979; Figure 1). The Avalon Zone extends offshore to the eastern edge of the continental margin, and has a width nearly twice that of the orogen as a whole. Much of this eastern (or "Avalonian") margin of the Appalachians is formed by late Neoproterozoic volcano-plutonic arcs and marine to terrestrial sedimentary basins of peri-Gondwanan paleogeographic affinity (O'Brien *et al.*, 1996) that range in age between approximately 760 and 540 Ma. In southeastern Newfoundland, these are capped unconformably by a Lower Paleozoic shale-dominated cover sequence with an Acado-Baltic faunal assemblage (*see* Boyce, 1988), distinct from that found in similar-aged platformal rocks on the western (North American) Appalachian margin.

The same late Neoproterozoic and earliest Paleozoic rocks continue southwestward from Newfoundland through Maritime Canada, New England and into the Carolinas and Georgia, in a continuous Appalachian tectonostratigraphic belt that is positioned outboard of early to mid-Paleozoic Iapetan (e.g. Appalachian-cycle) arc and continental margin successions (Figure 2). Analogous rocks comprise the southeastern margin of the Caledonides of Wales and England, inliers in the European Variscides (Cadomian belt), and extensive terranes within the Pan-African orogenic system. The Late Neoproterozoic Avalonian rocks record the development of a larger peri-Gondwanan orogenic system that is similar in scale and – in a general way – tectonic setting to the modern Pacific Rim magmatic arcs, i.e., the Andean belt of South America. Parts of this larger Avalonian-Cadomian-Pan African belt, including those rocks of the Newfoundland Avalon Zone, were reworked within or incorporated into the Appalachian Orogen during varied stages (e.g. Penobscottian, Salinic, Acadian, Alleghenian) of Paleozoic orogenesis.

The defining Proterozoic character of the Avalonian belt, both within and outside the Appalachian system, is linked to widespread magmatic activity, the peak of which occurred between about 645 and 545 Ma. At this time, extensive magmatic arcs developed in a variety of arc and back-arc or analogous continental extensional settings. Construction of these volcano-plutonic arcs coincided with, and in many cases was succeeded by, the accumulation of thick and diverse marine, deltaic and terrestrial siliciclastic sediments in basins of variable dimension, setting, complexity and age. These sediment successions are most completely preserved in Newfoundland, particularly on the Avalon and Bonavista peninsulas, and will be the focus of the second day of this field trip.

Many of the late Neoproterozoic magmas generated at this time rose to very high levels in the crust and were emplaced onto the surface as subaerial, caldera-vented volcanic rocks. In a number of instances, these magma chambers were the driving force behind large-scale hydrothermal convective systems active at high levels in the crust. The resultant hydrothermal alteration was, in some cases, accompanied by the deposition of gold, with or without silver, copper and in some instances zinc and arsenic, in a variety of volcanic, hypabyssal and plutonic settings. Day 1 of the trip will examine several examples of low-sulphidation,

[1] The Introduction and Day 1 stop descriptions 1-1 to 1-9 have been taken, with modification, from O'Brien et al., 1997a (CIMM Fall Fieldtrip Guidebook).

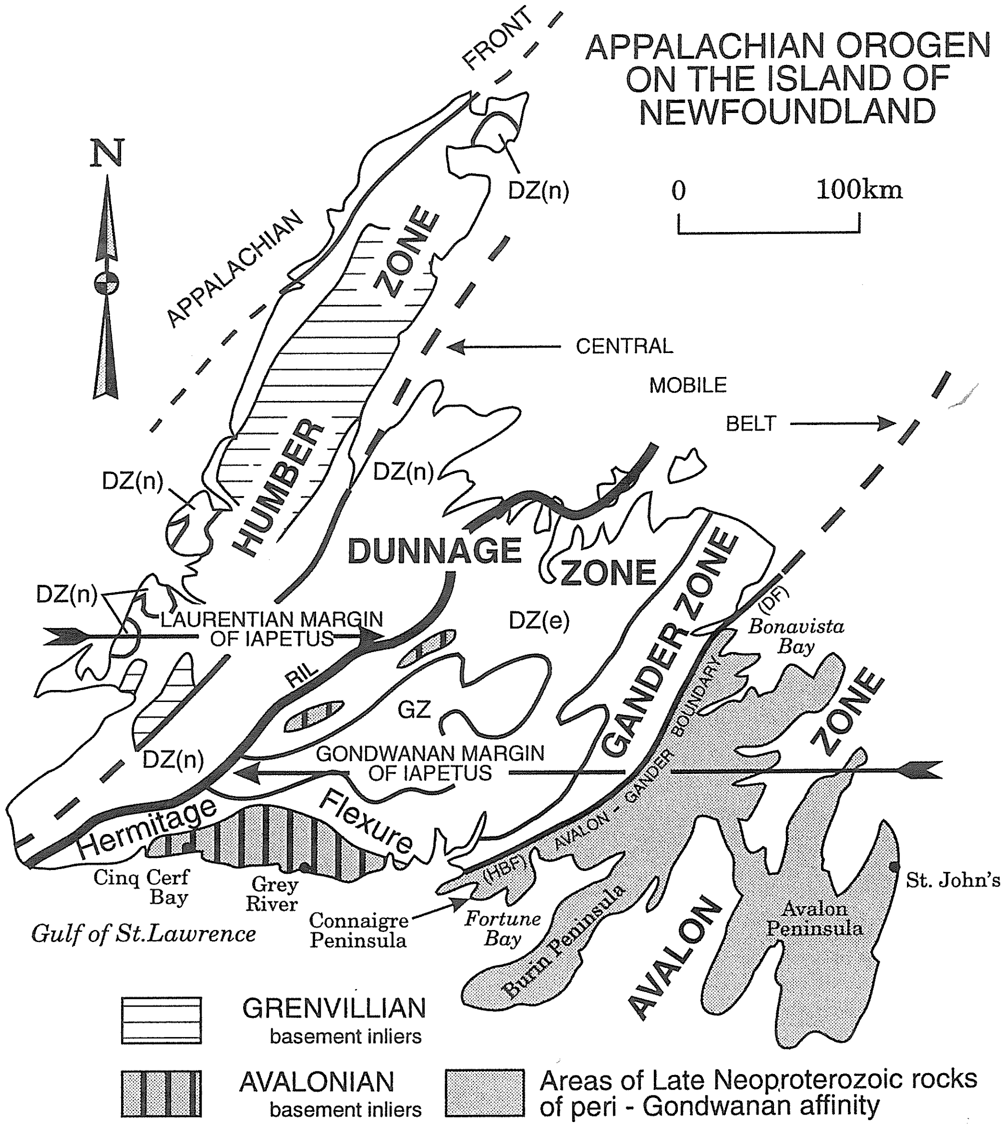

Figure 1. *Tectonostratigraphic subdivision of the Newfoundland Appalachians showing distribution of Avalonian rocks. DZ(e)= Dunnage Zone: Exploits subzone; DZ(n)= Dunnage Zone: Notre Dame subzone; GZ= Gander Zone; HBF= Hermitage Bay Fault; DF= Dover Fault; RIL= Red Indian Line (from O'Brien et. al. 1996)*

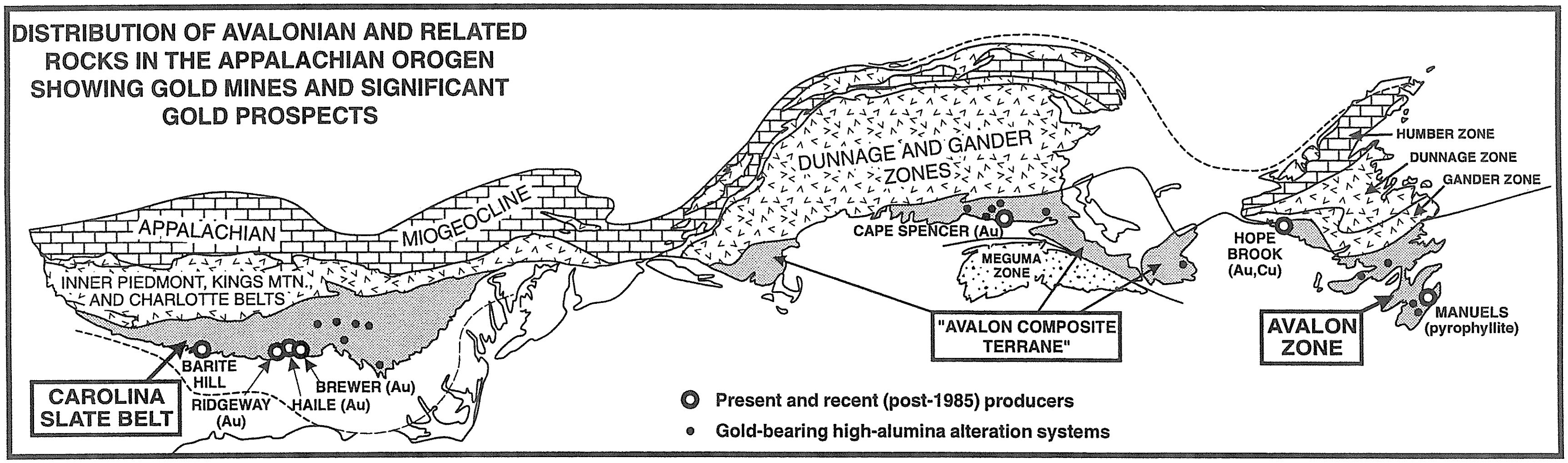

Figure 2. *Distribution of Avalonian and related rocks in the Appalachian Orogen showing gold mines and significant gold prospects(modified from Williams and Hatcher, 1983).*

High-sulphidation type and, potentially, porphyry gold mineralization and alteration in such environemtns. The acumulation of latest Neoproterozoicmarine, deltaic and terrestrial sediments - the latter associated with subaerial mafic and felsic flows – are also metallogenically significant, both from the point of view of sedimentary exhalative Pb-Zn mineralization and volcanic redbed-style copper mineralization, amongst other possibilities. Examples of both mineralizing styles will be examined near the end of Day 1.

Geology of the Avalon Peninsula: A Thumbnail Sketch

The eastern parts of the Avalon Peninsula is cored by a broad, north-south elongated periclinal dome (Holyrood Horst) of late Neoproterozoic, primarily subaerial volcanic and coeval plutonic rocks that have historically been assigned to the Harbour Main Group and the Holyrood Intrusive Suite (King, 1988a, 1990; O'Brien and O'Driscoll, 1996; O'Brien *et al.*, 1997, 1998; *Figure 3*). These low-grade rocks, which characteristically lack penetrative deformation, yield a variety of late Neoproterozoic U/Pb zircon ages (Krogh *et al.*, 1988), most of which fall in the bracket 640 to 580 Ma. This volcano-plutonic core contains outliers of marine siliciclastic rocks and is flanked by a younger, shoaling-upward succession of marine, deltaic and fluviatile siliciclastic rocks (Conception, St. John's and Signal Hill groups, respectively; e.g., King, 1988; see Day 2: King, this volume), concentrically disposed around the older succession.

Locally, the base of the marine succession is unconformable on the earlier volcano-plutonic rocks. An estimate of minimum total composite thickness of the stratified succession would be in the range of 7 to 10 km (e.g., King, 1988a). Tuff beds in the upper Conception Group are dated at 565 Ma; the age of the base of the flanking marine succession is largely unconstrained (Dunning, *in* King, 1988b).

The Conception Group in the southern Avalon Peninsula is locally intruded by a suite of gabbros and granites, which includes the Whalesback Gabbro and related rocks. A thick bimodal volcanic series (Bull Arm Formation) occupies a stratigraphic position above marine siliciclastic rocks in the western Avalon Peninsula and along the Isthmus of Avalon. These volcanic rocks pass up into fluvial and molasse-facies clastic rocks, part of the Musgravetown Group; correlatives of these late bimodal volcanic rocks may lie within the Holyrood Horst. A shale-rich cover of Early Cambrian to earliest Ordovician age lies with pronounced angular discordance on various levels of the folded and faulted Proterozoic succession (e.g., Hutchinson, 1962). Details of the Paleozoic stratigraphy are given in the introduction to Day 2 (King, this volume)

Early Silurian mafic sills and related intrusions are emplaced into this Cambrian cover in the southwestern part of the Avalon Peninsula (Greenough *et al.*, 1993). Diabase of Mesozoic age has intruded the Proterozoic succession, and coincides with a 110-km-long magnetic lineament that trends in a north-easterly direction across the southeastern Avalon Peninsula (Papezik and Hodych, 1980). A regional magnetic high of similar orientation parallels the south shore of Conception Bay, locally coinciding with exposure of post-tectonic diabase, possibly of similar age.

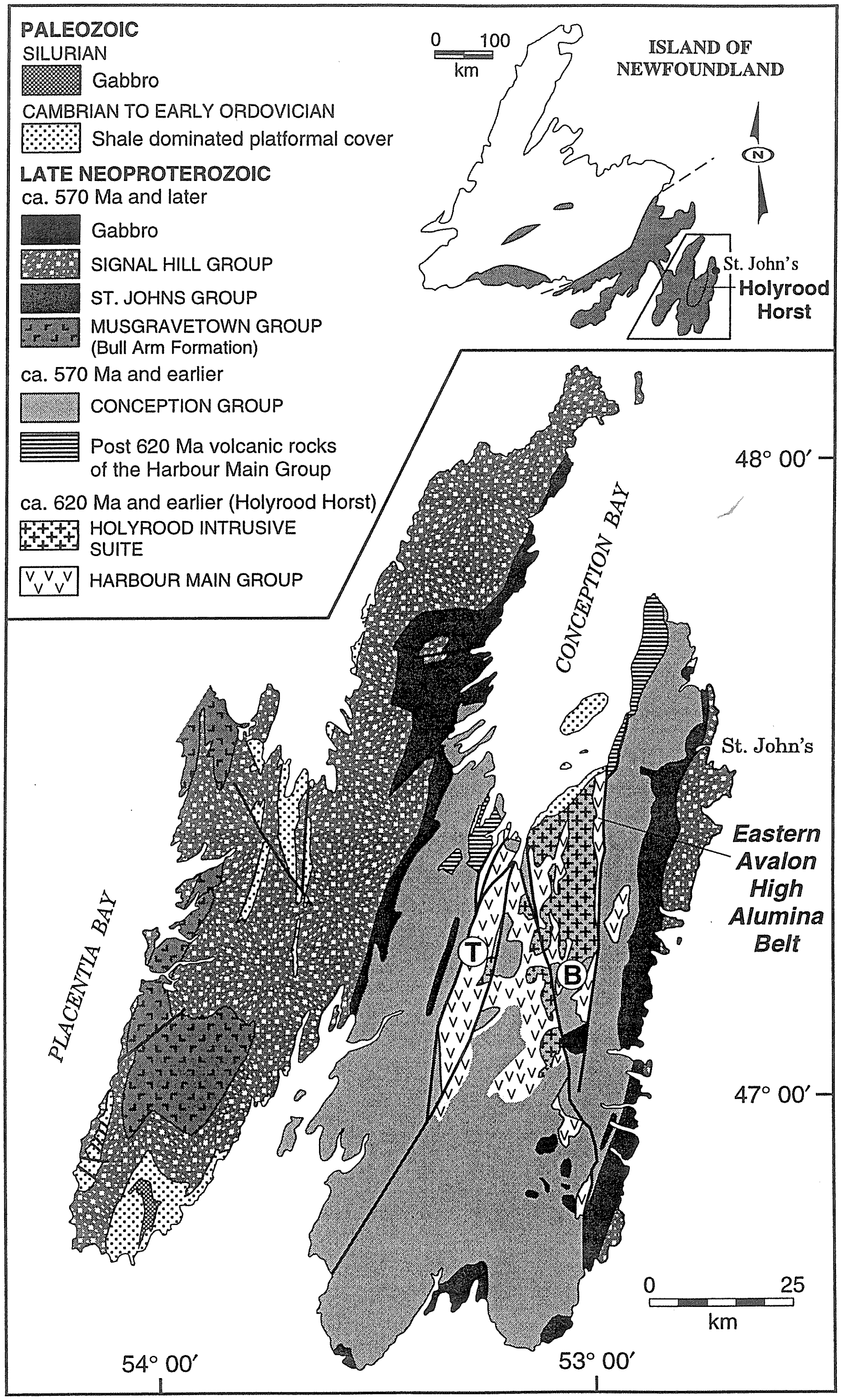

Figure 3. *Simplified geological map of the Avalon Peninsula (modified from King, 1998).*

DAY 1

Neoproterozoic Mineralization And Hydrothermal Alteration In The Eastern Avalon Zone, Newfoundland Appalachians

Leaders:

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Suggested citation: O'Brien, S.J., O'Driscoll, C.F., Mills, J. and Dubé, B. and Dawe, M., 1998: Neoproterozoic mineralization and hydrothermal alteration in the eastern Avalon Zone, Newfoundland Appalachians. *In:* Mineralizing Environments and Late Neoproterozoic Lithofacies of Conception Bay and Northeast Trinity Bay. Fall Field Trip Guidebook (October 3-4, 1998), Geological Association of Canada, Newfoundland Section, 59 pages.

STYLES AND SETTING OF HYDROTHERMAL ALTERATION ON THE EAST-CENTRAL AVALON PENINSULA

Late Neoproterozoic plutonism and volcanism, as recorded in the east-central Avalon Peninsula, was locally associated with widespread hydrothermal activity, and the development of significant areas of argillic, advanced argillic and phyllic alteration (*see* O'Brien and O'Driscoll, 1996b; O'Brien *et al.*, 1997a, 1997b, 1998 and references therein). Alteration occurred at high crustal levels, within the epithermal and porphyry domains. On a regional scale, the volcanic-hosted alteration and related precious and base-metal mineralization is typically preserved near the margins of late Neoproterozoic intrusions and, in many instances, near the boundary with overlying late Neoproterozoic sedimentary basins (Figure 1-1). Mineralization and alteration is, in places, associated with zones of relatively high strain, although in most instances, much or all of the alteration is pre-tectonic.

The largest continuous zone of hydrothermal alteration on this part of the Avalon Peninsula is the 'eastern Avalon high-alumina belt' of Hayes and O'Driscoll (1990) (Figure 1-2). This extensive area of epithermal-style alteration is sited along the eastern side of the Holyrood Horst, adjacent to the Holyrood Intrusive Suite. Alteration is developed primarily in subaerial pyroclastic volcanic rocks, and to a lesser degree in comagmatic plutons. Alteration is exposed along a strike-length of more than 15 km; the zone has a maximum width of about 1 km. Its northern extension is covered by a thin, gently dipping to flat-lying early Paleozoic platformal sedimentary succession. This zone, best known for its deposits of pyrophyllite, including the Oval Pit Mine, is also host to epithermal gold mineralization related to high- and low-sulphidation style hydrothermal alteration.

The volcanic succession that hosts much of the alteration is characterized by subaerial, rhyolitic to dacitic volcanic rocks. These include caldera-facies thicknesses of welded and variously flattened, pumice-rich ash-flow tuffs, which are stratigraphically associated with dome-facies flows and breccias of broadly similar composition. The hydrothermal system produced extensive zones of argillic, advanced argillic and massive silicic alteration, locally affecting or subsequently overprinted by hydrothermal breccias. The observed mineralogy (in particular the assemblage pyrophyllite, diaspore, barite) is most consistent with an advanced argillic alteration system related to a magmatically derived high-sulphidation system. In the northern part of the belt, however, similar volcanic rocks host a different style of hydrothermal alteration, in the form of gold-bearing veins related to low-sulphidation (adularia-sericite) alteration.

Hydrothermal alteration in this area is primarily pre-tectonic with respect to the regional deformation and most likely has followed the original 'plumbing' system of the host Late Neoproterozoic magmatism. Syn-volcanic structural and lithologic controls are similarly linked to primary volcanic architecture. The advanced argillic alteration zone, the associated pyrophyllite deposits, and the gold mineralization in the eastern Avalon high-alumina belt most probably constitute parts of a large, tilted hydrothermal system spatially and genetically related to one or more phases of the Holyrood Intrusive Suite. The potential for significant gold mineralization within this system remains high.

The volcanic rocks in this belt are intruded by polyphase, mainly high-level plutonic rocks. These display evidence of extensive magmatic degassing, and are affected by hydrothermal alteration. There is a range in composition and texture on a regional scale, from gabbro through granite to quartz-feldspar porphyry, with ample evidence of magma mixing. Plutons include I-type hornblende-biotite intrusions of calc-alkaline chemical affinity. Field and existing geochronological evidence indicate

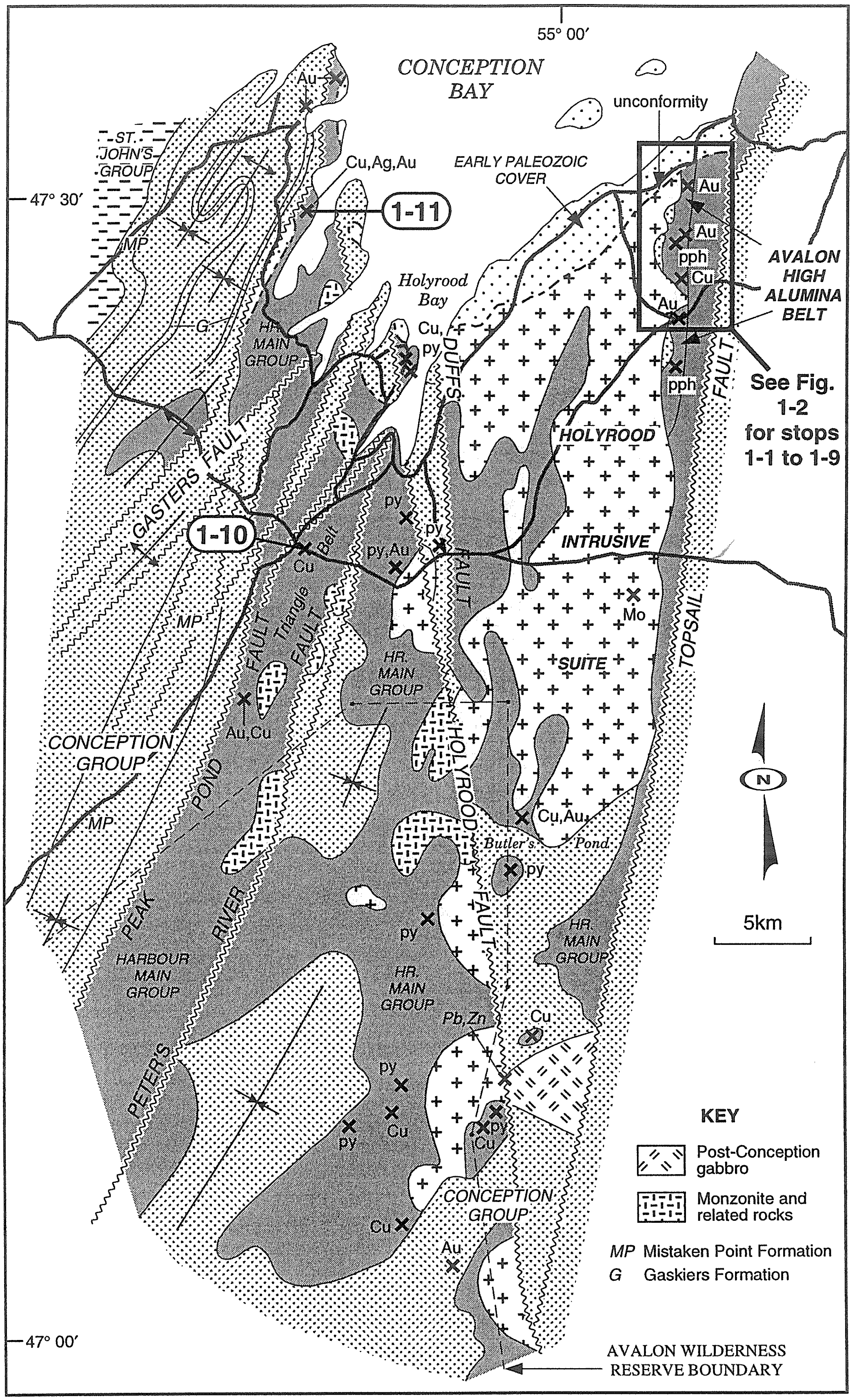

Figure 1-1. *Simplified geology of the Holyrood Horst (Day 1), showing location of field trip stops 1-10 and 1-11, and some representative mineral occurrences on the central Avalon Peninsula.*

that these are coeval with various parts of the intruded volcanic pile. The intrusive suite includes, as presently outlined, pre- and/or syn-alteration and post-alteration phases. Altered plutonic rocks are exposed in a number of areas south and along strike of the eastern Avalon high-alumina belt. Silica-altered intrusions locally carry disseminated pyrite, chalcocite, chalcopyrite, bornite and molybdenite, and locally contain hydrothermal magnetite veins.

Volcanic-hosted hydrothermal alteration in the Avalon Peninsula, like elsewhere in the larger Avalonian belt, occurs primarily at or near the boundary with Proterozoic sedimentary rocks (depositional boundaries and/or basin margin faults), or at or near the boundary with felsic to intermediate elements of coeval plutonic suites. Zones of relatively high strain are at least spatially associated with alteration on the Avalon Peninsula, although in most cases alteration has pre-dated the latest strain. There is significant potential for further discoveries within the eastern Avalon high-alumina belt, and elsewhere in the Holyrood Horst.

The low-sulphidation system represented in the north of the eastern Avalon high-alumina belt may be broadly coeval with, and distal to, the high-sulphidation system typified by the Oval Pit Mine and related advanced argillic alteration in the eastern Avalon high-alumina belt. Low- and high-sulfidation deposits are two members of the tripartite epithermal–porphyry clan, which also includes porphyry (gold–copper) deposits. If any one type of deposit is present in a magmatic system, the potential for others is high. Intrusion-related gold occurrences such as those at Triangle Pond and at Butlers Pond (12.2g/tAu; 6% Cu) (*see*: O'Brien and O'Driscoll, 1996b and O'Brien *et al.*, 1997, 1998 and references therein), located on the west and eastern flanks of the Holyrood Horst, are strong evidence that this third member of the epithermal–porphyry gold clan is preserved in the Avalon Peninsula. The occurrence of silicic alteration with disseminated Cu, Mo and Fe sulphides, coupled with the local development of hydrothermal magnetite veins and copper mineralization within plutons of the Holyrood Intrusive Suite (both in the eastern Avalon high-alumina belt and farther south, for more than 30 km), clearly points to potential for porphyry-style alteration and mineralization. The geological setting of extensive (calc-alkaline) subaerial volcanism, the existence of composite comagmatic high-level plutonism, the observed widespread advanced argillic alteration, and the presence of hydrothermal hematite and, locally, magnetite and K-feldspar, further underscore the potential for porphyry-style Au–Cu mineralization on the Avalon Peninsula.

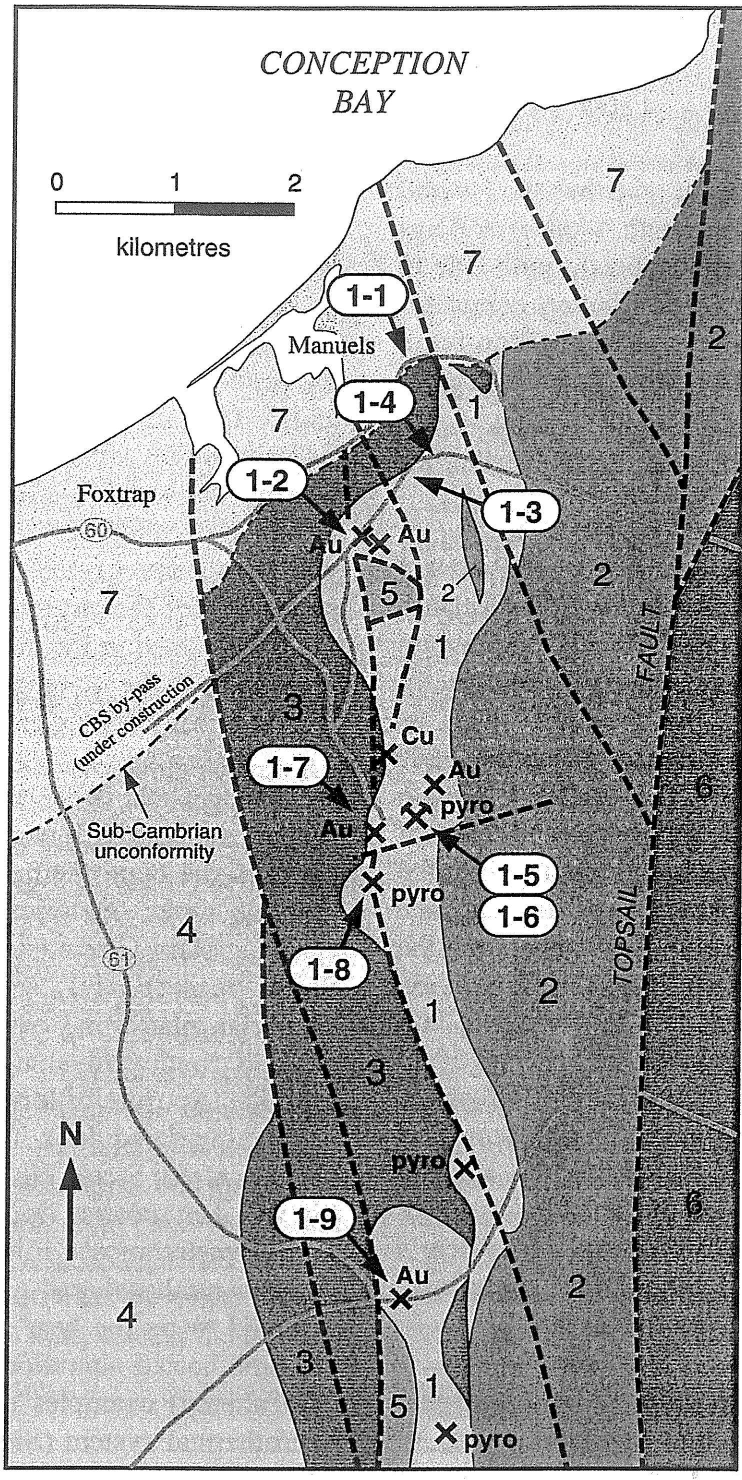

Figure 1-2. *Location of field trip stops 1-1 to 1-9 in the eastern Avalon High-Alumina Belt; (map updated from Hayes and O'Driscoll 1989; scale approximately 1:50 000). Legend: 1= eastern Avalon high-alumina belt and related rocks of the Harbour Main Group; 2= unseparated mafic and felsic flows and sediments of the Harbour Main Group; 3= unseparated monzonite, gabbro, granite and porphyry phases of the Holyrood Intrusive Suite, in many instances with hydrothermal alteration; 4= mainly weakly altered (chlorite- epidote) quartz-rich biotite granite (Holyrood Intrusive Suite); 5= sediments of uncertain stratigraphic affiliation; 6= Conception Group marine sediments; 7= Cambrian cover sequence of mainly shaly rocks.*

TRIP ITINERARY FOR DAY ONE

Assemble at the parking lot of either the Natural Resources Building (50 Elizabeth Avenue) or Bergs Famous Ice Cream store (Manuels), north side of Conception Bay Highway. ***Introductory comments will be given at Bergs.*** Then proceed to Stop 1-1, a few hundred metres farther west.

Overview: Day 1

The field trip departs the Natural Resources Building en route to the intersection of Routes 1 and 2. From there, follow Route 2 west to Manuels, and turn southwest (left) at Manuels Bridge onto Route 60 (Conception Bay Highway). Geologically, the route we follow to the first stop takes us downward through much of the late Neoproterozoic stratigraphic section of the eastern Avalon Peninsula: from the deltaic sandstones and shales of the St. John's Group (which underlie much of the city of St. John's), downwards through the Mistaken Point Formation and other marine siliciclastic sedimentary rocks of the Conception Group, across the Topsail Hill fault system, into volcanic and plutonic rocks of the Harbour Main Group and Holyrood Intrusive Suite, at the eastern edge of the Holyrood Horst. Our first stop is a roadcut on the south side of Route 60, situated approximately 500 m west of the Manuels River Bridge. The field trip will first reassemble at Berg's parking lot (just east of Stop 1) for some brief introductory comments from the leaders.

The Day 1 itinerary includes 12 field stops that will focus primarily on various styles of hydrothermal alteration and related gold, copper and silver mineralization within Late Neoproterozoic volcanic and plutonic rocks of the eastern Appalachian Avalon Zone. **Stops 1-1** to **1-9** are located in the *eastern Avalon high-alumina belt* (AHAB Zone of Hayes and O'Driscoll, 1990), an extensive area of hydrothermal alteration, greater than 15km long and up to 1 km wide, located along the eastern flank of the Holyrood Horst. **Stops 1-10** and **1-11** are located west of the Holyrood Intrusive Suite, within Cu-, Cu-Au-, and Cu-Ag-Au bearing subaerial mafic flows (and associated intrusive rocks) that locally form some of the youngest parts of the Neoproterozoic volcanic succession of the eastern Avalon Peninsula. **Stop 1-12** is located in the marine to deltaic transition zone within the overlying (565 Ma and later) Neoproterozoic siliciclastic succession.

The trip will begin at the northern end of the eastern Avalon high-alumina belt, at the contact between the hydrothermally altered volcanic and plutonic rocks (historically included within the Harbour Main Group and the Holyrood Intrusive Suite, respectively) and unaltered shale-rich Cambrian platformal cover (**Stop 1-1**). We then proceed southward along the alteration belt, to examine exposure of low-sulphidation style gold-bearing quartz-adularia-hematite veins and related breccias at the Steep Nap prospect (**Stop 1-2**). The trip will then traverse from west to east across part of the easternmost Holyrood Horst, examining hydrothermally altered granitic rocks (**Stop 1-3**) assumed to be the heat source for the overlying volcanic hosted alteration, and viewing unaltered (and altered) examples of the host rocks to the hydrothermal system (**Stops 1-4, 1-4a**)[2]. The trip will proceed farther south, stopping in the advanced argillic alteration system and the overlying Neoproterozoic sediments in and around the Oval

[2] *Many of the descriptions given below were based on exposures created during initial construction of the new CBS by-pass road. Subsequent road construction and blasting may have changed the surface of outcrops along the new by-pass road. Significant parts of Stops 1-3 and 1-4, as described below, have been since transformed into road aggregate.*

Pit pyrophyllite mine (**Stops 1-5 and 1-6**), in nearby silicic altered and auriferous breccias of the Mine By-Pass prospect (**Stop 1-7**) and in high-strain zones within the advanced argillic alteration at the Mine Hill Quarry (**Stop 1-8**), all on the mine property. Our final stop in the eastern Avalon high-alumina belt is located on Route 1, near the intersection with Route 61 (Foxtrap Access Road), where the advanced-argillic-altered volcanic rocks and related gold-bearing (up to 10.2g/t) hydrothermal breccias of the Roadcut gold prospect are well exposed (**Stop 1-9**).

We will then head west along Route 1, crossing the multiphase (and multi-age?) Holyrood Intrusive Suite, stopping again in mineralized mafic rocks of the Triangle Belt (**Stop 1-10**), part of the central block of the Harbour Main volcanic pile. From here we head west to the Avoidable Access Road and then north to rejoin the Conception Bay Highway, which we will follow west to Marysvale. There, mineralized (Ag-Cu-Au) subaerial basalt flows lie unconformably beneath a boulder conglomerate at the base of the marine Conception Group (**Stop 1-11**). We leave Marysvale en route to Roaches Line and thence to Carbonear. The final stop of the day (**Stop 1-12**), near Victoria, will examine sediment-hosted sulphide mineralization in transitional marine to deltaic facies of the Neoproterozoic sedimentary pile, and demonstrate the depositional environment and exploration potential of these rocks. Vulcan Minerals' drill core from targets elsewhere in this immediate area will be also be available for study during the trip.

Stops Descriptions

***STOP 1-1*: UNCONFORMITY BETWEEN EARLY CAMBRIAN SHALE AND LATE NEOPROTEROZOIC HYDROTHERMALLY ALTERED GRANITIC AND VOLCANIC ROCKS, EASTERN AVALON HIGH-ALUMINA BELT**

Location: *South side of Conception Bay Highway, just west of Berg's Store (opposite Cherry Lane); park in lot adjacent to old railway line, south side of highway (Yetmans sheet metal shop).*

The outcrop on the south side of the road exposes the disconformity between fossiliferous Lower Cambrian shale of the Brigus Formation and the underlying hydrothermally altered succession of the eastern Avalon high-alumina belt. Sub-Cambrian basement here includes volcanic rocks assigned to the Harbour Main Group, and associated porphyry and granite, assigned to the Holyrood Intrusive Suite. This outcrop provides stratigraphic evidence for the pre-Cambrian age of the alteration system. This is one of the northernmost exposures of this hydrothermal system, which continues at (initially, at least) very shallow depth, northward under the gently dipping to flat-lying Cambrian cover.

A regolith zone is well developed below the basal Cambrian contact. There has been carbonate infilling along the regolith and within fractures extending a metre or more into the basement rocks. Both the volcanic and plutonic rocks below the unconformity are altered (sericite-silica, with minor hematite and pyrite). The Neoproterozoic rocks are cut by structurally controlled (extensional) sub-horizontal and (less pronounced) steep quartz and carbonate veins. An earlier set of thin, banded quartz-hematite veins are hydrothermal in origin. Hydrothermal quartz-hematite ± K-feldspar veins and breccias having variously elevated gold values occur locally, both in outcrop, and as large angular blocks immediately south and north of here; similar veins are exposed in the outcrop near our parking area.

The same sub-Cambrian unconformity is exposed nearby in Manuels River and new roadcuts on the CBS by-pass road near Dunns Hill Road. At Manuels Bridge, a basal conglomerate is well developed, and contains detritus with pre-incorporation hydrothermal alteration. At Dunns Hill Road, the basal unconformity is spectacularly preserved above weakly altered (locally with malachite) granite. Within that outcrop, metre-scale boulders rest on the well-preserved paleosurface that is developed on weakly altered and mineralized granitoid phases of the Holyrood Intrusive Suite.

STOP 1-2: STEEP NAP GOLD PROSPECT: LOW – SULPHIDATION STYLE, AURIFEROUS QUARTZ-K-FELDSPAR – HEMATITE VEINS AND BRECCIAS

***Location**: Steep Nap Road: Turn south off Conception Bay Highway onto Anchorage Road (look for "Ziggy's" sign at intersection). Proceed through underpass below the new CBS By-pass road, and turn left onto new Steep Nap Road "access". Stop at long exposure on the south side of the road. Please do not hammer that part of the outcrop with the main banded Au-bearing vein bundle; samples of this texturally distinctive material can be collected from amongst the loose blocks underfoot.*

The blasted outcrop on the south side of the road forms part of the Steep Nap Prospect. Discovered in 1995, the prospect consists of gold-bearing hydrothermal quartz-hematite-K-feldspar veins in pyroclastic and hydrothermal breccias within Harbour Main Group pyroclastic rocks. The veins in this exposure have many of the characteristics of low sulfidation (adularia-sericite) epithermal gold mineralization. This outcrop is a superb example of one of three main types of late Neoproterozoic epithermal mineralization/ alteration in the eastern Avalon high-alumina belt (e.g., high-sulphidation-low-sulphidation-porphyry "clan").

We are located in the northern part of the eastern Avalon high-alumina belt, about 3 km to the north of the Oval Pit pyrophyllite mine, and about 1.5 km SSW of Stop 1. The largest veins in this outcrop carry up to 3.3 g/t Au (O'Brien and O'Driscoll, 1996a, 1997; O'Brien et al., 1998). This 60 m long outcrop of felsic pyroclastic rocks contains at least 100 veins, ranging in size from 1 mm up to 1.7 m; most are less than 2 cm wide. Several types of breccia are also exposed. The main auriferous material forms a 1.7 m wide composite vein composed of crustiform bands of K-feldspar–quartz–chalcedony and minor hematite. Very little sulfide mineralization is present in any of the veins. The largest auriferous veins have been traced, with consistent thickness, intermittently along strike for at more than 300 m.

The earliest veins are crustiform-banded, and consist of grey recrystallized chalcedony and white quartz, with or without minor chlorite and hematite. A second group of veins consist of crustiform and locally colloform bands of K-feldspar, grey recrystallized chalcedony, white quartz and hematite. The latest veins are characterized by weakly banded quartz along the margin, bounded by crystalline comb quartz nearer the centre, surrounding a hematite core. In many instances, especially in the larger veins, internal brecciation of the vein material by hematite has occurred. Hematite fracturing of the surrounding outcrop occurs locally.

The earliest hydrothermal breccias are gold-bearing and have a matrix of grey recrystallized chalcedony and minor K-feldspar, that forms cockade textures cored by sericite-chlorite-altered clasts. This breccia is crosscut by the main adularia-quartz-hematite vein, and by smaller veins cored by comb-quartz and hematite. Other, later breccias have either black, chlorite-rich and/or brown, hematite-rich matrix. These breccias contain fragments of banded vein material, and are thus either late syn-, and/or post-veining. The two matrix types are typically mixed. The late breccias with vein material fragments return anomalous gold values.

Sericite, chlorite, and hematite are the main wall-rock alteration phases; there is also evidence of some potassic and silica alteration. Most (although not necessarily all) of the more intense sericite alteration is post-veining, and related to brittle deformation. Less intense but more pervasive sericite alteration is present in the northern half of the outcrop. Chlorite alteration is mainly confined to thin halos around pre-veining fractures and veinlets. A more extensive area of chloritic alteration (ca. 2 m wide) is developed adjacent to (west of) the widest vein. Hematite alteration occurs sporadically throughout the outcrop, both as early remobilization halos and later patches and halos around late veinlets and fractures.

STOP 1-3: HYDROTHERMALLY ALTERED GRANITE, HOLYROOD INTRUSIVE SUITE

Location: *New Conception Bay South by-pass road. Turn and follow Steep Nap Road westward, bearing left onto Anchorage Road, and thence south to the intersection with Minerals Road. Turn right onto Minerals Road and head north, then right (east) onto new CBS bypass for approximately 2 km.*

Outcrops (once found on both sides of the road) expose hydrothermally altered (silica; sericite-pyrite) rocks assigned to the Holyrood Intrusive Suite. The compositionally and texturally diverse, variously altered intrusions found along the eastern part of that suite present a window into the magmatic hydrothermal system related to the advanced argillic alteration characteristic of the Avalon high alumina belt. This outcrop is also supporting evidence for the existence of the second member of the aforementioned hydrothermal "clan": namely, the porphyry environment.

Weakly altered, medium-grained biotite granite containing disseminated pyrite in this area is cut by unaltered, foliated diabase dykes (once well exposed on the south side of the road). Pale green sericitic alteration is accompanied by minor pyrite which occurs as disseminations (locally up to 2 percent), and within quartz veinlet stockwork; this alteration is associated with anomalous concentrations of copper and molybdenite. The pyrite–sericite alteration is situated at the periphery of a significant zone of silicic alteration, which reaches a maximum width of approximately 30 m in this general area. At the edge of the silicic alteration, the granite is bleached (albitized?); biotite is readily recognizable. Farther into the zone, the granite is replaced by fine grained grey (mostly featureless) silica, in which irregular zones of altered granite and/or relict feldspar crystals can be recognized. The altered granite is crosscut by sub-horizontal extensional quartz-chlorite veinlets.

The zone of silicic alteration passes eastward into sericite-silica altered rocks of uncertain protolith. The intrusive contact between relatively unaltered granite and volcanic is exposed on a flat surface in the ditch several metres to the east of a brittle fault, which delimits the hydrothermally altered rocks.

STOP 1-4: HYDROTHERMAL ALTERATION OF VOLCANIC ROCKS IN THE HARBOUR MAIN GROUP

Location: *New Conception Bay South by-pass road. Continue east along new highway, stopping at light-colored, hydrothermally altered rocks exposed in south-side roadcut.*

The roadcut on the south side of the new highway has exposed a 5.5 m-wide zone of silica-sericite alteration typical of much of the alteration found in the area. Here, the hydrothermal alteration developed in red, purple and grey ash-flow tuffs, at the boundary with an overlying, thin succession of syn-volcanic sedimentary rocks. The alteration zone strikes NNW, dips NE, and is oriented subparallel to bedding in the overlying sediments. Silica-hematite-chlorite (± K-feldspar?) alteration is prominent in the upper part of the zone, whereas sericite (± pyrophyllite) and minor silica forms its lower part. Late chlorite cross-cuts the main alteration zone. Ellipsoidal shaped relicts of hematite-rich altered rhyolite are preserved within silicic material in the eastern part of the alteration zone.

Sedimentary rocks above the zone include red sandstone and siltstone, green-grey grit and tuffaceous granule to pebble conglomerate, with red silty interlayers. The sediments above the alteration contain minor amounts of altered detritus. The lowermost part of this unit may have also been affected by the alteration. The sediments (and successively younger volcanic rocks) are intruded by one of a suite of thick diabase dykes that is sited near the eastern edge of the Holyrood Horst in this area.

STOP 1-4A: VOLCANIC FACIES IN THE HARBOUR MAIN GROUP

Location: *Conception Bay South by-pass road; continue east from Stop 1-4 to nearby flagged roadcut on the south side of the road.*

This stop is located within a thick (≥1 km), steeply dipping to vertical succession of primarily rhyolitic to rhyodacitic (*field terms*) volcanic rocks that are typical of this part of the Holyrood Horst, including the host succession to much of the hydrothermal alteration in this region. On fresh surface these are massive, conchoidal-fractured, sparsely feldsparphyric rocks, containing rare, very fine-grained quartz crystals. The more weathered surfaces at this locality (and loose blocks, underfoot) reveal the true texture of these rocks. These are pyroclastic deposits, mainly pumice-rich ash-flow tuffs. Various degrees of welding, flattening and post depositional flow can be seen on weathered surfaces preserved along the outcrop. Later brecciation may be in part due to syn-volcanic degassing (hydrothermal in origin) although some tectonic brecciation has also occurred.

The succession to the east of here consists of grey, coarsely- to intricately-banded to massive rhyolite flows, hosting narrow zones of sericite ± silica ± pyrite ± pyrophyllite. The succession below this is dominated by red, grey and purple, K-feldsparphyric flow-banded rhyolitic rocks associated with fine- to coarse-grained volcanic breccia. Thick diabase dykes are common in the eastern part of this section, and may be related to the mafic volcanicity in the younger parts of the Proterozoic succession, which is exposed on the northeast shore of Conception Bay.

Much of the advanced argillic alteration, including the pyrophyllite deposits, in the eastern Avalon high-alumina belt is developed within sub-aerial pumice-rich ash-flow tuffs such as these, and within parallel-banded to highly distorted rhyolite flows, and *in situ* volcanic breccias (remember to compare this outcrop with pyroclastic texture and flow-banding textures in pyrophyllite ore in Stop 1-6). The nature, thickness and internal facies distribution of the volcanic succession is most consistent within eruption and accumulation within or immediately adjacent to an eruptive centre, most likely a caldera. The precise scale of such a feature is unknown.

STOPS 1-5 AND 1-6: OVAL PIT MINE

Location: *Trinity Resources and Energy (Newfoundland Pyrophyllite Division) Oval Pit Mine property: Turn and head west on new road to intersection with Minerals Road; follow Minerals Road south (left) to pyrophyllite mine. Stop at the Mine office. Time and weather permitting, we will first take the mine road to a look-out point on the edge of the Oval Pit, for an overview of the pit. We will then proceed back this road and into the pit, stopping on the 470 level. The view from the top of the pit shows a number of features including the outline of the pyrophyllite ore zone, the overlying sediments rich in detrital alteration, and some of the larger scale faults and folds affecting the alteration system.*

EXERCISE CAUTION! KEEP AWAY FROM EDGE OF OPEN PIT.

The pyrophyllite deposits of this area (discovered in 1898) were first mined in the period from 1903 to 1905, with approximately 7750 tons of hand-picked ore shipped from a quarry near Johnnies Pond (presumably at or near the site of the Mine Hill deposit; Vhay 1937; Spence, 1940). Pyrophyllite ore was produced intermittently in the mid-1930s and 1940s by the Industrial Minerals Company of Newfoundland, mainly from area around Mine Hill, but also from the Trout Pond and Dog Pond prospects, located farther south. Mining of the Oval Pit pyrophyllite deposit was carried out continuously from 1956 to 1996 (e.g., Lee, 1958; Batten and Hume, 1978), first by Newfoundland Minerals Ltd., and eventually, by Armstrong World Industries Canada Ltd. Exploration drilling of all deposits was carried out over this interval. Until now, pyrophyllite from this deposit has been traditionally used exclusively for ceramics applications, and was shipped in bulk to the US ceramics plants. The former Armstrong property has recently been acquired by Trinity Resources and Energy Limited (August, 1998) and is operated by its Newfoundland Pyrophyllite Division. The new owners will produce a variety of high-end pyrophyllite products, including fillers for paper, plastic and paint, and granules for roofing shingles. Plans include milling and packaging on-site.

The earliest geological study of the pyrophyllite deposits was carried out by Buddington (1916). A detailed study of the Mine Hill, Trout Pond and Dog Pond prospects was carried out by Vhay (1937). A number of investigations followed the development of the Oval Pit Mine (e.g., Keats, 1970; Papezik and Keats, 1976, Papezik and Hume (1984). The most recent geological mapping of this region is that of Hayes and O'Driscoll (1989, 1990), and Hayes (1996) and by the authors (O'Brien *et al.*, 1997, 1998).

A well-exposed section through an extensive advanced argillic hydrothermal system is preserved in the Oval Pit Mine and in the immediately surrounding area. Alteration can be subdivided from east to west into subzones of argillic, advanced argillic and massive silicic alteration. The argillic zone is characterized by the presence of silica and sericite, with or without pyrophyllite, and the common occurrence of hydrothermal hematite. The advanced argillic zone contains subzones of massive pyrophyllite, sericite and diaspore, with minor barite and rutile (e.g., Oval Pit), and of silica, pyrophyllite and sericite, locally with 5–10 percent pyrite. Smaller zones of massive silicic alteration are mainly in the form of metre-scale pods of high-grade silica, containing less than 5 percent sericite and/or pyrophyllite. Locally, pyrite forms the matrix of associated silica breccias. No large and continuous zone of silicic alteration has been identified at surface. The zones of silicic alteration are irregularly distributed in detail, but appear to be located mainly to the northeast of the advanced argillic zone. The original distribution of silica and pyrophyllite within the advanced argillic alteration zone indicate that they are essentially contemporaneous. Pyritic rocks intimately associated with the pyrophyllite are not typically anomalous in gold, although values up to 0.8g/t have been noted locally. The highest gold values noted to date are associated with hydrothermal breccias at the edge of the advanced argillic zone (e.g., see Stop 1-7)

The advanced argillic alteration zone passes outward into red subaerial rhyolites showing mild silicic alteration associated with the formation of quartz-hematite veins and breccia. The first stage of hematite alteration is regionally distributed, predates the advanced-argillic-alteration, and formed by syn-volcanic thermal oxidation. A younger hematite-alteration event is the result of leaching from hematite-rich volcanic rocks during advanced argillic alteration, and has resulted in the formation of the afore-mentioned hematite veinlets and breccias. The commonly developed anastomosing pattern illustrated by the outcrop-scale distribution of silica and pyrophyllite in zones of low to medium strain is the result of inhomogeneous post-alteration deformation.

The presence of pyrophyllite [$Al_2Si_4O_{10}(OH)_2$] and diaspore [$AlO(OH)$], together with barite, coupled with the almost total absence of kaolinite, is compatible with an advanced argillic alteration system associated with a magmatic-derived high-sulphidation system. The apparent absence of widespread silica alteration, vuggy silica and alunite within the alteration zone may indicate that the pH was not acid enough to produce this assemblage. A pH in the range 3-to-5 is implied by the observed presence of pyrophyllite and diaspore with quartz, and is consistent with this suggestion. However, in the apparent absence of the topaz, lazulite, andalusite and zunyite (diagnostic minerals of ascending hypogene acid fluids with probable magmatic components), it remains to be confirmed whether this alteration system is entirely magmatically derived, or alternatively, steam-heated (*cf.* Reyes, 1990).

STOP 1-5: **OVAL PIT PYROPHYLLITE MINE – Pit Floor** We will examine several large blocks of pyrophyllite ore on the floor of the pit. Beautifully preserved flow-bands in rhyolites and pumice lapilli in ash-flow tuffs demonstrate the nature of the protolith and argue for the pre-tectonic nature of the alteration. This pyrophyllite ore is texturally comparable to the unaltered pyroclastic rocks exposed farther north at Stop 5. Other blocks display the development of silica and pyrophyllite (and in some cases fine pyrite) in alternating bands, parallel to flow banding, crosscut by the regional cleavage. Diaspore nodules and massive pyrophyllite ore are exposed in the floor of the pit and in the walls of the most recent workings.

STOP 1-6: **OVAL PIT PYROPHYLLITE MINE – Top of Pit** If time allows, we will walk up to the 560 foot level, to examine the overlying sedimentary rocks, pausing briefly to look at zones of massive silica alteration (560 level), and the high-grade pyrophyllite-diaspore ore (490 level) occurring below altered conglomerate, immediately below the unaltered red sedimentary units.

The volcanic-hosted advanced argillic alteration zone is overlain by a succession of immature siliciclastic sedimentary rocks that are well exposed in the upper benches on the west side of the open pit. The lower part of the succession (ca. 60m thick), consists mainly of red to purple, fine to coarse-grained fluvial/ alluvial siliciclastic rocks, containing rare reworked tuffaceous layers. One such tuff bed occurs at or near the base of the succession, where it overlies a yellow-weathering boulder conglomerate, ca. 3 m thick. It is this conglomerate, itself pyritized, that is in contact with the underlying advanced argillic alteration zone.

The redbeds are overlain by grey and green, extensively slumped units of siltstone, sandstone and conglomerate. A steep reverse fault exposed immediately to the south of us, brings the alteration zone (in the southern extension of the pit) in contact with the sedimentary succession at a point approximately 60 m above its base. The same structure has a significant component of sub-horizontal displacement. Vertical and horizontal displacement of the ore zone along this fault is mimicked in the overall shape of the open pit, particularly the southwest extension.

Conglomerate beds in the lower part of the succession are rich in clasts derived from the advanced argillic alteration zone, as well as a large number of intricately laminated and banded rhyolite clasts. The proportion of hydrothermally altered material within the detrital assemblage decreases stratigraphically upwards. No clasts (altered or otherwise) with pre-incorporation deformation were noted, an observation consistent with a syn-volcanic and pre-tectonic origin for the earlier hydrothermal event.

This sedimentary succession is deformed by an open southeast-plunging syncline. The base of the succession does not appear to have a significantly irregular morphology, although the nature of the epithermal alteration beneath the sediments would imply some uplift to bring these rocks to the (syn-sediment) paleosurface. The trip will traverse down-section through the sediments, to the basal contact, where we will discuss the nature of this basal contact.

STOP 1-7: MINE BY-PASS PROSPECT

***Location**: Newfoundland Pyrophyllite Division (Trinity Resources and Energy, Limited) pyrophyllite mine property: new roadcut near south end of Mine Hill.*

This new roadcut exposes a wide zone of auriferous hydrothermal breccia and related advanced argillic alteration developed in a sequence of flow-banded rhyolite and related pyroclastic rocks. Alteration here is manifest chiefly by polyphase hydrothermal brecciation and silica flooding. We begin near the eastern end of this locality, and traverse westward from relatively massive (albeit flow-banded) rhyolite, through a zone of silica breccia veins and stockwork, into a silicic hydrothermal breccia with a chlorite-pyrite matrix. Farther west in the outcrop, a thrust surface is exposed, part of a high-strain zone developed in a zone of silica-sericite-pyrite alteration. The same chloritized silica-rich hydrothermal breccia found in the east end of the outcrop reappears below the thrust farther west in the outcrop. In both areas, these hydrothermal breccias, which are locally flooded by hematite, contain anomalous precious metal values (up to 1.8g/t Au, 6 g/t Ag).

Within the breccias, pyrite occurs as individual mm-scale euhedra, and in irregular zones, in which the pyrite is fine grained and heavily disseminated. Multiple generations of silica alteration is recorded by fragments within the breccias. Dark grey silica fragments within the breccia show evidence of pre-breccia hematite alteration.

Continuing westward along the exposure we cross zones of pyrite-sericite and quartz- sericite-pyrite alteration in a variety of pyroclastic and hydrothermal breccias, locally with silica-flooded matrix, passing into a pyrophyllite-silica zone developed in rocks of uncertain (locally spherulitic) protolith. The western end of the exposure consists of sericite-silica ± hematite altered fragmental rock.

STOP 1-8: MINE HILL QUARRY: HIGH-STRAIN ZONE IN ADVANCED ARGILLIC ALTERATION; PYROPHYLLITE ORE

***Location**: Mine property; turn left onto narrow road immediately west of Johnnies Pond.*

The Mine Hill Quarry represents one of the early attempts at commercial production from the pyrophyllite deposits of this region. Prior to the development of the Oval Pit deposit in the mid-1950s, most production from this area had come from the immediate Mine Hill–Johnnies Pond area.

Reverse-sense ductile shear zones with accompanying, intense, steeply dipping foliation are well exposed in the quarry wall. The protolith of the alteration is likely a welded tuff. Discontinuous pyritic zones are developed within the advanced argillic zones in this area. Most of the eastern and central portions of the quarry expose highly strained pyrophyllite-sericite-quartz rock, in which the silica forms discrete knobs. The western end of the quarry exposes highly strained pyrophyllite-sericite ore. Elsewhere on Mine Hill, this alteration zone is intruded by an unaltered, pre-tectonic (albeit weakly foliated) diabase dyke.

The high strain in evidence at this locality is in contrast to the situation around much of the Oval Pit Mine, where, excepting narrow high strain zones, the overall ductile strain is much lower. The contrast may reflect the location of the Oval Pit pyrophyllite ore zone in the core of a syncline (as indicated by the generally east-west trend of the bedding), relative to that of Mine Hill on the syncline's attenuated north-south trending limb.

In general, the zone of advanced argillic alteration has accommodated most of the strain in much of the eastern Avalon high-alumina belt. This is chiefly due to competence contrast between the adjacent unaltered rhyolites relative to the pyrophyllite-rich rocks within the alteration zone.

If time permits we will return to Mineral Road (farm access extension) to view nearby outcrops of extensively pyritized silica alteration within the pyrophyllite-bearing advanced argillic alteration.

STOP 1-9: ROADCUT PROSPECT

Location: *North side of Route 1 (Trans-Canada Highway) immediately east of ramp onto the Foxtrap Access. Leave pyrophyllite mine property via Minerals Rd., turn west onto new CBS by-pass, then south (left) onto Route 61 (Foxtrap Access road). Park immediately north of westbound ramp onto Route 1. Cross Route 61* ***(EXERCISE CAUTION)*** *and walk up the access ramp that routes traffic from Route 1 onto Route 61. Stop at outcrop on north side of Route 1.* ***CAUTION: ONCOMING TRAFFIC ON RAMP!***

The outcrop on the north side of the west-bound lane on Route 1 exposes a 100-m-wide section through a locally auriferous (up to 11.2 g/t Au) zone of advanced argillic alteration developed in the same late Neoproterozoic volcanic succession as in today's earlier stops. The prospect is sited near the western edge of the eastern Avalon high-Alumina belt, approximately 4 km along strike to the south from the Oval Pit pyrophyllite mine and the Mine By-Pass prospect. Hydrothermal alteration (silica– sericite ± pyrophyllite ± chlorite ± pyrite ± magnetite) is developed in a succession of flow-banded rhyolite, pumice-rich lapilli tuff or tuff-breccia, and lithophysae-bearing ash flow material, near the contact with overlying tuffaceous sedimentary rocks, and within several hundred metres of the boundary of the host volcanic rocks with monzonite-diorite-granite complex and the edge of the Holyrood Intrusive Suite. The latter are exposed nearby, immediately south of Route 1.

Much of the outcrop consists of zones of silica alteration, containing in excess of 90 percent (by volume) of silica-rich material, with remnant sericite and/or pyrophyllite; small pink patches seen in the western part of the outcrop are relict (silica-altered) lithophysae. Silica-rich (silica-flooded?) material contains blocks of sericite ± pyrophyllite ± silica alteration, which is developed parallel to fine eutaxitic- and flow-banding in felsic rocks. Late subhorizontal extensional quartz veins crosscutting sericite-silica altered rocks exposed at the western edge of the outcrop, are related to late vertical movements along the western edge of the high-alumina belt.

The larger silicic alteration zone contains areas of "pebbly" breccia, composed of dark grey sericite-pyrophyllite-pyrite fragments in a silica matrix, as well as zones of more angular to subrounded breccia with silicic-altered rhyolitic material in a chlorite-rich matrix. Both are present within a significant, ca. 10m-wide zone of gold mineralization in the central part of the outcrop. A chip sample taken across this zone averaged 3 g/t over 10 m (P. Saunders, personal communication). Anomalous gold values occur in the pebbly breccias, but highest gold values (up to 11.2 g/t) are obtained from silica-rich breccia with chlorite–pyrite (plus minor K-feldspar and muscovite) matrix and from felsic hydrothermal breccia with banded rhyolite clasts (O'Brien and O'Driscoll, 1996a, 1997: O'Brien *et al.*, 1997, 1998). Pyrite occurs as disseminations, clots and thin veinlets within the matrix of the breccias. The auriferous breccias yield assays up to 210 g/t Ag and 2 g/t As. The gold-bearing breccias at this locality are comparable in many respects to those seen in the previous stop, (4 km on-strike to the north).

STOP 1-10: TRIANGLE BELT

Location: *Stop 1-10 is a low roadcut adjacent to the west-bound lane of Route 1, several hundred metres east of Triangle Pond.*

A number of small copper (chalcocite, bornite, covellite ± chalcopyrite) showings, hosted by basalt flows, tuffs and breccia are present in this, the central block of the Harbour Main Group. The basalt-hosted copper occurrences on a regional scale are spatially associated with altered intrusive rocks (here and elsewhere in the Triangle Belt; see O'Brien and O'Driscoll, 1996; O'Brien *et al.*, 1997b). Their origin is uncertain. In some instances, mineralization is not accompanied by any extensive hydrothermal alteration, and bears similarity to volcanic-redbed copper mineralization (as noted by Kirkham, 1995; see also Stop 1-11). Elsewhere in the same belt, mineralization is associated with extensive auriferous silica-rich hydrothermal alteration, that is intimately associated with intrusive rocks of mainly monzonitic composition (Rennie, 1989; Beischer, 1991; O'Brien and O'Driscoll, 1996). Here vesicular to massive basaltic rocks and associated diabase, with hematite-chlorite-epidote alteration are intruded by fine to medium grained intermediate intrusive rocks. Calcite and quartz veins and vein breccias associated with chlorite and or chloritoid and hematite occur in several parts of the outcrop. Veinlets contain weakly elevated gold concentrations. Nearby intrusions are extensively hematitized.

STOP 1-11: MARYSVALE (TURKS GUT): BASAL CONCEPTION GROUP UNCONFORMITY; TURKS GUT CU-AG-AU PROPERTY

Location: *Continue westward on Route 1. Take Avoidable Access Road to rejoin Conception Bay Highway (Route 60). Turn left onto Route 60, proceed northwest to Marysvale. Turn right onto side road through Marysvale ending at the coast at Turks Gut.*

Outcrops adjacent to the parking area near the wharf expose coarse-grained, very well-rounded boulder conglomerate, rich in basaltic detritus, that unconformably overlies basalt flows of the (post-610 Ma) western block of the Harbour Main Group. The overlying Conception Group siliciclastic beds are exposed in the opposing cliff-face on the west side of the gut. The dipping unconformity surface between the Harbour Main and Conception groups is itself overstepped unconformably by Lower and Middle Cambrian beds preserved in outliers exposed nearby.

The basalts under the Conception Group along much of the northwest edge of the Holyrood Horst contain copper-bearing calcite-quartz±chlorite±grey silica veins, stringers and fractures. These copper occurrences are locally associated with elevated gold values but most typically with high silver contents. The main Turks Gut Ridge shaft (55 m deep), one of several showings in the immediate area, is located on the east side of the gut (farther south, near the water pipe), at the top of the talus slope. Mineralized samples (chalcocite, bornite ± covellite) are most easily found in the talus slope. The shaft, which dates back to the mid-eighteenth century, is sunk in cupriferous breccia veins that cut basaltic rocks that also contain disseminated copper mineralization. The larger veins are composite and multiply brecciated and contain fine-grained pale grey, green or grey-green silica. Grab samples from the prospect return assays of up to 33% Cu and 11.6 oz/ton Ag; a 1 m channel sample yielded an assay of 11.3% Cu, 269.3 g/t Ag, and 0.97 g/t Au (E. Benson, written communication). Wall rock alteration is developed, for the most part, immediately adjacent to the mineralized veins, and is chlorite-apatite-silica±hematite.

STOP 1-12: PYRRHOTITE-PYRITE-BEARING ROCKS OF THE ST. JOHN'S GROUP

Location: *Route 74 (road to Hearts Content) near Victoria, behind Carbonear.*

Rusty exposures of the Renews Head Formation of the St. John's Group are exposed adjacent to the road to Hearts Content, near Victoria. This occurrence of pyrrhotite is part of one of numerous stratabound sulphide horizons found in the Renews Head and Fermeuse Formations of the St. John's Group in this area. These typically include blebby, disseminated, fracture-controlled and locally bedded pyrrhotite and less extensive pyrite, galena and sphalerite. The mineralization occurs within thin- and lenticular-bedded (locally slumped) black and dark grey shale and silty sandstone. The occurrences are coincident with a large-scale multi-element lake-bottom sediment anomaly (Zn, Pb, Cu, Ag, Au) and bear similarity to sedimentary-exhalative base metal style mineralization. Recent drilling by Vulcan Minerals near here, designed to test coincident lake sediment anomalies and electrical conductors, encountered intersections of 1.2 m of 4.10% Pb and 1.58% Zn and 0.6m 1.44 % Zn and 1.63% Pb.

DAY 2

Stratigraphy and Late Neoproterozoic Lithofacies of The Avalon Zone

Leader

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GEOLOGICAL SETTING

A.F. King

The Avalon Peninsula is geological part of the Avalon Zone (Figure 2-1) of the Newfoundland Appalachians. A simplified model for the late Neoproterozoic and early Paleozoic development of the Avalon Zone of Newfoundland is shown in Figure 2-2. The Avalon Zone consists of a thick, late Neoproterozoic (ca. 635-545 Ma) succession, which contains, in ascending order, volcanic arc rocks of the *Harbour Main Group*, turbiditic sandstones of the *Connecting Point* and *Conception groups*, basinal-deltaic shales-sandstones of the *St. John's Group*, and molasse-like sandstones and conglomerates of the *Musgravetown* and *Signal Hill groups* that define major, elongate, structural domes and basins (Figures 2-3 and 2-4).

The rocks were first deformed in the late Neoproterozoic Avalonian Orogeny and subsequently regionally deformed and metamorphosed during the mid-Paleozoic Acadian Orogeny. The volcanic rocks were intruded during the closing stages of the Avalonian Orogeny by 620±2 Ma (Krogh *et al.*, 1983, 1988) granitoid rocks of the Holyrood Intrusive Suite as well as by undated monzonite and diorite plutons. The Late Neoproterozoic 'Avalonian Orogeny' predates Iapetus and is assumed to mark the original westward extension of the Cadomian Orogeny of western Europe and the Pan-African Orogeny of northwest Africa. Both volcanic and granitoid rocks are nonconformably overlain in southeastern Conception Bay by fossiliferous Cambrian and Ordovician marine shelf sedimentary rocks.

Regional lithological correlations indicate some degree of formational homogeneity in the 10 km thick succession of siliciclastic Neoproterozoic rocks exposed in the central and eastern Avalon Peninsula. For example, along western Conception Bay (Figure 2-5), major stratigraphic units are lithologically similar to those of the eastern Avalon are represented by the Conception, St. John's and Signal Hill groups. However, in eastern Trinity Bay, between New Melbourne and Dildo, a major divide separates these groups from the molasse-like facies of the Musgravetown Group to the west (Figure 2-5). This group contains a thick bimodal volcanic assemblage at its base, the Bull Arm Formation. West of the Avalon Peninsula, the Musgravetown Group either unconformably overlies or is faulted against a thick marine sedimentary succession, the Connecting Point Group, which bears gross lithologic and stratigraphic similarities to the Conception Group.

In eastern Trinity Bay, a major unconformity separates the Musgravetown Group from the overlying Lower Cambrian Random Formation. The Lower Paleozoic paleontology has been reviewed by Hutchinson (1962), Bergström (1976), Anderson (1981), Bengston and Fletcher (1983), Ranger *et al.* (1984), Boyce (1988) and Landing (1996).

The following account summarizes the late Neoproterozoic and early Paleozoic lithofacies of the Avalon Peninsula of Newfoundland, with emphasis on the Conception, St. John's, Signal Hill and Musgravetown groups and the enigmatic nature of the related Avalonian Orogeny.

LITHOSTRATIGRAPHY AND PALEOGEOGRAPHIC EVOLUTION

Schematic diagrams of the paleogeographic evolution of the Avalon Peninsula, shown in Figure 2-4, are based on regional studies by King (1980, 1988a, 1988b, 1990) and are applicable to

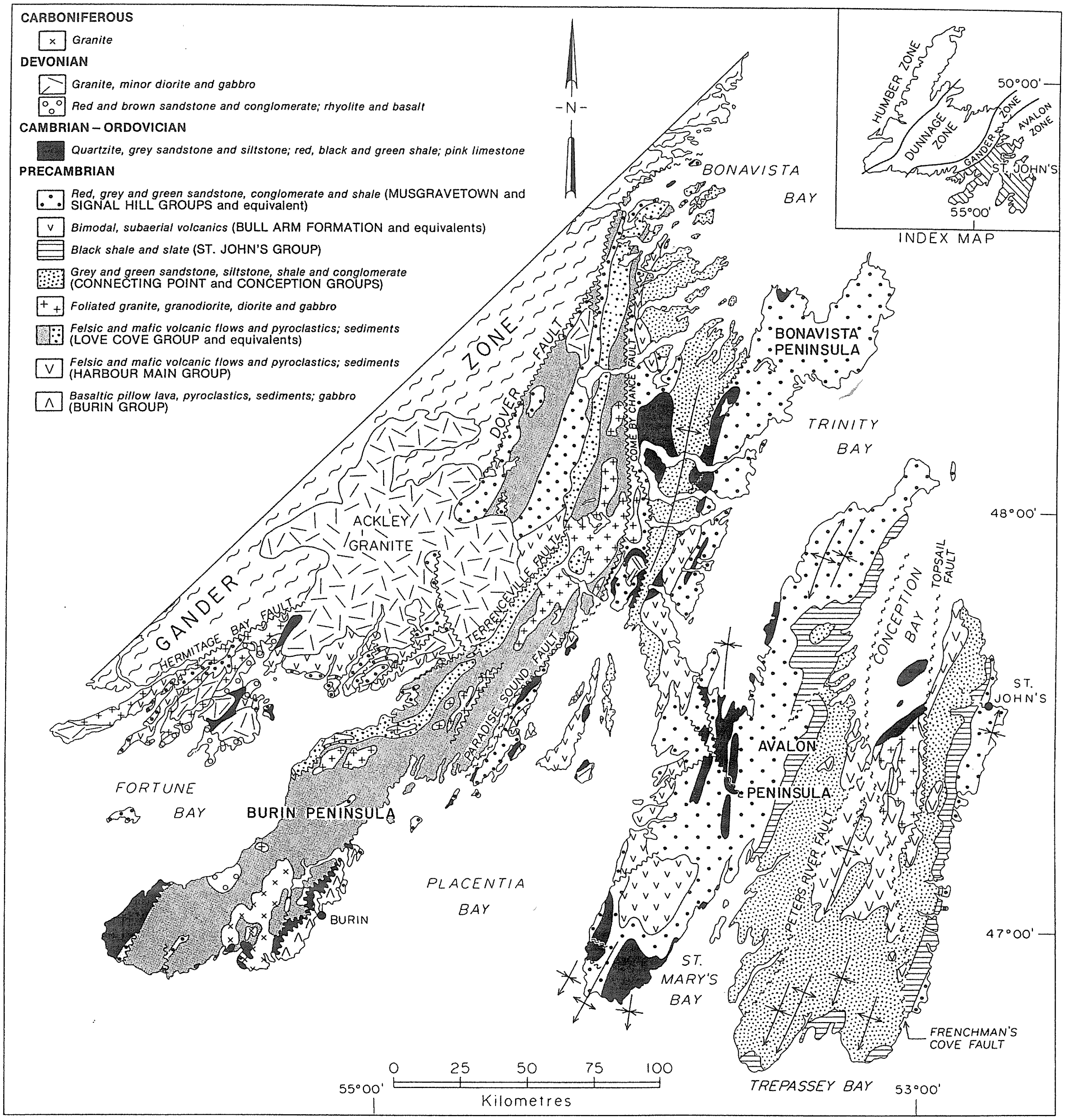

Figure 2-1. *Simplified geological map of the Avalon Zone in Newfoundland (King, 1990). The index map illustrates the major tectonostratigraphic zones of the Newfoundland Appalachians.*

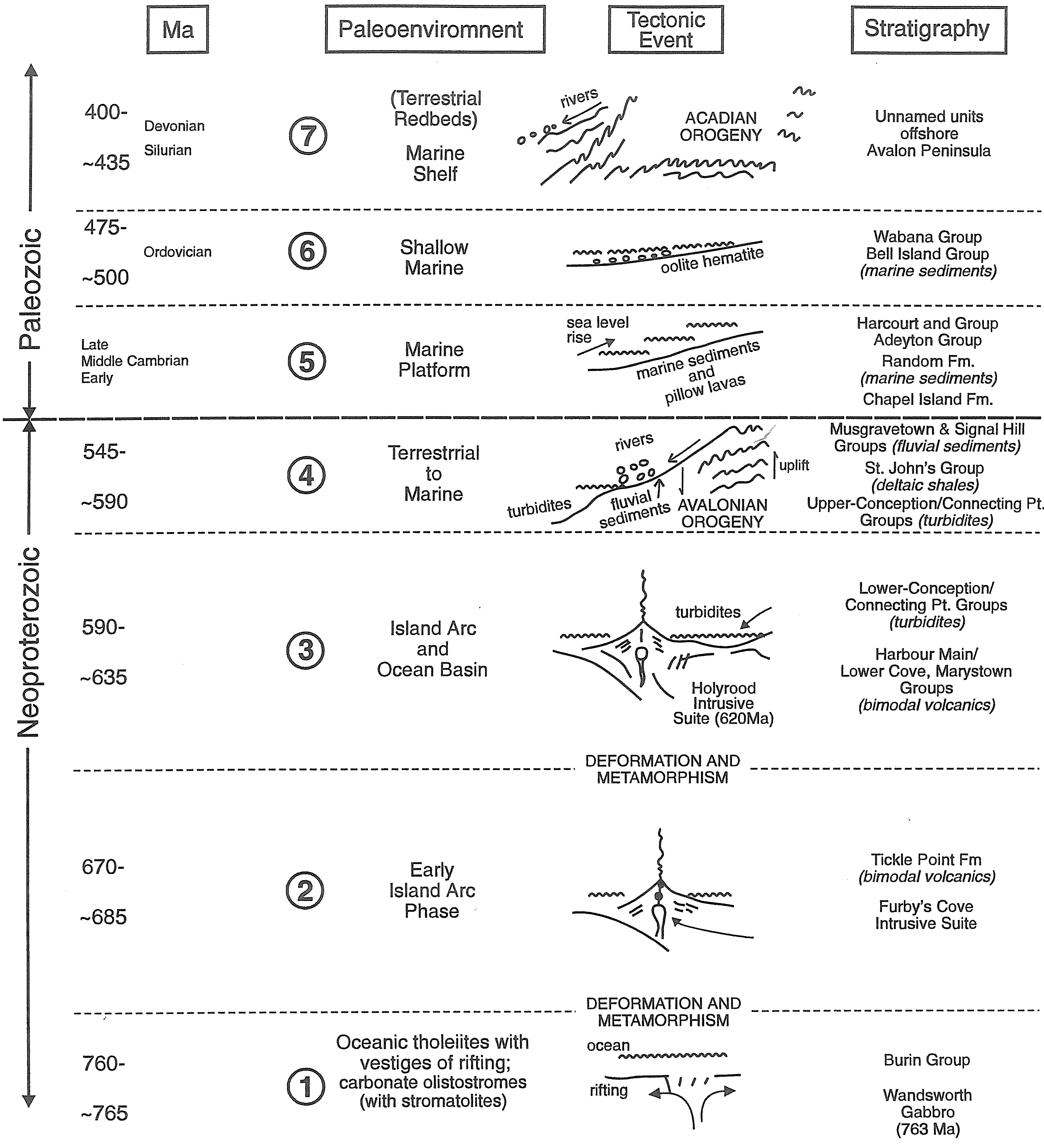

Figure 2-2. *Outline of principle paleoenvironments, tectonic events and stratigraphic examples in the Avalon Zone of Newfoundland.*

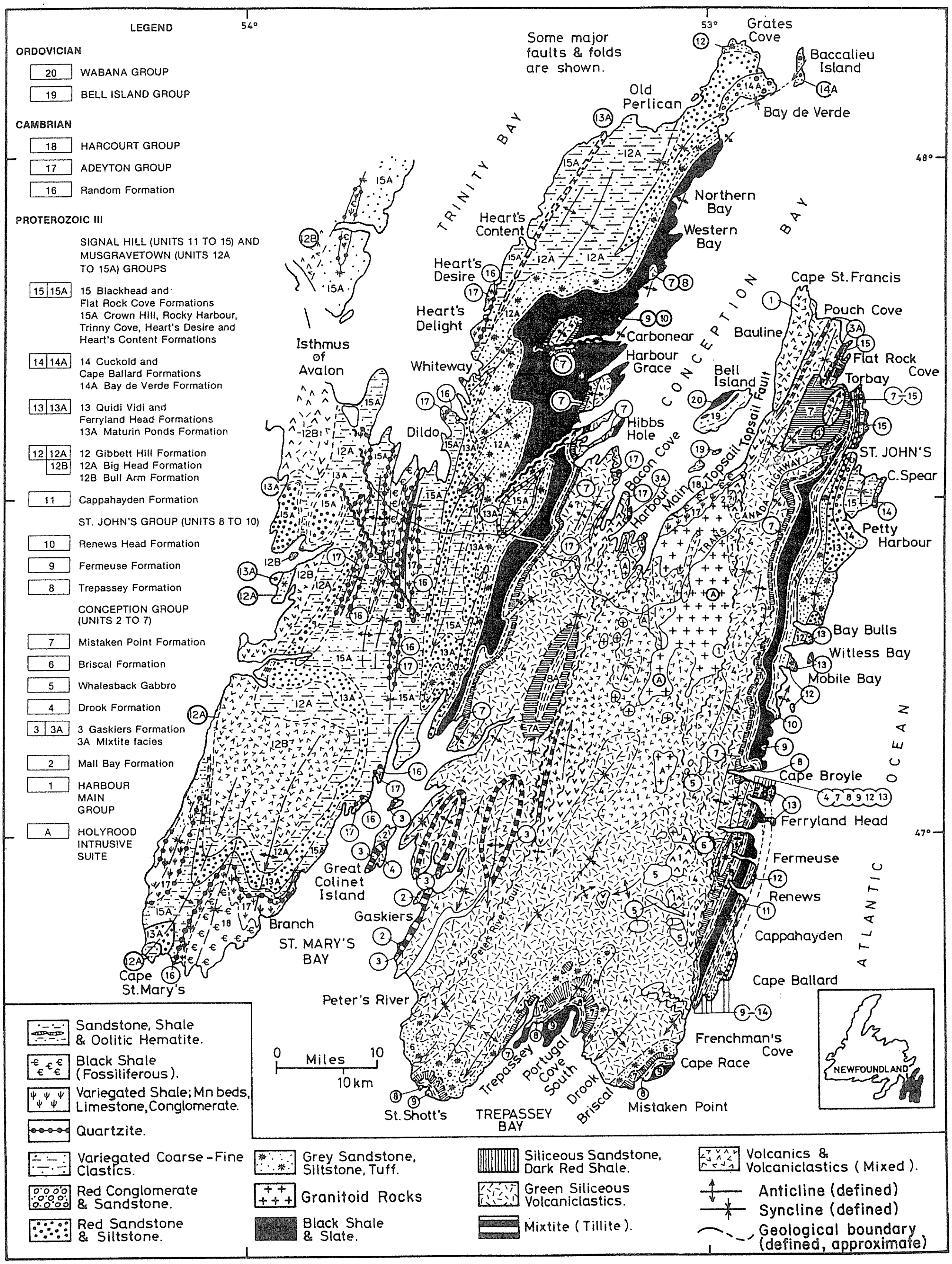

Figure 2-3. *Geological map of the Avalon Peninsula (King, 1990).*

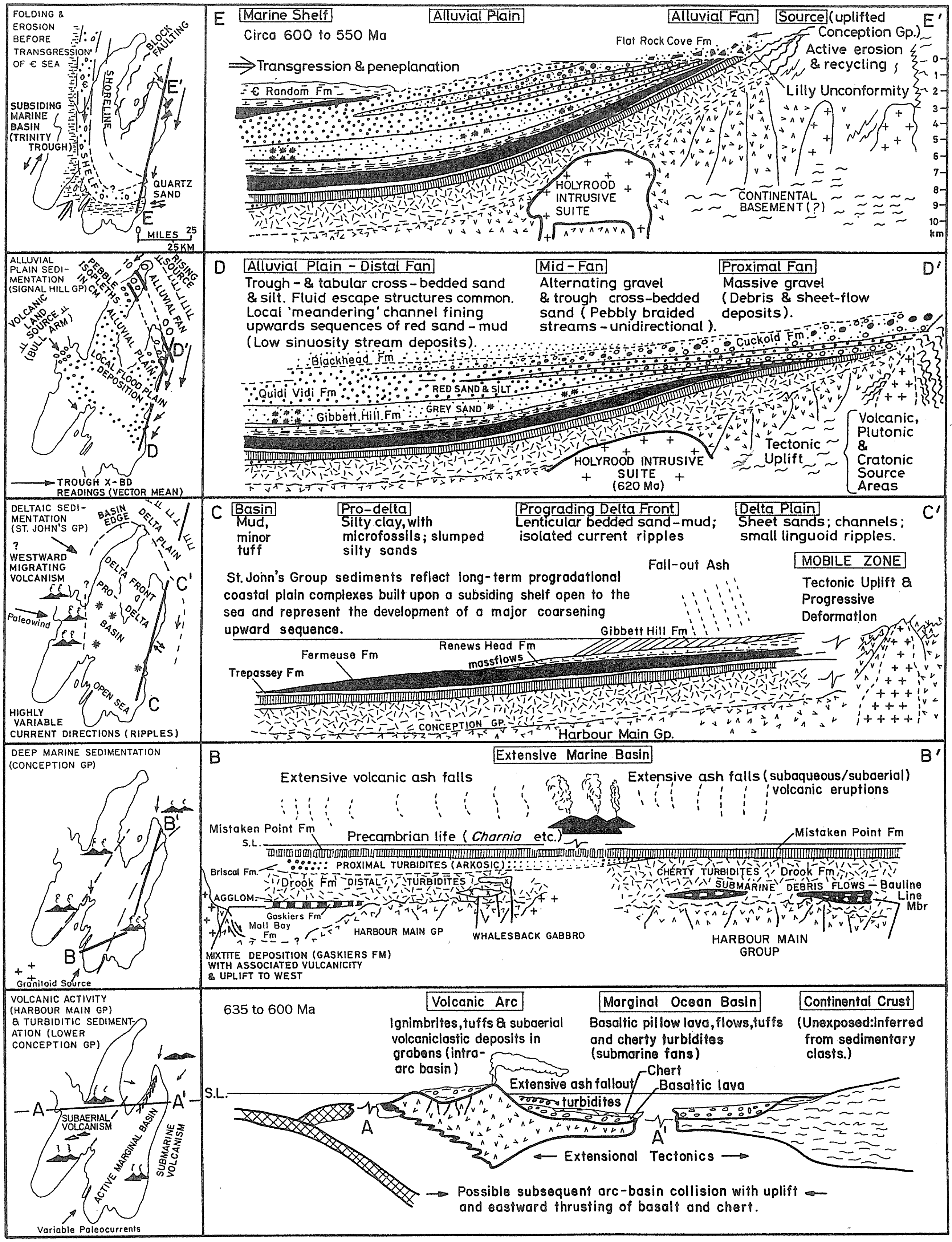

Figure 2-4. *Late Precambrian and Early Paleozoic development, eastern Avalon Peninsula (King, 1990).*

LEGEND

CAMBRIAN

MIDDLE TO UPPER CAMBRIAN

HARCOURT GROUP (Manuels River and Elliott Cove formations)

HCo	*Grey, green, black micaceous shale; siltstone*

LOWER TO MIDDLE CAMBRIAN

ADEYTON GROUP (Bonavista, Smith Point, Brigus, Chamberlain's Brook formations)

AC	*Red, green, purple shale, slate, minor limestone*

- - - - - - - - - - - - - - *unconformity* - - - - - - - - - - - - - -

CR	Random Formation: *Quartz arenite, basal conglomerate*

- - - - - - - - - - - - - - *unconformity* - - - - - - - - - - - - - -

NEOPROTEROZOIC

MUSGRAVETOWN GROUP

MHC	Crown Hill Formation: *Red pebble conglomerate and sandstone; minor red siltstone*
MHHD	Heart's Desire Formation: *Olive-green sandstone*
MHHC	Heart's Content Formation: *Grey to black shale; sandstone laminae*
MHM	Maturin Ponds Formation: *Red sandstone, mudstone; minor conglomerate*
MHBI	Big Head Formation: *Grey to green tuffaceous siltstone and arkose*
MHBA	Bull Arm Formation: *Felsic and mafic volcanic rocks*
MHCC	Cannings Cove Formation: *Conglomerate and sandstone*

SIGNAL HILL GROUP

SHBVo,b	Bay de Verde Formation: *Red and gray sandstone, siltstone, mudstone (Old Perlican Member); red conglomerate and sandstone (Baccalieu Member)*
SHG	Gibbett Hill Formation: *Thickly bedded, light-grey sandstone; local red sandstone, siltstone*

ST. JOHN'S GROUP

JHR	Renews Head Formation: *Dark-grey sandstone and minor shale*
JHF	Fermeuse Formation: *Grey to black shale; minor sandstone and siltstone*
JHT	Trepassey Formation: *Grey sandstone and shale; minor tuffaceous*

CONCEPTION GROUP

CHMP	Mistaken Point Formation: *Red and green tuffaceous sandstone; metazoan fossils near top*
CHD	Drook Formation: *Green, siliceous siltstone and sandstone; silicified tuff*

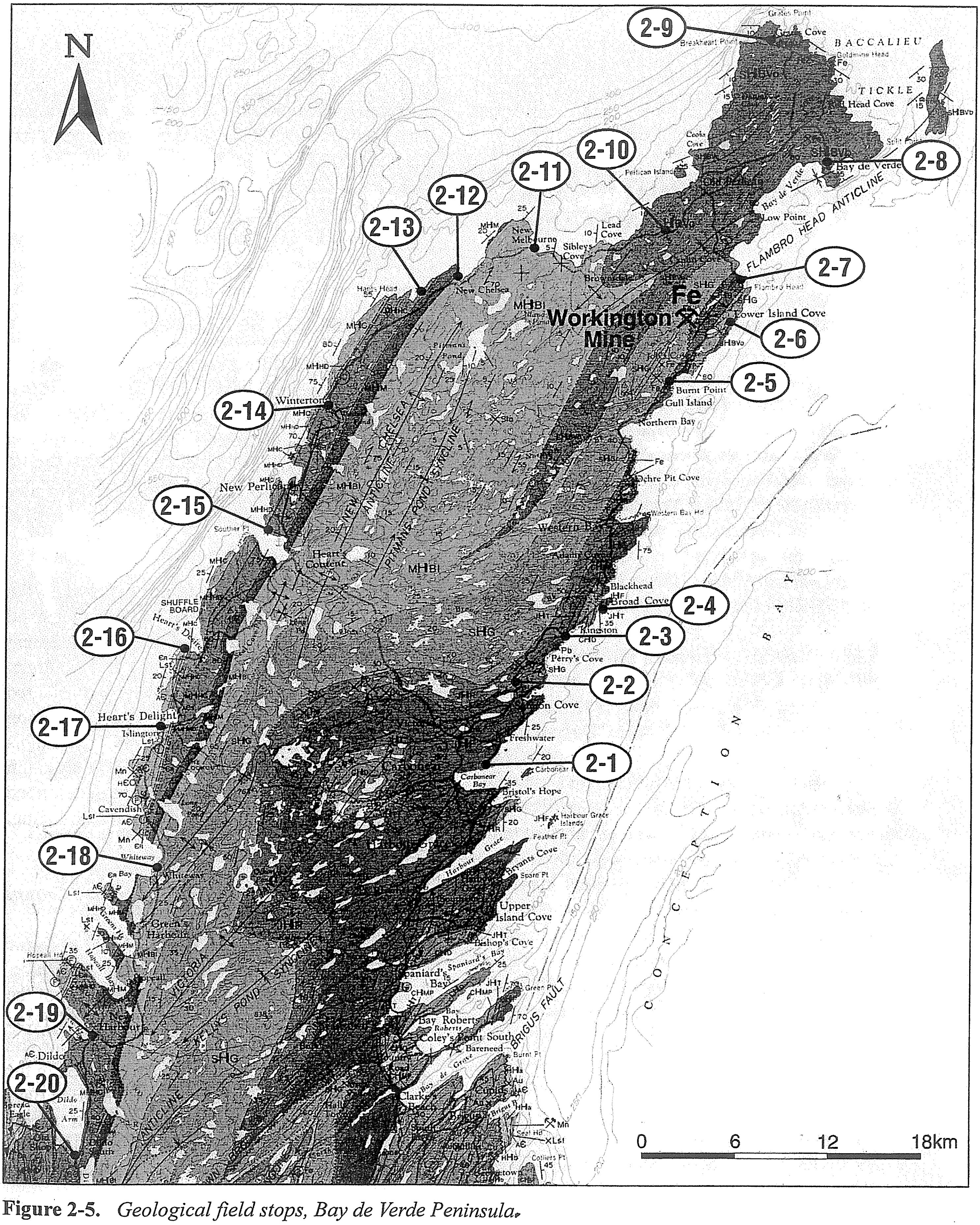

Figure 2-5. *Geological field stops, Bay de Verde Peninsula.*

the Neoproterozoic and Cambrian rock units. They reflect a long history (over 100 million years) of volcanic activity, marine and terrestrial sedimentation, uplift and subsidence.

MAJOR NEOPROTEROZOIC FACIES AND FORMATIONS

Submarine and Subaerial Volcanism

The Harbour Main Group

Bimodal volcanic rocks, which formed in submarine and subaerial environments, are diagnostic of the Avalon Zone. In Newfoundland, these rocks are exposed in separate, mainly northeast trending belts (Figure 2-1). The oldest rocks on the Avalon Peninsula (Figure 2-3) comprise a bimodal volcanic assemblage, the Harbour Main Group (Rose, 1952), which formed between 635 and 600 Ma. (King 1988; Krogh *et al.*, 1988, O'Brien *et al.*, 1990, 1997).

Along eastern Conception Bay (between Cape St. Francis and Topsail) basaltic pillow lava, massive mafic flows, tuffs and associated clastic rocks of the Harbour Main Group, represent an early history of submarine volcanism and widespread marine turbidite and pelagic sedimentation (King, 1990). The mafic flows are chemically similar to the "hawaiites" present in the Harbour Main volcanic belt west of Colliers (Papezik, 1970). Tuffite-rich "proximal" turbidites at Portugal Cove, represent a transition into the cherts and turbiditic sandstones of the Conception Group. The Harbour Main Group and the lower part of the Conception Group in the St. John's region are therefore largely penecontemporaneous (King 1990).

Mafic, intermediate and felsic flows and pyroclastic rocks, which formed mainly in an explosive subaerial environment are diagnostic of the Harbour Main Group of the central Avalon Peninsula (see Day 1 excursion stops). Along the southern and eastern shores of Conception Bay, felsic and mafic flows, pyroclastics and minor volcaniclastics, are intruded by the high level Holyrood Intrusive Suite, dated at 620 Ma ± 2Ma (Krogh *et al.*, 1988); these rocks are unconformably overlain by fossiliferous Lower Cambrian shale and limestone (e.g. at Dunn's Hill Road). The volcanic rocks (rhyolite-rhyodacite-dacite) dated at 631±2 Ma (U-Pb zircon, Krogh *et al.*, 1998) host extensive zones of syn-volcanic hydrothermal alteration and brecciation and are locally accompanied by epithermal-style gold and pyrophyllite mineralization (O'Brien *et al.*, 1997). In the type locality of Avondale-Harbour Main, southwestern Conception Bay, acidic ash-flow tuffs are locally intercalated with fluvial and lacustrine volcanogenic sediments and overlain by terrestrial massive and amygdaloidal basalt flows (Nixon, 1974; Nixon and Papezik, 1979; O'Brien *et al.*, 1997).

The base of the group is not exposed in the Avalon Zone of Newfoundland and it is presumed to be underlain by continental gneissic basement (O'Brien *et al.*, 1983). In central and southern Avalon Peninsula, the group is generally considered to be unconformably overlain by the Conception Group (Rose, 1952, McCartney, 1967; Williams and King, 1979, O'Brien *et al.*, 1997) although examples of interfingering have also been described (Hughes and Bruckner, 1971; Williams and King, 1979).

The Bull Arm Formation (Musgravetown Group)

The Bull Arm Formation, a bimodal volcanic suite within the lower part of the clastic Musgravetown Group, is well exposed on the isthmus of the Avalon Peninsula (Figure 2-3), at Hopeall Head (north of Dildo), and between Long Harbour and southeast Placentia. It is also poorly exposed in the major dome between Placentia and St. Mary's Bays (Figure 2-3). The formation consists of basalt, rhyolite, ash flows and associated volcaniclastics, with a variable aggregate thickness of about 2.5 km.

Volcanism represented by the Bull Arm Formation was probably an important source of ash for the tuffaceous Gibbett Hill formation to the east and thus may be significantly younger than and unrelated to the Harbour Main Group volcanism. The Bull Arm Formation on the Isthmus of Avalon Peninsula is underlain by the Connecting Point Group; the nature of the contact is somewhat enigmatic, but has been interpreted as conformable by McCartney (1967).

Marine Turbiditic and Pelagic Sedimentation

The Connecting Point Group

Marine volcaniclastic sediments on the Isthmus of Avalon Peninsula (e.g. between Arnold's Cove and Little Harbour East) and to the west are known as the Connecting Point Group (Figure 2-1); possible correlatives on the Avalon Peninsula are termed the Conception Group.

The Connecting Point Group is a fault-bounded, turbiditic sandstone and black shale unit; the total exposed thickness of the Group was estimated by Jenness (1963) to be 7.5 km. The black shales of the Connecting Point Group are the most prolific Late Riphean to Vendian micro-fossil level in the Avalon Zone of Newfoundland (Hoffmann *et al.*, 1979).

The Conception Group

The Conception Group (Rose, 1952) occurs throughout the Avalon Peninsula (Figure 2-3) and is dominated by green to grey siliceous sandstone, siltstone and mudstone. Basal conglomerate defines the boundary between the Harbour Main and Conception groups, approximately 3 km south of Duffs hydroelectric station (O'Brien, *et al.*, 1997). No complete section of the group is exposed. The abundance of tuff and other volcanic detritus throughout the estimated 3 to 5 km thick marine succession, suggests submarine fan sedimentation (Figure 2-6) contemporaneous with volcanism (Figure 2-7). Perhaps, as suggested by Hughes and Bruckner (1971), related in time to Harbour Main Group volcanism. The basal part of the Conception Group is older than the 620 Ma (Krogh *et al.*, 1983) Holyrood Intrusive Suite, although a zircon date of 565±3 Ma (Benus and Dunning *in* King, 1988b, 1990) on the youngest beds indicates that the group was formed over a period of 60 Ma or more.

The lower part of the Conception Group is well exposed along the coast of eastern St. Mary's Bay and southern Conception Bay. Deep-water siliceous turbidites of the *Mall Bay Formation* (>800 m), are overlain by mixtites of the *Gaskiers Formation* (300 m) interpreted as glaciogenic, submarine debris flows (Anderson and King, 1981), and then by more turbidites which define the *Drook Formation* (estimated formation thickness 1500 m). The depositional history can be summarized as follows: (1) deposition of the Mall Bay Formation by progradation of a submarine fan from a volcanic source terrane (island) with reworking of slope deposits by relatively strong bottom currents (Figure 2-7); (2) deposition of mixtites of the Gaskiers Formation from glaciogenic debris flows and other high-concentration flows; and (3) renewed submarine fan progradation as a new volcanic centre became the dominant source for the lower part of the Drook Formation (Gardiner 1984; Gardiner and Hiscott, 1988). The Gaskiers Formation of St. Mary's Bay is lithologically comparable with till-like beds which form distinctive mixtite units up to 100 m thick in the Bacon Cove-Harbour Main area of southwestern Conception Bay (O'Brien *et al.*, 1997); precise correlation of all these units is, however, uncertain.

Green, siliceous, volcaniclastic sedimentary rocks of the Drook Formation (Williams and King, 1979) constitute much of the Conception Group throughout the Avalon Peninsula including the core of a large anticline west of Carbonear (Victoria Anticline) and at Kingston (Figure 2-5). In the type locality of Drook, near Portugal Cove South, southern Avalon Peninsula, the formation contains

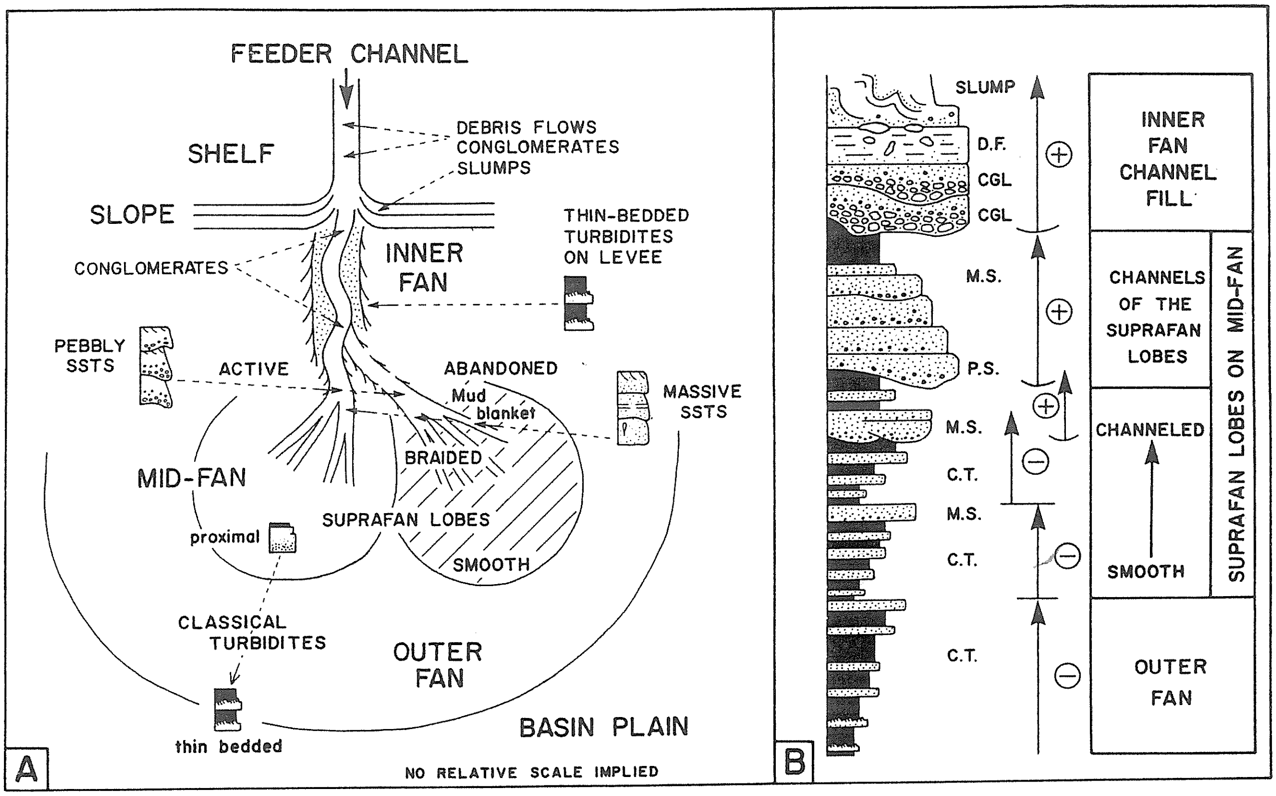

Figure 2-6. Submarine fan facies models. A- Original fan model proposed by Walker (1979). B- Generalized hypothetical sequence produced during over-all fan progradation (Walker 1979). *(CT= classical turbidites; MS= massive sandstone; PS= pebbly sandstones; CGL= conglomerate; DF= debris flow; SL= slump. Thinning- and fining-upward sequences = ⊕, thickening- and coarsening-upward sequences = ⊖).*

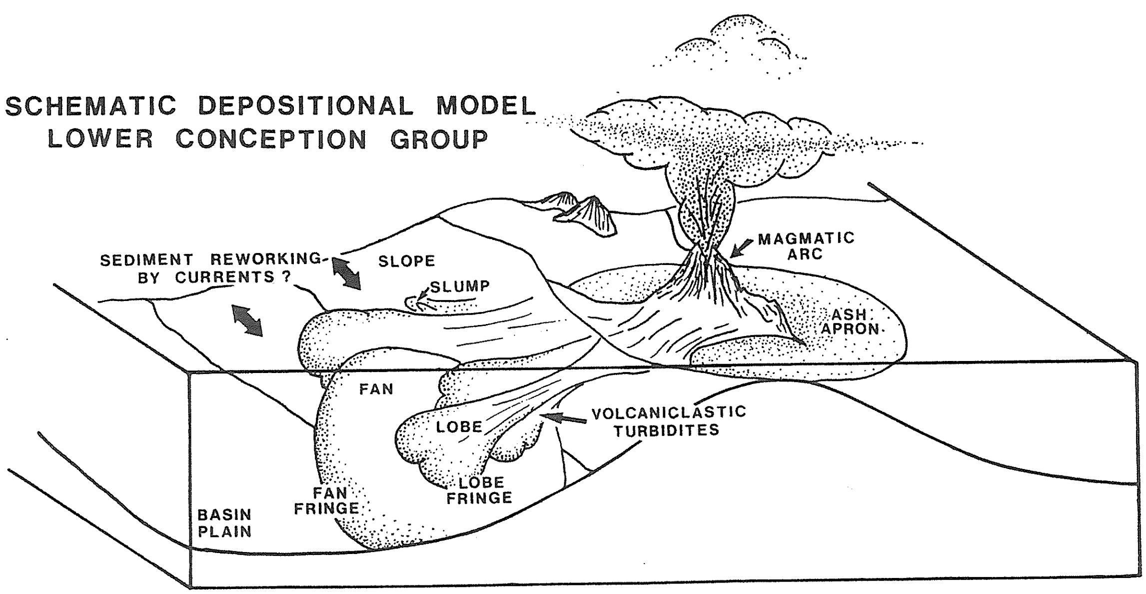

Figure 2-7. *Schematic depositional model for the Lower Conception Group (from Gardiner, 1984).*

chert, siliceous siltstone, sandstone, and silicified tuff; it is conformably overlain there by coarse grained, thick-bedded sandstones of the *Briscal Formation.* Williams and King (1979) calculated a minimum estimated thickness of 1500 m, and noted that the Briscal Formation thins or pinches out northward towards the central Avalon Peninsula. Along the Roaches Line (approximately 6 km north of the TCH), the Drook Formation is capped by a thin unit of coarse grained green sandstone comparable in facies, although not in thickness, to the Briscal Formation (O'Brien *et al.,* 1997). In the St. John's area the Drook Formation is divisible into four members (King, 1990) and these were primarily deposited by turbidity currents, probably on a middle to outer fan environment (Figure 2-7); thin interbeds of tuff and cryptocrystalline chert of volcanogenic origin indicate active volcanism during sedimentation. The Drook Formation rocks throughout the Avalon Peninsula are relatively competent and form large scale elongate domes and basins, corresponding with areas of topographic high and low relief.

The name *"Mistaken Point Formation"* was proposed by Williams and King (1979) for the interbedded greenish grey and reddish purple tuffaceous siltstones, shales and sandstones that conformably overlie the Briscal Formation in the southern Avalon Peninsula (Figure 2-3). At its type section on Mistaken Point, the formation is profusely fossiliferous with a variety of frond-like and disc-like impressions (Anderson and Misra, 1968, 1969a, 1969b; Williams and King, 1979; Anderson and Conway-Morris, 1982; King, 1988b). The fossiliferous Mistaken Point strata define a biostratigraphic zone as well as a lithologic formation. The late Precambrian fossils occur on bedding plane surfaces and in most cases occur beneath dark, thin tuff horizons that are less than one cm thick. Metazoan fossil horizons are most common toward the top of the formation and nine fossiliferous horizons have been identified at the type locality. A concentration of thin tuff beds near the top of the formation are dated at a 565±3 Ma (Benus, *in* King 1988b, 1990) indicating that it is an actual chronologic unit as well. This easily recognized formation was therefore chosen by Williams and King (1979) to define the top of the Conception Group.

The Mistaken Point Formation has been traced northward from the type locality to Cape Broyle, where it directly overlies the Drook Formation and from there, through the Mt. Pearl - St. John's - Windsor Lake area to Torbay. In the central Avalon Peninsula, the most complete profile of the Mistaken Point Formation is exposed in a large quarry adjacent to, and south of the TCH, at its intersection with the Avondale access road (see O'Brien, *et al.,* 1997). It is also exposed in new roadcuts south of Makinsons (Conception Bay South Bypass) and in the core of a major, elongate domes near Hibbs Cove–Clarke's Beach-Spaniard's Bay, in the Victoria Anticline of Carbonear and in the nose of a plunging anticline between Kingston-Broad Cove, southwestern Conception Bay (Figure 2-5).

The Mistaken Point Formation is about 400 m thick throughout the Avalon Peninsula. It is divisible into a lower unit (*Middle Cove Member*) characterized by a generally fining upward sequence of grey turbiditic sandstone and siltstone, chert and tuff, which is overlain by an upper unit (*Hibbs Cove Member*) of red and green tuffaceous mudstone and siltstone (cf. original Hibbs Hole Formation of Hutchinson, 1953). The volcanogenic Mistaken Point Formation (particularly the Middle Cove Member) represents a period of explosive felsic volcanic activity associated with turbiditic sedimentation. Turbidity currents transported much of the coarser volcanic detritus into a shelf or basin that at the same time was receiving considerable influx of pyroclastic material. Medium to thick bedded tuffs with a composition close to that of alkaline rhyolite (Hughes, 1976), may have formed by fallout into water from subaerial volcanoes or may have originated by fallout from underwater eruptions. Thick bedded units of lithic tuff are interpreted as subaqueous, pyroclastic (ash) flow deposits. Crude, sub-parallel orientation of clasts within the lithic tuffs, suggests an initially dense semi-fluidized mass, which flowed rapidly with essentially laminar motion, analogous to a flow-banded rhyolite. The presence of granophyre fragments and clasts showing micrographic intergrowth may indicate proximity to ring-dykes, concomitant with eruption and caldera collapse (Hughes 1976). Sedimentary textures and structures within the overlying upper member indicate deposition by low-density turbulent flows in a basin plain transitional with an outer-fan fringe and slope. Parallel-laminated tuffaceous siltstones and mudstones intercalated with the medium bedded argillaceous sandstones probably represent pelagic and hemipelagic detritus reworked by traction flow processes.

Shallowing Upward Basinal - Deltaic Sedimentation

The St. John's Group

The Conception Group is conformably overlain by up to 2 km of marine shale and interbedded sandstone of the St. John's Group, a fluvial-dominated deltaic sequence (King, 1980, 1990) which progrades and thickens southward on a shallow-marine coastal plain environment. The St. John's Group (Williams and King, 1979) consists of three units, from bottom to top, the *Trepassey*, *Fermeuse* and *Renews Head* formations. In western Conception Bay (Figure 2-5) the 'lower division' of the Carbonear Formation of Hutchinson (1953) has been correlated with the Fermeuse Formation and the 'upper division' with the Renews Head Formation by King (1980).

Greenish grey tuffaceous siltstone and argillaceous sandstone of the Trepassey Formation represent a transitional zone into the underlying Mistaken Point Formation with its distinctive metazoan fauna. These fine sands and muds were primarily deposited by "distal" turbidity currents in a basinal shelf or plain (Figure 2-6); they reflect high-concentration gravity and traction flow processes and are interpreted as deposits of a turbidite-fronted delta. Pelagic and hemipelagic detritus, including microplankton and volcanic ash were deposited above the sands and were reworked by bottom traction currents.

The overlying black shales of the Fermeuse Formation exhibit slumped and resedimented features caused by gravity slumping and sliding; these features are common in the shales exposed in the Carbonear-Harbour Grace-Shearstown area, and are interpreted as submarine slope deposits which were fed by a delta front as it prograded southwards over the shelf. Sediment instability resulted in gravity slumping and disruption of strata on an ancient slope of some considerable magnitude; considering the widespread distribution of this facies throughout the Avalon Peninsula, the depositional basin probably exceeded 10,000 km^2. Similar features on continental slopes have been well documented by a number of workers (e.g. Kelling and Stanley, 1976; Sangree *et al.,* 1976; Nardin *et al.,* 1979).

As shown in Figure 2-4, the marine basin subsided as it was infilled with sediment while uplift was taking place beyond its northern margin. The Fermeuse and Renews Head formations of the St. John's Group and the Gibbett Hill and Quidi Vidi formations of the Signal Hill Group are in part diachronous or coeval and formed by lateral accretion and progradation of onshore to offshore facies.

The upper unit of the St. John's Group, the Renews Head Formation, is well exposed along new roadcuts near Halls Town and in high hills between Kelly's Pond, Gull Pond, Perry's Cove, Ochre Pit Cove and Flambro Head (Figure 2-5). Thin, lenticular-bedded, rusty-brown weathering sandstone with dark shale laminae, pass upward into thin irregular beds showing ripple-drift cross-lamination, indicating a greater influx of silt and fine sand with traction flow processes becoming increasingly important. This formation represents a shoaling upward of the marine basin. Thin graded beds with sharp bases suggest some transport by turbidity currents. Small scale asymmetrical, straight crested, linguoid and interference ripple marks and flaser bedding were caused by reworking of the upper part of the sand beds by waves, currents and tides, probably in an inactive distributary-mouth bar environment (e.g. Miall, 1976). Rare gutter casts, flaser bedding (in which mud lenses were deposited in ripple troughs) and dessication cracks, occur near the top of the Renews Head Formation and may also have formed on a delta top environment that was modified by storm(?) waves or currents. Large-scale, trough cross-stratified, channelized sandstones that are intercalated with the shales are interpreted as major frontal or distal distributaries, sheet sands and lobes of the Gibbett Hill Formation, which generally prograded southward into a shallow marine environment. Their stratigraphic position varies throughout the Renews Head Formation, strongly suggesting diachronous relationships. Rapid deposition of sand above muds resulted in convolute bedding and internal loading.

Numerous varieties of the problematical markings *Aspidella terranovica* Billings, 1872, are present within the shales. Some of the larger disc-like varieties resemble *Charniodiscus* and may be medusoid impressions. Other unusual forms thought to represent impressions of soft-bodies fauna have been described by Anderson and Conway-Morris (1982). The shales between Carbonear and Kingston also contain some Vendian microfossils, including *Bavlinella* (Hofmann, *et al.,* 1979), but most microbiota recovered are either poorly preserved or include compressions of simple, allogenic spheroidal and filamentous forms with long stratigraphic range. Local tuff beds in the Trepassey and Renews Head formations record intermittent but waning volcanic activity.

The Renews Head Formation exposed on the Heart's Content barrens, contains minor pyrite and pyrrhotite together with traces of chalcopyrite, sphalerite and galena (Dean and Meyer, 1983; Butt, 1993). The sulphides are preferentially sited in sandy laminae within the shales and bear some affinities with stratabound SEDEX-style mineralization (see O'Brien *et al.,* 1997).

Fluvial Sedimentation

The Signal Hill and Musgravetown groups

Alluvial plain conditions developed across the Avalon Zone by latest Neoproterozoic in response to major uplift (north of the present Bonavista and Avalon Peninsulas) related to the Avalonian Orogeny (Figure 2-2). This period of tectonic upheaval is represented by molasse-like clastic rocks of the Signal Hill Group of central and eastern Avalon Peninsula and by parts of the volcanic and clastic successions that comprise the Musgravetown Group and equivalents further west (Figure 2-1). The clastic successions of both groups contain grey and green tuffaceous siltstone and sandstone at the base, which are overlain by red and green arkose and conglomerate. However, significant facies changes between these groups occur along eastern Trinity Bay between Old Perlican and Dildo. The Mus-gravetown Group is unconformably overlain by the Lower Cambrian *Random Formation* (Figure 2-5).

In the eastern Avalon Peninsula, the Signal Hill Group has a maximum exposed thickness of 5 km and extends from Flat Rock to Cape Ballard (Figure 2-3). Within the type area (Signal Hill), it includes four distinct mappable units of formational status, which in ascending order are the *Gibbett Hill*, *Quidi Vidi, Cuckold* and *Blackhead* formations (Figure 2-3). The *Flat Rock Cove*, *Cappahayden*, *Ferryland Head*, and *Cape Ballard* formations are facies variations. A comparable belt of rocks in western Avalon Peninsula extends from Colinet (St. Mary's Bay) to Grates Cove (Figure 2-3).

The buff to greenish gray sandstones of the Gibbett Hill Formation are well exposed in the range of hills between Snows Pond, Halls Town, the Heart's Content barrens, Flambro Head and Grates Cove (Figure 2-5). This unit is equivalent to the Halls Town Formation of Hutchinson (1953). It represents southward prograding deltaic sands, a transition from shallow marine (e.g., Renews Head Formation, St. John's Group) to subaerial alluvial plain sedimentation (e.g., Quidi Vidi Formation, Signal Hill Group). Tabular and trough crossbeds, as seen in good exposures at Lower Island Cove, indicate paleoflow to the south and southwest. Numerous, small-scale fining upwards cyclic sequences (sandstone-siltstone-shale) occur throughout the formation; grey-black shale units with marine microfossils decrease in thickness and frequency upwards and thick, grey-green, tuffaceous sandstone beds become dominant at the top. Thick to thin irregular beds of laminated sand with primary current lineation are interpreted as the product of flash floods depositing sand under upper flow regime plain bed conditions (e.g., Miall, 1985; Rust, 1978). Mudcracks, major channels and red sheet sands at the top of the formation (e.g. between Northern Bay and Job's Cove) show the development of a subaerial paleoenvironment, probably as a southward prograding delta plain. Comparable facies occur within the Big Head Formation of the Musgravetown Group on the western Avalon Peninsula (e.g on the Heart's Content barrens).

Facies within the red sandstones of the Quidi Vidi Formation of the eastern Avalon Peninsula are characteristic of an alluvial flood plain environment with fields of dunes occupying the deeper portions of broad active channels. On the Bay de Verde Peninsula comparable facies occur within the *Old Perlican Member* of the *Bay de Verde Formation* of the Signal Hill Group (e.g. at Lower Island Cove and at Low Point; Figure 2-5). Thick bedded units with primary current lineation and unidirectional cross-bedding were probably generated under flash flood conditions with rapid flow (e.g., Miall, 1985). Paleocurrent studies of trough crossbeds within the arkosic sandstones indicate southeast to southwest flowing streams. An abundance of red mud flake breccia in the sandstones and extensive scours preserved in thick underlying mudstones attest to the streams erosive nature. As flooding waned, gradual deposition of silt and mud took place in floodplains or in shallow, intermittent playa lakes. Thin sandstones interbedded within thick red mudstone units may represent crevasse splays. During dewatering, mudcracks developed; local fluidized flows of mudflakes and sand were injected as dykes and sills. Abundant large-scale load structures within the thick sandstones indicate that the sands were liquefied and behaved as quicksands; some mud layers in the fluidized sand were deformed, disrupted and brecciated as a result of liquefied flow.

Conglomeratic facies developed in the Cuckold Formation, of the eastern Avalon Peninsula and the correlative *Baccalieu Member* of the Bay de Verde Formation, are characteristic of braided river deposits. Large-scale trough and planar-tabular crossbeds indicate unidirectional, high energy traction currents with paleoflow to the south- southwest. The decrease in pebble size, the relatively high silt and mud content, and the presence of thixotropic deformation structures, also support a more distal alluvial plain environment to the south. The gravels and sands accumulated on an alluvial plain or on the slopes of a major alluvial fan which built out into an extensive alluvial basin (Figure 2-4). The wide variety of structures and textures clearly shows that more than one agent or sedimentary process operated here in the distant past. In both the eastern Avalon Peninsula and in the Bay de Verde area the overall sandstone-conglomerate sequence coarsens and thickens upwards toward the central part of the respective formations and then shows gradual fining - and thinning - upwards near the top. Both vertical and lateral variations in structures and textures reflect a tectonically active basin margin to the north; maximum uplift of the region may have occurred during this period of sedimentation. Pebbles in the conglomerates are predominantly rhyolitic with minor granite and granophyre; clasts of quartz sericite schist occur within the Cuckold Formation (Cape Spear Member) and may have been derived from uplifted continental basement rocks or from highly altered felsic volcanic rocks.

The Cuckold Formation conglomerates wedge out to the south by passing into a red sandy facies near Bay Bulls that resembles both the Quidi Vidi and Blackhead formations (Figure 2-3). These combined units at Ferryland, about 60 km south of the type section, are termed the *Ferryland Head Formation* (Williams and King, 1979). In comparison, the Bay de Verde Formation also wedges out to the south (Figure 2-5) within the sandstones of the *Big Head Formation* of the Musgravetown Group.

The Flat Rock Cove Formation, to the north of St. John's, is a large clastic wedge that overlies the Cuckold Formation and also pinches out to the south (Figure 2-3); it is therefore a distinctive local facies, rather than an extension of the Blackhead Formation. The Flat Rock Cove Formation, interpreted as a small, localized, alluvial fan deposit, provides an important stratigraphic link with a once tectonically active basin margin, represented by the Lilly Unconformity (King, 1990).

Sheet-like, variegated sandstones with large trough-crossbeds, abundant mudstones and mud-flake breccias, are characteristic of the Blackhead Formation; the sandstones formed in a braided stream environment and the mudstones probably developed in playa or intermittent lakes. Large internal loads, deformed mudflake horizons, sandstone dykes and sills, and oversteepened trough crossbeds are also common throughout the Blackhead; these textures reflect liquefaction produced by ancient groundwaters migrating laterally and upwards on a more distal part of the alluvial plain environment. Comparable facies occur within the Old Perlican Member (Bay de Verde Formation) south of Old Perlican where it intertongues with the Big Head Formation of the Musgravetown Group (Figure 2-5).

Wavy bedded, gray to green tuffaceous siltstone and sandstone of the Big Head Formation pass downwards into the Gibbett Hill Formation of the Signal Hill Group (e.g., good examples occur on the summit of the Heart's Content barrens) but are sharply overlain by other units of the Musgravetown Group, such as red sandstone and mudstone of the *Maturin Ponds Formation* followed upwards by marine black shales of the *Heart's Content Formation* (Figure 2-5). The shales gradually pass upwards into fluviomarine olive sandstones of the *Heart's Desire Formation* which are overlain by alluvial plain conglomerates of the *Crown Hill Formation*, the highest unit of the Musgravetown Group in the Trinity Bay area. The marine beds within the Musgravetown Group represent the base of another major coarsening upwards cycle comparable in development with that of the St. John's Group; however, they have no precise correlatives within the Signal Hill Group.

OUTLINE OF MAJOR PALEOZOIC FACIES AND FORMATIONS

Platformal Deposits

A now dispersed cover sequence of platformal Cambro-Ordovician sedimentary rocks rich in Atlantic trilobite fauna and minor associated volcanic rocks, overlies the late Neoproterozoic volcanic, sedimentary and granitoid rocks of the Avalon Peninsula (Figure 2-3). The basal Cambrian contact may be represented as a unconformity, nonconformity or disconformity. These hiatuses have a bearing on the Avalonian Orogen (King, 1988b). In the Manuels River area, an unconformity separates the base of the Cambro-Ordovician succession from underlying late Neoproterozoic volcanic rocks (Harbour Main Group) and granitoids (Holyrood Intrusive Suite). At Duffs and Dunn's Hill Road, lower Cambrian mudstones and limestone rest nonconformably above granitoids (Holyrood Intrusive Suite). At Bacon Cove, Lower Cambrian sediments rest with marked unconformity on late Neoproterozoic mixtite and siltstones of the Conception Group. In eastern Trinity Bay, the Lower-Cambrian Random Formation rests with angular discordance above the Crown Hill, Heart's Desire and Heart's Content formations (Figure 2-5).

Major Paleozoic facies and formations of central and eastern Avalon Peninsula include, in ascending order:

1. Basal Cambrian shallow marine quartz arenite and siltstone - the *Random Formation*;
2. Lower Cambrian variegated shale, pink sabka-type limestone and red shale – the *Bonavista*, *Smith Point* and *Brigus* formations respectively (see Landing, 1996);
3. Middle Cambrian, *Paradoxides* bearing gray to black shale, pillow-basalt and tuff - *Chamberlains Brook* and *Manuels River* formations (see Boyce, 1988);
4. Upper Cambrian grey and green shale – *Elliot Cove Formation*;
5. A Tremadoc shallowing upwards sequence of marine shale, siltstone, sandstone, quartzite and oolitic ironstone – the *Clarenville* and *Bell Island groups*;
6. An Arenig shallow marine sequence of sandstone, quartzite, oolitic ironstone and shale – the *Wabana Group* (see Ranger *et al.,* 1984; Pickerill *et al.,* 1988);
7. An associated suite of gabbro, diorite and granitoids.

Ordovician and Silurian marine siltstones and Devonian continental sandstones have been obtained from submarine drill cores and dredge samples on the Grand Banks east of St. John's (King *et al.,* 1986; King, 1988a). Silurian (?), Devonian and Carboniferous molasse-like sedimentary rocks also occur in the southwestern Avalon Zone of Newfoundland (Figure 2-1).

NEOPROTEROZOIC AND PALEOZOIC MAGMATISM

Granitoid and gabbroic plutons are an important component of the eastern margin of the Apppa-lachians. In the Avalon Zone of Newfoundland, three major episodes of Neoproterozoic plutonism are recognized (O'Brien *et al.,* 1996b). However, on the Avalon Peninsula, only the youngest episode, with isotopic ages mainly between 570 to 620 Ma, is present. Hornblende-biotite granitoid rocks of the Holyrood Intrusive Suite were intruded during late Neoproterozoic orogenesis. Chemical studies of the Newfoundland examples have shown them to be of calc-alkaline affinity (Strong and Minatides, 1975; O'Driscoll and Strong, 1979), comparable with the granitoids in the Andean and western North American Cenozoic terrains, i.e. transitional between orogenic and non-orogenic environments.

A Paleozoic plutonic episode, dated about 360 Ma, produced granites locally of batholithic proportions which were introduced during late stages of Acadian orogenesis (O'Brien *et al.,* 1983). These granites (Figure 2-1) were intruded into high crustal levels in the western Avalon Zone of Newfoundland and are locally mineralized (e.g. fluorite-bearing st. Lawrence Granite).

STRUCTURAL GEOLOGY AND METAMORPHISM - SYNOPSIS

Regional Structural Setting

Two periods of deformation have been identified in the Avalon Peninsula: (1) an enigmatic late Neoproterozoic (Cadomian or Pan-African) orogenic episode, named the "Avalonian" by Rodgers (1972) and first described as the "Avalonian Orogeny" by Lilly (1966); (2) a major Siluro-Devonian (ca. 395 Ma) disturbance - the "Acadian Orogeny".

On the Avalon Peninsula, the Avalonian Orogeny appears to be relatively dominant. Unconformities in widespread localities throughout the Avalon Peninsula provide evidence of late Neoproterozoic folding, thrusting, block-faulting, granitoid emplacement and general crustal instability (e.g., McCartney, 1967; Anderson, et al., 1975; Anderson, 1981; King, 1980; O'Brien and O'Driscoll, 1996a). The present concentric arrangement of late Neoproterozoic sedimentary rocks around a volcanic core in the central and eastern Avalon Peninsula (Figure 2-3) appears to be the result of Precambrian structural doming, as Lower Cambrian strata overstep the Conception Group to lie directly upon the Holyrood Intrusive Suite and Harbour Main volcanics at Conception Bay (McCartney, 1967, 1969).

The effects of Acadian deformation and metamorphism in the Avalon Zone of Newfoundland are variable, reflecting the inhomogeneity of the Acadian event (O'Brien *et al.,* 1996b). In the western Avalon Zone of Newfoundland it is represented by the unconformity of Devonian sediments on fossiliferous Upper Cambrian strata and is accompanied by folding, faulting, greenschist facies regional metamorphism and granitoid plutonism (e.g O'Brien, *et al.,* 1983). Metamorphism in the eastern Avalon Peninsula occurred under prehnite-pumpellyite facies conditions (Papezik, 1972, 1974). Neither the Avalonian nor the Acadian orogenic episodes within the Avalon Peninsula are accompanied by extensive high grade metamorphism or widespread penetrative fabric development.

Folds

The late Neoproterozoic rocks of the Avalon Peninsula are open to tightly folded, depending upon lithology and bed thickness. Broad elongate domes and basins with near vertical north-northeast trending, axial surfaces, and with associated doubly plunging parasitic folds are the dominant structural style (King, 1988a). Axial planar cleavage varies around the vertical from steeply southeast to steeply northwest dipping.

The late Neoproterozoic rocks provide evidence of progressive phases of deformation; the earliest phase commenced during the Avalonian Orogeny and is overprinted by younger Acadian episodes. Although the Paleozoic rocks locally show similar structural features, there are extensive areas (e.g eastern Conception Bay, including Bell Island) where the rocks have only gentle dips and are virtually undeformed.

Faults

Throughout the Avalon Peninsula are numerous major strike-slip, normal and thrust faults (Figures 2-1, 2-3). The Topsail Fault Zone extends along much of eastern Conception Bay and separates Harbour Main Group volcanic rocks to the east from downthrown Ordovician sediments to the west. It merges with the Frenchman's Cove Fault (King, 1988a) which in the Fermeuse area is near vertical with its eastern side downthrown. The Peter's River Fault trends northeast from Peter's River to Holyrood (Williams and King, 1979; O'Brien *et al.,* 1997). Conception Group rocks are crushed and broken where cut by the Peter's River Fault. In the Flat Rock-Torbay-St. John's area, Conception Group rocks are thrust as much as 3 km over highly fractured black shales of the St. John's Group exposed to the east; this structure, known as the Flat Rock Thrust Zone, is one of the best exposed thrust faults on the Avalon Peninsula.

Tectonic Models

Since the pioneering studies of Buddington (1919), a variety of tectonic models has been proposed for the late Neoproterozoic development of the Avalon Peninsula and the Avalon Zone of Newfoundland. McCartney (1969) proposed a model that would permit sequential development of the sedimentary units on the Avalon Peninsula in response to Neoproterozoic tectonism. Evidence for such deformation has been cited by Lilly (1966), McCartney *et al.* (1966) and Poole (1967) and this gave rise to the view that the emplacement of the Holyrood Intrusive Suite took place during an "Avalonian Orogeny" which post-dated Harbour Main volcanism and pre-dated the deposition of the Conception Group sediments. McCartney (1969) suggested that a north-south trending horst developed in volcanic and other rocks in the central part of the Avalon Peninsula and that arkosic detritus was shed to basins on either side.

In previous accounts of the Avalon Zone, two contrasting tectonic models have emerged. One depicts the "Avalonian" terranes as having formed in an ensialic rift setting (e.g., Papezik, 1970; Strong *et al.,* 1978). The second model utilizes a consuming plate margin or ensialic island arc concept (e.g., Hughes and Bruckner, 1971; Rast *et al.,* 1976; Skehan and Murray, 1980; Rast, 1980) to explain the late Proterozic evolution of the zone.

A consequence of the rifting model is that it has led to the concept of the Avalon Zone as a precursor stage to the opening of Iapetus and, therefore, the implication of a genetic relationship with the Appalachian Orogen (e.g., Papezik, 1970; Williams *et al.,* 1972). The late Precambrian age and bimodal nature of many of the Avalon Zone volcanics, coupled with the continuity of the zone along the eastern margin of the Appalachian Orogen support this model. However, the model does not adequately explain either the absence of the Avalon Zone in the Scandinavian Caledonides or its apparent continuity with the Pan-African terranes of North Africa and Europe. While this model is compatible in some aspects with the late Neoproterozoic volcano-sedimentary facies of the zone, it is not applicable to its earlier facies development (O'Brien *et al.,* 1983).

The tectonic significance of the Avalon Zone and its extensions in any plate tectonic model for the Caledonian-Appalachian Orogen of the North Atlantic region has more recently been reviewed by Nance *et al.* (1991). The overall similarity in age, lithology, faunal assemblages and tectonic history between the Avalon Zone of Newfoundland and Pan-African belts of northwest Africa implies that they evolved in similar tectonic environments (O'Brien *et al.,* 1983, 1990, 1996b).

TRIP ITINERARY FOR DAY TWO

Overview: Day 2

The main purpose of this trip is to provide an overview of the late Neoproterozoic and early Paleozoic stratigraphy and lithofacies on the Bay de Verde Peninsula.

Initial stops along western Conception Bay will emphasize facies developments within the Neoproterozoic Conception, St. John's and Signal Hill groups (Figure 2-5). The route for this segment is from Fong's Hotel in Carbonear, through town, to Crockers Cove (approximately 5 km); next, rejoin the main highway (Route 70) - 'the Baccalieu Trail' - and follow it north to Old Perlican (approximately 62 km from Fong's) with stops en route. Examples of the late Neoproterozoic Bay de Verde Formation will be examined between the Old Perlican area and Bay de Verde, approximately 11 km northeast of Old Perlican on Route 70. Return to Old Perlican to the convenience store and gas bar at the intersection of Routes 70 and 80.

The second segment of the trip along the 'Baccalieu Trail' of eastern Trinity Bay will proceed south (Route 80) to Heart's Content (approximately 45 km to the junction with the Victoria Road, Route 74) and on to South Dildo (approximately 95 km south of Old Perlican). Stops will be made in the Bay de Verde Formation and the Neoproterozoic Musgravetown Group to illustrate the formational and member succession, sedimentology and depositional history. The route between Heart's Content and Dildo parallels a major north-northeast trending angular unconformity involving Lower Cambrian clastic and carbonate rocks and underlying siliciclastic rocks of the Musgravetown Group; stops will be made to illustrate the depositional and tectonic history related to the Avalonian Orogeny. Continue from South Dildo (south on Route 80 for approximately 8 km) to the junction with the TCH (St. John's is approximately 75 km to the east).

(**NOTE:** The stratigraphic names used in this paper are after King (1988a) (Geology of the Avalon Peninsula - Map 88-01). Major revision in the stratigraphic nomenclature and age of post-Random Formation Cambrian bio-stratigraphic units have been proposed by Landing (e.g. see Landing *et al.,* 1988; 1996; 1998)).

Stops: Day 2

STOP 2-1: **FERMEUSE FORMATION (ST. JOHN'S GROUP), CROCKERS COVE, CARBONEAR**

Location: *5 km east of Fong's Hotel. A headland on the south side of the cove, Crockers Point, forms the northeast part of Carbonear Bay.*

The panoramic view from the north side of Crockers Cove includes the eastern shore of Conception Bay to Cape St. Francis (30 km to the ENE), Bell Island, Bristols Hope Cove and Carbonear Island. On a historical note, in the early 17th century, Gilbert Pike, a member of Peter Easton's pirate band, rescued an Irish Princess – Sheila NaGeira from a Dutch warship; they married and made their home at Bristols Hope. Carbonear Island, a National Historic Site, is where the residents of Carbonear successfully took a stand, in 1697, against a French attack, led by Pierre Le Moyne d'Iberville.

Description: Along the shore of Crockers Cove, black cleaved shales of the Fermeuse Formation (St. John's Group) are well exposed. These mud-dominated rocks with their low, gently undulating dips and steep cleavage, occur along the axis of a small southward plunging antiform. They are typical of the estimated 1200 m shale-siltstone succession in the Carbonear-Harbour Grace area.

Intercalated buff sandstone and siltstone define thin beds and laminae in otherwise structureless mudstone. Some sandstones show turbiditic features, e.g. ripple-laminations (Bouma Tc division), upper parallel laminae (Td) and pelite or mudstone (Te). Poorly preserved marine microfossils occur in the less-cleaved shales (Hofmann, *et al.,* 1979). This formation is most notable for its abundance of gravity-controlled, soft-sediment deformation structures such as chaotic folding, slumping and brecciation of strata (ranging in scale from 1 cm to 10 m); these features were initiated by down slope creep leading to submarine gravity slides, detachment and submarine debris flows.

STOP 2-2: **RENEWS HEAD FORMATION (ST. JOHN'S GROUP), SALMON COVE**

En route: *The route to Salmon Cove traverses folded Fermeuse Formation strata. Continue from Crockers Cove along the coast road for 1.5 km to Freshwater United Church where the road forks; turn sharp left and continue to the main Victoria Road (Route 70) about 3 km west of the fork and stay on Route 70.* ***(NOTE: At the Junction of Route 74 to Hearts Content be sure to turn right on Route 70 to Salmon Cove).***

Location: *Small quarry on right side of highway, approximately 6.7 km from Junction of Route 74 and Route 70 and approximately 1.5 km beyond sign near entrance to Salmon Cove Sands Provincial Park.*

Description: This locality is taken as a transitional boundary between the Fermeuse Formation to the south and the conformably overlying Renews Head Formation to the north. The Renews Head Formation consists of thin, lenticular bedded, rusty-brown weathering sandstones alternating with thin to thick interbeds of dark shale.

These rocks dip 25 to 30 degrees NW; they are the basal part of a 700 m thick formation in which sand content and bed thickness increases upwards. This weather resistant unit forms a distinctive escarpment on the north side of the highway between Victoria and Salmon Cove. The Renews Head Formation is gradationally overlain by thick-bedded green sandstones of the Gibbett Hill Formation (Signal Hill Group) which is exposed in another escarpment about 1.5 km north of this stop; a topographic northwest-southeast trending profile resembles a cuesta (i.e. alternating escarpments and dip slopes). The Renews Head-Gibbett Hill succession represents a shoaling of the marine basin (Figure 2-4).

The rusty color of these rocks is due to preferentially sited sulphides within the sandy laminations and lenticular beds. As previously noted, the Renews Head Formation exposed on the Heart's Content barrens (via Route 74) contains minor pyrite, pyrrhotite, with traces of chalcopyrite, sphalerite and galena (Dean and Meyer, 1983; Butt, 1933; O'Brien *et al.,* 1997).

STOP 2-3: **ST. JOHN'S AND CONCEPTION GROUPS BOUNDARY, KINGSTON (Brief Stop)**

En route: *The route to Kingston (approximately 7 km) traverses west dipping shales and sandstones of the Renews Head Formation. At Perry's Cove (northeast of Stop 2-2), calcite stringers with some galena cut arenaceous slates but not in sufficient quantity to be of commercial value (C.R. Gillespie, Private Report to Geological Survey of Newfoundland, 1952).*

Location: *Coastal vantage point, east side of main road, Kingston. Limited parking.* ***KEEP AN EYE ON TRAFFIC.***

Description: The panoramic view of eastern Conception Bay extends from Cape St. Francis to Butterpot in the south. In the foreground, exposed in coastal cliffs, is a significant anticline whose axis extends north along the coast to Flambro Head, the Flambro Head Anticline. In the core of the fold at Upper Small Point, are cherty, porcellaneous turbiditic sandstones of the Drook Formation (Conception Group). On the west and east limbs of the anticline (at Kingston and Lower Small Point) the ascending succession (to be examined in part at Stop 2-4) consists of purple and green sandstones-mudstones of the Mistaken Point Formation (top of the Conception Group) and dominantly black shales of the Trepassey, Fermeuse and Renews Head formations (St. John's Group).

STOP 2-4: MISTAKEN POINT FORMATION (CONCEPTION GROUP), SMALL POINT (Optional Stop)

Location: *Continue north 2 km to the community of Small Point. Turn right on minor road and drive 0.5 km to a cove east of Lower Small Point.* ***PARK IN FIELD BUT NOT TOO CLOSE TO HIGH COASTAL CLIFFS.***

Description: The Mistaken Point Formation is here exposed on the eastern limb of the Flambro Head Anticline (Stop 2-3); it is divisible into a lower, 100-200 m thick unit (cf. the Middle Cove Member of King, 1990) and an upper, 100-200 m thick unit (cf. the Hibbs Cove Member, King 1990). In the lower unit, between Upper Small Point and this vantage point, interbedded siliceous sandstone, siltstone and mudstone show Bouma Ta through Td divisions; local amalgamation of thin turbidites has resulted in thick to "massive" turbidites. Purple, red and green mudstones and siltstones in the upper unit are interpreted as hemipelagic layers.

Poorly preserved concentric markings resemble those of *Charniodiscus*. These facies probably formed in a relatively distal, deep marine lobe fringe setting (Figure 2-7) at a deep marine outer submarine fan (Figure 2-6).

Good coastal exposures between this vantage point, Lower Small Point and Broad Cove (to the east), show the upward transition of the Mistaken Point Formation into the overlying Trepassey and Fermeuse formations.

STOP 2-5: VANTAGE POINT, BURNT POINT (Brief Stop)

En route: *The route to Burnt Point (approximately 18 km north of Small Point) is via Western Bay, Ochre Pit Cove, and Northern Bay Sands. These places are on the western limb of a major north plunging anticline (Flambro Head Anticline, see Stops 2-3 and 2-7) and from south to north involve strata of the Conception, St. John's and Signal Hill groups. Note the abundance of red, iron oxide staining on the sandstones (the red ochre at Ochre Pit Cove may have been used by Beothuck Indians).*

Location: *Public vantage point at Burnt Point. Erected by the Flambro Head Heritage Society.*

Description: The view southwest is of the headlands at Northern Bay, Ochre Pit Cove and Western Bay; sea arches, seastacks and caves are common marine erosional features.

Below this site, northwest dipping strata of the Renews Head Formation, pass upwards into green sandstones of the Gibbett Hill Formation, which in this area, is about 800 m thick; this formation thickens southward to about 1500 m on the Heart's Content barrens and then thins to about 850 m at Halls Town.

About 2 to 2.5 km northwest (beyond our view), red fluvial sandstones and siltstones form a 50-60 m thick member within the Gibbett Hill Formation. Between this member and the base of the formation, thin lenticular veins and joint are filled with hematite; these hematite veins and iron oxide stains extend 5 km NE along strike to western Lower Island Cove, the site of the Workington Iron Mines.

The view to the northeast is of the headland at Job's Cove, where a northerly trending, sinistral strike-slip fault offsets the NE trending Flambro Head Anticline (Figure 2-5). Botryoidal hematite and quartz veins occur near this fault in the vicinity of Workington.

Extensive preparation for mining the Workington iron deposits took place in 1898-99, including the construction of a surface plant, a 7 mile railway between the mine and Old Perlican, where a loading pier was built. According to A.K. Snelgrove (Newfoundland Geological Survey, Information circular No. 4, 1938, pp. 80-81), the Newfoundland Iron Ore Company sunk 7 prospect shafts ranging in depth from 40 to 170 feet. The main deposit ranged from 5 to 7 feet in thickness with a dip of 31 degrees SE; average analysis of dump hematite ore yields 60.37 % iron. Apparently only a few tons were shipped and the operation folded in 1903. The property was drilled in 1928 by the Bethlehem Steel Corp. Inc. (government unpublished report, 1929).

STOP 2-6: SIGNAL HILL GROUP, LOWER ISLAND COVE

Location: *Continue north along Route 70 for 5.5 km to 'Main Street' Lower Island Cove (immediately south of the post office). Turn right onto a minor paved road for 0.6 km to Lower Island Cove breakwater. Park in a field with a red fishing shack adjacent to the breakwater.*

Description: This site, on the east dipping limb of the Flambro Head Anticline (Figure 2-5), consists of thick beds of buff weathering, green sandstones of the Gibbett Hill Formation. Large linguoid and straight-crested ripples, cross-bedding, and small scale slump folds indicate paleoflow to the southwest. The formation is overlain by red arkosic sandstone (Old Perlican Member, Bay de Verde Formation). Both of these units are interpreted as alluvial plain facies which developed across much of the Avalon Peninsula by latest Neoproterozoic (Figure 2-4).

STOP 2-7: PANORAMIC VIEW, FLAMBRO HEAD LOOKOUT (Brief Stop)

Location: *On route 70, approximately 2.5 km north of the Lower Island Cove Post Office, is a prominent lookout and parking area prepared by Flambro Head Heritage Society. (The name Flambro may be derived from the English 'Flamborough' meaning spit or headland.) The wrecks of more than 20 ships lie under the waters that surround Baccalieu Island, with a loss of over 200 lives.*

NOTE: SEA CLIFFS AND MARINE CURRENTS ARE DANGEROUS IN THIS REGION.

Description: Below this site is the axis of the northeast trending Flambro Head Anticline. The core consists of highly contorted shales and sandstones of the Renews Head and Fermeuse formations; the limbs are green sandstone of the Gibbett Hill Formation which crop out as far west as Caplin Cove and east between Flambro Head and Lower Island Cove.

The vantage point provides a distant panoramic view, from west to east of Low Point, the community of Bay de Verde (about 9.5 km across the bay) and the south end of Baccalieu Island (about 16 km NE). All these localities are underlain by red sandstone and conglomerate of the late Neoproterozoic Bay de Verde Formation (Figure 2-5). The red beds formed in an alluvial plain environment. The axis of a major structure, the Bay de Verde Syncline, passes through the community of Bay de Verde.

STOP 2-8: BAY DE VERDE FORMATION (SIGNAL HILL GROUP), BAY DE VERDE (Optional Stop)

En route: *The road to Bay de Verde traverses folded and locally faulted red bed facies of the Bay de Verde Formation. Follow Route 70 for 7.7 km to*

Old Perlican, turn right at the junction with Route 80 to Hearts Content and continue on Route 70 for 11 km to the prominent water tower just past the entrance to the community of Bay de Verde.

Location: *Entrance to community of Bay de Verde.*

Description: This stop is on the west limb of the Bay de Verde Syncline whose axis coincides with a deep valley (dip slope) through the community.

The Baccalieu Member of the Bay de Verde Formation is a very distinctive red sandy to pebble conglomerate. Clasts are mainly of felsic volcanic origin; they increase to cobble size in a northeast direction. Trough and tabular cross-beds indicate paleoflow of sheet floods and braided streams to the south. Alluvial facies developed in this member are comparable with those of the Cuckold Formation of the Signal Hill Group, eastern Avalon Peninsula.

Baccalieu Island is located 3 km northeast of Split Point across Baccalieu Tickle (Figure 2-5). The island (6 x 1 km) is the type locality of the Baccalieu Member and is broadly synclinal along its axis. Access to the island is difficult. It was declared an ecological reserve in 1995 as it is said to support the largest major seabird colony (over 77 species) in this province, including the largest breeding colony of Leach's Storm Petrel (over 3.4 million pairs; Source: W.A. Montevecchi, 1994).

STOP 2-9: GRATES COVE MEMBER (BAY DE VERDE FORMATION; SIGNAL HILL GROUP), GRATES COVE (Optional Stop)

En route: *On the way back to Old Perlican take the 7 km road to Grates Cove, the most northerly community on the Baccalieu Trail. According to legend, John Cabot landed here and carved an inscription* 'IO CABOTO...' *on the rock. The rock-walled landscape of Grates Cove has been officially recognized as a nationally culturally significant site by the Historic Sites and Monuments Board of Canada (Summer 1997).*

Location: *Sea cliffs, Grates Cove.*

Description: This is the type locality of the Grates Cove Member of the Bay de Verde Formation (Signal Hill Group). Interbedded green siltstone and thick beds of green sandstone strike east-west and dip about 15-25 degrees south. These rocks may be correlatives of the Gibbett Hill Formation but they also show facies comparable with the Big Head Formation (Musgravetown Group). Iron staining is common, particularly between Goldmine Head and Red Head Cove (Figure 2-5). The Grates Cove Member is overlain by red sandstones and conglomerates of the Bay de Verde Formation.

STOP 2-10: BAY DE VERDE FORMATION (SIGNAL HILL GROUP), OLD PERLICAN (Brief Stop)

En route: *Return to Old Perlican (the origin of the name is uncertain, possibly a derivative of "Pelican", a name given to English ships. The community was settled by the English in the late 1500s; it was destroyed by French under d'Iberville, 1697). Commence this segment from a convenience store/ gas bar at the junction of Routes 70 and 80. Drive south along route 80 for 4.5 km. Note trackway of old "Workington Railway".*

Location: *Road-side outcrop, Old Perlican.*

Description: This extensive road-side outcrop is composed of flat-lying, white to pale red sandstones and mudstones of the Old Perlican Member, Bay de Verde Formation (King, 1988a). It is comparable in facies to the Maddox Cove Member, Blackhead Formation (Signal Hill Group), eastern Avalon Peninsula. The mudstones were deposited in shallow pools on the distal part of an alluvial plain; ancient groundwaters migrated laterally and upwards producing thixotopic deformation structures. Several kilometers to the south and west of this stop (e.g. Lead Cove), this facies inter-tongues with lacustrine and marine siltstones of the Big Head Formation (Musgravetown Group).

STOP 2-11: BIG HEAD FORMATION (MUSGRAVETOWN GROUP), NEW MELBOURNE

En route: *Drive 10 km, via Lead Cove and Sibley's Cove, to the shingle beach at New Melbourne.*

Location: *Large parking/picnic area on the beach near St. Stephen's United Church.*

Description: Exposed at the base of low cliffs are exposures of yellowish green to gray weathering, tuffaceous siltstone and sandstones of the Big Head Formation. Numerous silt and sand layers commonly show wavy to discontinuous laminae and very small scale slump folds. Gravity slumping and sliding would explain the origin of soft-sediment deformation structures such as the small scale disrupted and contorted laminae. This formation throughout the Avalon Peninsula is characterized by its abundant soft-sediment deformation structures and wavy-laminations.

Elsewhere on the Bay de Verde Peninsula (e.g Heart's Content barrens, Route 74), the siltstones of the Big Head Formation were deposited above sands of the Gibbett Hill Formation probably under more distal or prodeltaic, shallow subaqueous conditions; minor down-slope creep of silty layers may have been shock-induced as a result of unstable or tectonic motion. In the western Avalon Peninsula and the Isthmus of Avalon, this formation overlies volcanic rocks of the Bull Arm Formation; the tuffaceous laminae in the Big Head Formation throughout the Avalon Peninsula may relate in time to this period of explosive volcanism.

STOP 2-12: MUSGRAVETOWN GROUP SUCCESSION, NEW CHELSEA (Brief Stop)

Location: *Drive 5 km southwest of New Melbourne to west side of New Chelsea Harbour.*

Description: Near this stop is a northwest dipping contact between the Big Head Formation and overlying red arkosic sandstone, mudstone and siltstone of the Maturin Ponds Formation, both of the Musgravetown Group. Between this contact and Hants Head, 6 km to the west (Figure 2-5), more than 2.5 km of upper Musgravetown Group strata are exposed along the coast. In ascending order, above the Maturins Pond Formation, are marine black shales of the Heart's Content Formation, olive-green sandstones of the Heart's Desire Formation, and red sandstones and conglomerates of the fluvial Crown Hill Formation. All of these formations have been traced to southern Trinity Bay (King, 1988a) and will be seen or examined in subsequent stops. However, between Heart's Desire and Dildo (Figure 2-5), this succession is erosionally truncated by the Lower Cambrian Random Formation; in the Whiteway area (Stop 2-18) about one-half or 1.3 km of the latest Neoproterozoic succession (i.e. Crown Hill, Heart's Desire and upper Heart's Content Formation) is missing. The actual surface of the unconformity is poorly exposed in eastern Trinity Bay; in general, on outcrop scale it appears as a disconformity but on the regional scale, as an angular unconformity.

STOP 2-13: HEART'S CONTENT FORMATION (MUSGRAVETOWN GROUP), HANT'S HARBOUR (Optional Stop)

En route: *Drive 4.6 km southwest along Route 80 to the junction with the Hant's Harbour Road. Turn right and drive about 1 km on the lighthouse road to the east side of the harbour.*

Location: *Road-cuts along the road to the lighthouse.*

Description: Good road-cut exposures of northwest dipping black shales and thin interbedded, ripple-laminated, sandstones of the Heart's Content Formation are exposed along the road to the lighthouse. The shales contain marine microfossils (Hofmann, *et al.,* 1979).

Hant's Head, 2 km west of the lighthouse, is accessible by coastal trail from Hant's Harbour. A thin stratigraphic unit (50 to 100 m thick) of olive-green sandstones (Heart's Desire Formation) overlies the black shales and is overlain by the Crown Hill Formation (difficult access). Note how the green sandstones thicken very gradually towards Heart's Desire (the type locality, King 1988a) and thins towards Whiteway (Figure 2-5). South of Hant's Head, the Crown Hill Formation is exposed in spectacular coastal cliffs (e.g. King's Head) which rival those of Logy Bay, near St. John's.

STOP 2-14: MUSGRAVETOWN GROUP, WINTERTON (Optional Stop)

Location: *Continue from the Hant's Harbour Road junction for 9.2 km to Hindy's Esso Gas Bar, near Western Point Road, Winterton harbour.*

Description: From parking lot of the garage, view northwest dipping Musgravetown Group strata. Heart's Content and Heart's Desire formations are exposed along a coastal road on the south side of the harbour. Red pebbly sandstones of the Crown Hill formation are accessible by a trail linking the end of the coastal road with the prominent headland of Sugar Loaf.

STOP 2-15: HEART'S CONTENT FORMATION (MUSGRAVETOWN GROUP), HEART'S CONTENT LIGHTHOUSE (Optional Stop)

En route: *Drive 12 km to the junction with the Heart's Content lighthouse road. En route, note the northeast plunging anticline in the Heart's Content Formation at Bloody Point, New Perlican (resembles an enormous whalesback in the centre of the harbour). At Heart's Content, turn sharp right onto the lighthouse road, and drive 1.2 km to the Norther Point lighthouse.*

Location: *Park in the large parking lot at the Norther Point lighthouse (picnic tables are generally available).*

Description: This is the type area of the Heart's Content Formation (King, 1988a). At the commencement of the lighthouse road, red sandstones of the Maturin Ponds Formation are overlain by black shales and cross-laminated sandstones of the Heart's Content Formation. Just north of the lighthouse, the northwest dipping shale succession is transitionally overlain by olive green sandstones of the Heart's Desire Formation.

STOP 2-16: UNCONFORMITY, HEART'S DESIRE

En route: *Return to Route 80, turn right and head south past the Heart's Content Cable Station, a provincial historic site (Turks Cove is where the first Trans Atlantic telegraph cable was landed in 1866). Turn right at the junction with Route 74, around a convenience store/gas bar and drive along Route 80 for 10 km to Wharf Road, Heart's Desire. Turn right and drive 100 m to the harbour.*

Location: *Shoreline of Heart's Desire harbour.*

Description: Black shales of the Heart's Content Formation are conformably overlain by olive-green sandstones of the Heart's Desire Formation (the type locality), which are overlain at Gannet Point (1 km west) and at the Shuffle Board (2.5 km north) by trough, cross-stratified, red sandstones of the Crown Hill Formation.

Near Gannet Point, pink to brick red limestones of the Lower Cambrian Smith Point Formation are exposed in a small, northeast trending syncline with a core of red mudstones of the Brigus formation above and green and red mudstones of the Bonavista formation below. Boulder beach deposits presently obscure the unconformity and the extent of the sub-trilobitic, Lower Cambrian Random and Bonavista formations is uncertain; their combined thickness is probably 75m or less. The limestones here are a distinctive sub-trilobitic unit (approximately 10-15 m thickness exposed) which show algal mounds, oncolites, red argillaceous laminae and rounded detrital grains near their base. They formed on a carbonate ramp platform above the clastic succession below, probably as a shallow marine transgression under high energy, tidal flat conditions in which carbonate beach deposits developed (i.e. as peritidal carbonates).

This is the most northerly exposure of the Lower Cambrian succession on land in eastern Trinity Bay. Offshore is a large northeast trending marine trough with a depth of 55m (Figure 2-5) whose axis may coincide with that of the Trinity Bay Synclinorium (King, 1988a).

STOP 2-17: LOWER PALEOZOIC STRATA, HEART'S DELIGHT (Optional Stop)

En route: *Return to the main road and drive 5 km south to Heart's Delight.*

Location: *Coastal sections along Heart's Delight harbour.*

Description: Along the east side of Heart's Delight Harbour are exposures of the Heart's Content Formation.

On the south side of the Harbour, near the main road, is a small headland of 5 to 10 m thick white quartz arenite, the Lower Cambrian Random Formation (sheared at base). Throughout the Avalon Zone of Newfoundland, this unit is a major (up to 170 m thick), transgressive sand body which formed under high energy, shallow marine to tidal flat conditions (Hiscott, 1982).

The Random Formation is disconformably overlain by 50 m or more of red and green mudstones of the sub-trilobitic Bonavista Formation, followed stratigraphically upwards (to the west) by 10-15 m thick red limestones of the Smith Point Formation.

Between Heart's Delight and Boar Point (1 to 2 km north of Heart's Delight), the Smith Point Formation is overlain by the Brigus Formation; the latter is about 180 m thick and consists of red, bioturbated mudstones and limestones. Near Boar Point, the Brigus Formation is overlain by grey and green manganiferous shales of the Middle Cambrian Chamberlain's Brook Formation (see McCartney, 1967, for a description of the manganese beds).

STOP 2-18: NEOPROTEROZOIC-PALEOZOIC SUCCESSION, WHITEWAY (Optional Stop)

En route: *From Heart's Delight, drive 12 km south via Islington and Cavendish to Whiteway.*

Location: *St. George the Martyrs Church parking lot.*

Description: In cliffs north and south of Whiteway, there are good sections of the Gibbett Hill, Maturin Ponds, and Heart's Content (lower part) formations. The Random Formation has eroded deeply into the Heart's Content Formation; about 1.3 km of Musgravetown Group strata are erosionally truncated. Manganese beds up to 1 m thick crop out in west dipping Cambrian strata northeast of Whiteway. A sea stack, composed of green and red Cambrian slates, forms a distinctive center piece in the entrance to Whiteway harbour.

STOP 2-19: PALEOZOIC SUCCESSION, NEW HARBOUR (Optional Stop)

En route: *Continue south for 15 km through Greens Harbour and Hopeall, past the junction with Route 73 (21 km to Tilton) to New Harbour.*

Location: *Coastal section, New Harbour.*

Description: The shoreline and coastal cliffs from New Harbour to Hopeall Head (Figure 2-5) provide a good profile of the Lower Paleozoic succession which rests unconformably above the Heart's Content Formation. In this section, McCartney (1967) estimated about 1.3 km of late Neo-proterozoic strata were truncated by the Random Formation. He measured the Cambrian succession and recorded, in ascending order: 1) angular unconformity, ii) Lower Cambrian Random Formation (28 m thick); iii) Bonavista Formation (30 m); iv) Smith Point Formation (17 m); v) Brigus Formation (130 m); vi) Middle Cambrian Chamberlain's Brook Formation with a 1 to 2 m thick Mn carbonate nodular bed at its base and vii) basaltic flows. Greenough and Papezik (1985) stated that these Middle Cambrian basalts and lapilli tuffs show distinctly alkaline trace element characteristics, suggesting that this portion of the Avalon terrane experienced tension during the Cambrian.

STOP 2-20: HEART'S CONTENT FORMATION (MUSGRAVETOWN GROUP), SOUTH DILDO (Brief Stop, Summary and Conclusions)

Location: *Drive 8.5 km south of New Harbour to South Dildo (near junction with Old Shop Road).*

Description: Good exposures of Heart's Content Formation. Sandstone interbeds in black shale show cross-lamination and soft-sediment slumping and faulting indicative of unstable marine shelf conditions.

Summary of main points of field trip.

Depart for St. John's via Blaketown and TCH.

ACKNOWLEDGMENTS

We thank Copper Hill Resources Inc., Fort Knox Gold Resources Inc., Trinity Resources and Energy Limited (Newfoundland Pyrophyllite Division), Vulcan Minerals and Vinland Resources for allowing access to their exploration and mining properties during this trip.

We also thank the staff of the Geoscience Publications and Information Section, Department of Mines and Energy for their assistance in preparing the field guide.

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