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LATE NEOPROTEROZOIC GEOLOGY OF THE CENTRAL AVALON PENINSULA, NEWFOUNDLAND, WITH AN OVERVIEW OF MINERALIZATION AND HYDROTHERMAL ALTERATION

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ABSTRACT

Late Neoproterozoic volcanic and plutonic rocks, assigned to the Harbour Main Group and Holyrood Intrusive Suite, respectively, occupy most of the central core of the study area, where they form a faulted, elongated anticlinal dome, plunging southward from Conception Bay. Parts of the thick and stratigraphically complex, lower greenschist-facies volcanic succession have been intruded by coeval plutons of mainly felsic to intermediate composition and calc-alkaline affinity. Subaerial ash-flow tuffs and rhyolite dome-facies rocks are predominant in the lower part of the volcanic succession, where they are associated with breccias and subvolcanic porphyries; the latter have been dated at ca. 630 Ma. In the middle- to upper-stratigraphic levels of the Harbour Main Group, mafic and felsic flows and pyroclastic rocks interdigitate on various scales with immature, terrestrial volcanogenic sedimentary rocks.

The Holyrood Intrusive Suite, which includes gabbro, diorite, quartz monzonite, monzonite, and granodiorite, is composed primarily of quartz-rich, equigranular to sub-porphyritic, hornblende–biotite granite, locally dated at 620 ± 2 Ma. Most of the Harbour Main Group from the Gasters Fault, eastward to and including the Avalon High-Alumina Belt, either predates or is broadly coeval with the emplacement of this granite. Volcanic rocks west of the Gasters Fault postdate its emplacement by more than 10 Ma. Marine mafic volcanic rocks, adjacent to and east of the Topsail Fault, may be younger than and unrelated to the remainder of the Harbour Main Group.

Marine siliciclastic rocks of the Conception Group unconformably overlie parts of both the Harbour Main Group and the Holyrood Intrusive Suite. On the flanks of the central volcano-plutonic dome, bedding in the Conception Group is parallel or subparallel to that in the underlying Harbour Main Group. Bedding above and below the Harbour Main–Conception group boundary is locally discordant in instances where Conception strata are infolded with or occur as outliers on the volcanic succession. In most places, the external contacts of the Conception Group are steeply dipping, brittle structures, that may have coincided with original basin boundaries, since reactivated. The base of this argillaceous, turbidite-dominant siliciclastic succession is typically pebble to boulder conglomerate. Upper and lower turbidite divisions of the Conception Group are separated by a regionally extensive unit of massive green mixtite. In the western part of the study area, variegated, siliceous and argillaceous beds occur at the top of the Conception Group (Mistaken Point Formation), where they are locally interlayered with subaqueous ash-flow tuffs. This unit, which elsewhere on the Avalon Peninsula has been dated at ca. 565 Ma, is overlain conformably by dark-grey, marine shale of the latest Neoproterozoic St. John's Group. The shales are overlain by deltaic and subaerial sandstones of the Signal Hill Group immediately west of the study area.

The Conception Group and parts of the underlying volcanic succession have been intruded by monzonites, gabbros and a suite of quartz-rich granites and quartz monzonites. The granites resemble the older (pre-Conception) plutons of the Holyrood Intrusive Suite and in most previous maps, have been assigned to that suite.

Widespread hydrothermal activity accompanied volcanism and plutonism. Argillic, advanced argillic (with or without extensive pyrophyllitization), and silica alteration has affected the Harbour Main Group, primarily at, or near, the boundary with

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overlying Conception Group rocks. The highest (up to 10.2 g/t) and most consistently elevated gold values occur in hydrothermal breccias and quartz–K-feldspar veins, within silicified volcanic rocks of the Avalon High-Alumina Belt. Other mineralized and hydrothermally altered (propylitic, silicic and sericitic) zones occur in proximity to at least three ages of Proterozoic monzonite, granodiorite and granitic intrusions. The plutons, which may include pre-, syn-, and post-alteration phases, contain pyrite, hydrothermal magnetite (± K-feldspar and biotite), chalcopyrite as disseminations and veinlets, minor molybdenite, and gold.

INTRODUCTION

The following account emphasizes the preliminary results of 1:50 000-scale bedrock mapping and related stratigraphic studies carried out by the Newfoundland Geological Survey in the central part of the Avalon Peninsula in 1996. The study focused primarily on the Neoproterozoic rocks in the Holyrood (NTS 1N/6) map area, and to a lesser extent, those in the adjacent portions of the St. Catherine's (NTS 1N/3) and Bay Bulls (NTS 1N/7) map areas (Figure 1). Parts of the Proterozoic succession in the adjoining southwest corner of the St. John's (NTS 1N/10) map area and in the southeast corner of the Harbour Grace (NTS 1N/11) map area were also studied in 1996. This paper also includes published and unpublished data collected by each of us during other ongoing and previous studies (e.g., King, 1980, 1988a, 1990; O'Brien *et al.*, 1996a; O'Brien and O'Driscoll, 1996a and b[3]).

The accompanying geological map is based on our current (1996) and previous investigations, and includes compilation from a variety of sources, most notably McCartney (1954, 1967) and Mullins (1970). The work represents the westward extension of mapping of the north-eastern Avalon Peninsula by King (1990) and also builds upon the Geological Survey's metallogenic investigations in the Manuels pyrophyllite belt, carried out by Hayes and O'Driscoll (1990) and Hayes (1997).

The approximate western limit of the map area extends from Bay de Grave, southwestward to Mahers, and thence southeastward into the Avalon Wilderness Reserve to Gibbons Pond. The eastern boundary extends from St. Thomas, south to Mobile First Pond, from there to Butlers Pond, and thence southward to the Mummerine Marshes (Figure 1).

Our primary, long-term objective is to produce accurate 1:50 000-bedrock geological maps and 1: 100 000-regional compilations of the central Avalon Peninsula. Additional goals include 1) unravelling the lithofacies relationships within the Proterozoic volcano-sedimentary succession, 2) documenting the nature and chronology of Proterozoic plutonism, and 3) establishing the stratigraphic position, nature and genetic controls of hydrothermal alteration in the Proterozoic rocks of the Avalon Peninsula. The mapping is integrated with a recently initiated study of the nature and controls of hydrothermal alteration and gold mineralization throughout the Newfoundland Avalon Zone (O'Brien *et al.*, 1996a).

PREVIOUS GEOLOGICAL INVESTIGATIONS

Bedrock Mapping and Related Studies

The history of geological investigations of the central Avalon Peninsula, dating back to the last century, is reviewed, comprehensively, in Malpas and King (1987) and King (1990). Of particular importance is the work of Alexander Murray and James Howley (Murray and Howley, 1881a). Their broad reconnaissance investigations, carried out between 1869 and 1883, outlined the major lithostratigraphic units of the Avalon Peninsula. Murray and Howley showed the regional distribution and structurally concentric arrangement of these rocks on the first geological map of the Avalon Peninsula, published in 1881 (Murray and Howley, 1881b). Their work was incorporated, with minor modification, into Howley's (1907) map of Newfoundland, and stood as the definitive regional geological map for the Avalon Peninsula until new mapping in the late 1940s.

Systematic bedrock mapping was first carried out by the Geological Survey of Canada, as part of a regional 1:253 440 (1 inch to 4 miles) scale geological survey of the Avalon Peninsula (Rose, 1952; McCartney, 1954, 1967). The area north and west of Marysvale (Figure 1) was previously mapped at 1:63 360 (1 inch to 1 mile) scale by Hutchinson (1953). The Newfoundland Geological Survey carried out 1:63 360-scale bedrock mapping in the the eastern half of the St. Catherine's (1N/3) NTS map area (Mullins, 1970). The northeastern part of the study area, east of the Topsail Fault, overlaps areas previously mapped by Hsu (1975) and by King (1990). A compilation of all of this previous mapping is incorporated in a 1:250 000 geological map of the Avalon Peninsula by King (1988a).

[3] The reader is referred to O'Brien and O'Driscoll (1996b) for additional description and interpretation of rocks from this map area, which have not been repeated in detail in this report.

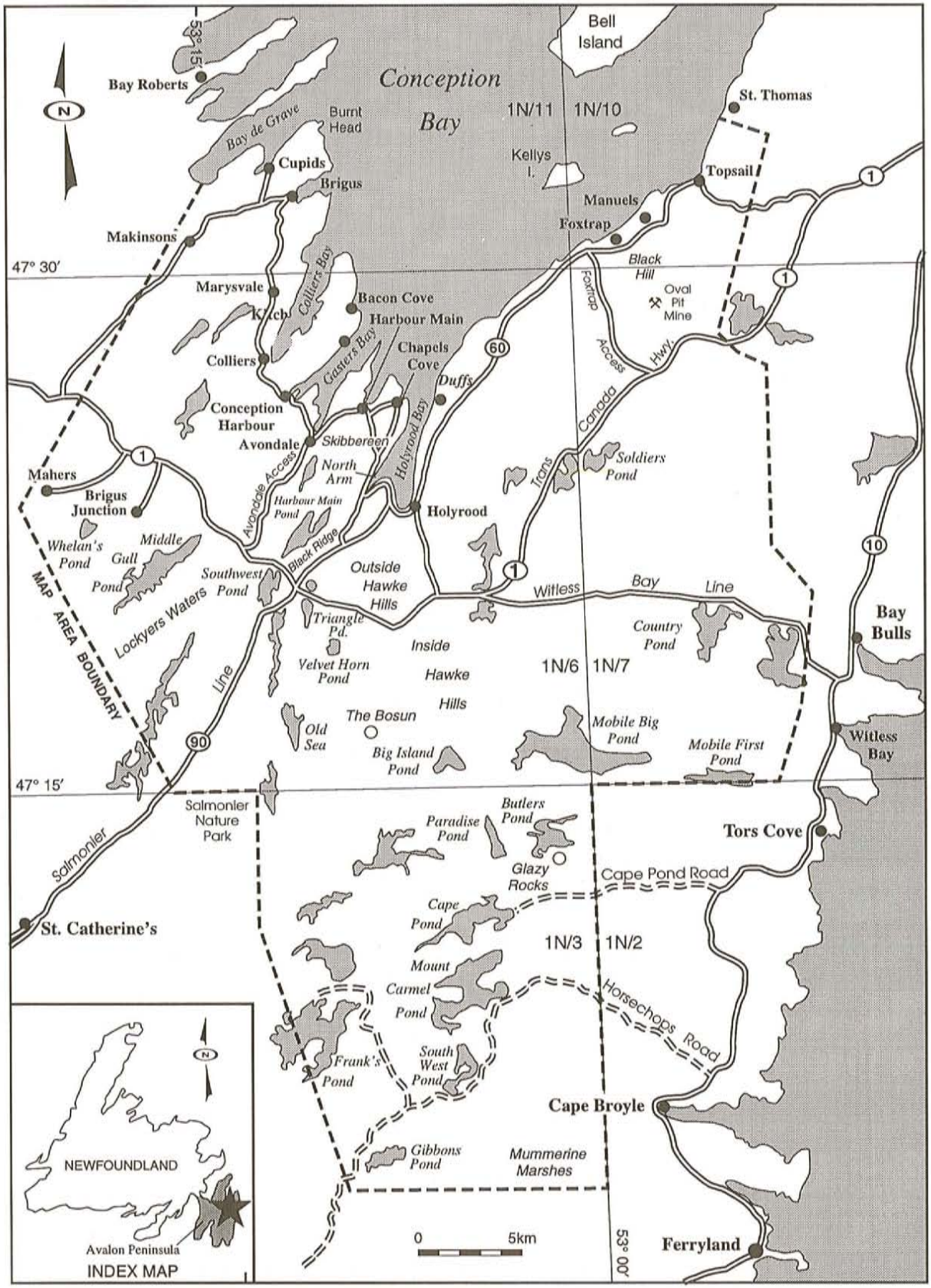

Figure 1. *Location of the study area, including localities referred to in the text.*

Petrologic studies of the Proterozoic volcanic and plutonic rocks near Conception Bay were first carried out by Buddington (1916, 1919). Papezik (1969, 1970, 1972) and Hughes (1971) undertook similar types of investigations, upon which they based their paleotectonic models for the region: e.g., Basin and Range environment (Papezik, 1970); volcanic island archipelago (Hughes and Brückner, 1971). Allied to this later work, and to that of Brückner (1969), are a number of unpublished theses (B.Sc. and M.Sc.) by Memorial University of Newfoundland students on the stratigraphy, external relationships and/or petrochemistry of some of the volcanic and sedimentary rocks bordering Conception Bay (e.g., Dawson, 1963; Barning, 1965; Pelley, 1968; O'Brien, 1972; Nixon, 1974; Ford, 1977; Jacobs, 1984; Cameron, 1986). Thornhill (1981) and Sparkes (1986) studied exposures of hydrothermally altered volcanic rocks in the more remote, southern parts of the region.

The most recent bedrock mapping (1:12 500) within the study area was undertaken by Hayes and O'Driscoll (1989, 1990) and Hayes (1997), as part of Newfoundland Geological Survey's metallogenic study of the eastern Avalon High-Alumina Belt. Pyrophyllite mineralization within this belt has been the focus of detailed studies by Vhay (1937), Keats (1970) and Papezik and Hume (1984), amongst others (*see below*).

Geochronological investigations of the Proterozoic rocks in the area include Rb–Sr and K–Ar whole-rock studies carried out by the Geological Survey of Canada (McCartney *et al.*, 1966), more precise U–Pb zircon age dating by Krogh *et al.* (1988), and K–Ar dating of Mesozoic rocks by Hodych and Hyatsu (1980).

Previous Mineral Exploration in Proterozoic Rocks

Mineral exploration on the Avalon Peninsula dates back to the mid-eighteenth century. Aspects of this history, including the development of small-scale mining ventures, have been presented by Martin (1983) and by King (1990), and is touched upon in the reports of Rose (1952), McCartney (1967) and Mullins (1970). Between 1850 and 1860, small shafts and adits were developed on several copper occurrences in the Harbour Main Group at Colliers, Marysvale, Avondale, Harbour Main and North Arm. Few of these prospects have been systematically evaluated since that time. One exception is the Turks Gut Ridge occurrence at Marysvale, which has been the focus of recent exploration activity (Laracy and Oates, 1994; Laracy, 1995).

In 1880, gold was reportedly discovered in quartz veins cutting siliceous sedimentary rocks of the Conception Group at Brigus (Murray and Howley, 1881a). Around this time, several small adits and shafts were driven along a number of the larger quartz veins in the general vicinity of Brigus. The location of these are given in a Murray and Howley map, reproduced and annotated by Howse (1934a).

Exploration and mining in the Avalon High-Alumina Belt began near the turn of the century, when pyrophyllite was first shipped from Manuels (Martin, 1983). Pyrophyllite ore was produced intermittently in the 1930s and 1940s by the Industrial Minerals Company of Newfoundland. After an assessment by the Mines Branch, including drilling in 1956 and 1958, which proved reserves of 1.5 million tonnes of ore, the government approached American Encaustic Tiling Company, which set up Newfoundland Minerals Limited to develop the deposit. New mining, milling and shipping facilities were opened in October, 1959 (Gibbons and Mercer, 1982). Newfoundland Minerals Limited is now a subsidiary of Armstrong World Industries Canada Limited. Since the mid-1980s, the pyrophyllite belt and adjacent rocks have also been the focus of small-scale prospecting programs for gold (e.g., Lenters, 1986; Saunders, 1986, 1991). A limited diamond-drilling program was completed on a gold occurrence within this belt, immediately north of the Trans-Canada Highway (Pickett, 1995).

Throughout the 1950s to the 1970s, the mineral rights to most of the study area were held by British Newfoundland Exploration Company (in the north) and Commodore Mining (in the south), under concession agreement with the Government of Newfoundland and Labrador. Both companies carried out prospecting, stripping and trenching in several areas; Commodore Mining completed small drill programs on prospects in the St. Catherine's (NTS 1N/3) map area (e.g., Rusty Zone, Rusty Fault Zone: McKim, 1971; Cant, 1974). Both entered into option agreements with Texas Gulf Sulfur Limited, who flew an airborne magnetic survey of the central part of the region. Texas Gulf drilled one of several chalcocite showings near Triangle Pond in the Holyrood (NTS 1N/3) map area, and completed a lithogeochemical sampling program over the 'Holyrood pyrite zone', in the Hawke Hills north of Route 1 (Mannard, 1969; Mann and Podolsky, 1969). Duval International Corporation (Langdon, 1981) carried out limited exploration near Mount Carmel Pond, in the eastern part of the St. Catherine's (NTS 1N/3) map area. Extensive exploration, including geophysical surveys and diamond drilling, has been undertaken farther northeast in the St. Catherine's (NTS 1N/3) map area, in the vicinity of Butlers Pond (Crocker, 1993; Crocker and Dalton, 1994; Pickett, 1996).

Vinland Resources discovered hydrothermally altered rocks and auriferous float and gold-bearing tills in a large area immediately east of the Salmonier Line and south of Route 1 in the mid-1980s (e.g., Chislett, 1990). This region was subsequently explored by Cominco (e.g., Rennie, 1989; Mersereau, 1990; Grosl and Milner, 1990), Inco (e.g., Beicher, 1991), and Avalon Mines Limited (Pickett and

Jacobs, 1995); assessment work included mapping, geophysical surveys, trenching and drilling. Preliminary drill reports (*see* summary in O'Brien and O'Driscoll, 1996b) led to extensive staking throughout the Holyrood (NTS 1N/6) area. Recent exploration has also been carried out in the northern part of this belt near Harbour Main Pond (Harris, 1996).

REGIONAL SETTING AND GEOLOGICAL FRAMEWORK

The Avalon Peninsula embodies the eastern edge of the Appalachian Orogen on the Island of Newfoundland. Much of this southeastern or "Avalonian" Appalachian margin is cored by Neoproterozoic (760 to 540 Ma) volcano-plutonic arcs and sedimentary successions, all of peri-Gondwanan paleogeographic affinity (c.f., O'Brien *et al.*, 1996b), capped by a lower Paleozoic shale-rich cover. The same rocks occupy a similar tectonic position – outboard of Iapetan arc and continental margin successions (*cf.*, Williams, 1979) – in a belt extending through Maritime Canada, coastal New England, and into the Carolinas and Georgia. Analogous rocks comprise the southeastern margin of the Caledonide orogen, inliers in the European Variscides, and parts of the Pan African orogenic system in West Africa (Keppie and Dallmeyer, 1989). The late Neoproterozoic successions chronicle a part of the development of a larger peri-Gondwanan orogenic system that was dispersed prior to, and variously reworked during the Appalachian-linked evolution of the southern Iapetus Ocean (Nance *et al.*, 1991; O'Brien *et al.*, 1996b).

The pre-Paleozoic character of the Avalon Peninsula, like much of this margin, is defined by the widespread occurrence of volcanic and felsic plutonic rocks of low metamorphic grade, formed between ca. 635 and 600 Ma (King, 1988a; Krogh *et al.*, 1988; O'Brien *et al.*, 1990). On the Avalon Peninsula, these volcano-plutonic arc rocks (Harbour Main Group and the Holyrood Intrusive Suite) are overlain by a thick, shoaling-upward succession of marine, deltaic and fluvial siliciclastic rocks of late Neoproterozoic age (Conception, St. John's and Signal Hill groups, respectively: King, 1980, 1988a; Williams and King, 1979). The marine sedimentary succession contains two globally significant marker units: well-preserved glaciogenic rocks (Gaskiers Formation), and soft-bodied metazoan (*Ediacaran*) fauna in tuffaceous turbidites (Mistaken Point Formation) (Anderson and Misra, 1968; Williams and King, 1979). A thick bimodal volcanic succession (Bull Arm Formation, Musgravetown Group) occurs stratigraphically above marine siliciclastic sediments in the southwestern Avalon Peninsula, where it passes up into late Neoproterozoic fluvial sedimentary rocks.

A shale-rich, fossiliferous cover sequence of Early and Middle Cambrian age, containing distinctive Acado-Baltic trilobite fauna (e.g., Hutchinson, 1962), lies with pronounced angular discordance on various levels of the folded and faulted Neoproterozoic succession, and is itself only locally deformed. Diabase of Mesozoic age has intruded the Proterozoic succession, and coincides with a 110-km-long magnetic lineament that trends in a northeasterly direction across the southeastern Avalon Peninsula (Papezik and Hodych, 1980). A regional magnetic-high of similar orientation parallels the south shore of Conception Bay and coincides with an exposure of posttectonic diabase, which may be of similar Mesozoic age.

DESCRIPTION OF THE LATE NEOPROTEROZOIC GEOLOGY

HARBOUR MAIN GROUP

The Neoproterozoic volcanic and related volcaniclastic sedimentary rocks of the study area are here, as in all previous accounts, included within the Harbour Main Group (*cf.*, Rose, 1952[4]). This group extends from the southern and eastern shores of Conception Bay to approximately 47°30' south. Mafic volcanic rocks occur in domes or periclinal outliers proximal to the periphery of the central volcanic massif (e.g., Brigus Junction, Country Pond; Figure 1).

The Harbour Main Group comprises a thick, areally extensive and stratigraphically complex succession of mafic, intermediate and felsic flows and pyroclastic rocks. The volcanic rocks are interlayered on various scales with several disparite facies of immature volcanogenic sediments and, in the easternmost part of the area, fine-grained siliciclastic strata. No formal regional division of this group has yet been proposed.

The earliest volcanism is primarily explosive, and represented by flows and pyroclastic rocks of felsic to intermediate composition. Rocks of this age are intimately associated with high-level granitic intrusions (Holyrood Intrusive Suite) and include the remnants of caldera complexes. Subsequent volcanicity is marked by both felsic and mafic eruptions, and was accompanied by rapid accumulation of immature volcaniclastic sediments. Youngest volcanicity is bimodal, and occured during a period of extensive terrestrial sedimentation. The resultant succession, which contains well-preserved ash flows (Nixon, 1974; Nixon and Papezik, 1979), is capped by subaerial basalts. Although Harbour Main volcanism was mostly complete prior to the onset of widespread marine siliciclastic sedimentation, the presence of devitrified glass shards and primary volcanic material within

[4] Previously designated "Avondale volcanics" by Buddington (1916) and "Harbour Main volcanics" by Howell (1925).

the latter rocks (Conception Group) implies later Proterozoic volcanicity locally coincided with marine sedimentation. The submarine mafic volcanic succession in the easternmost part of the area, is unlike that elsewhere in the Harbour Main Group, and is interbedded with marine siliciclastic sedimentary rocks.

Available geochronology indicates that rocks assigned to the Harbour Main Group, both within and outside the map area, have a range in ages in excess of 35 Ma, perhaps as much as 50 Ma (Krogh *et al.*, 1988). Although precise ages on most of the plutonic rocks are lacking, it is clear that some of the Harbour Main volcanism occurred more than 10 Ma after the emplacement of large granite plutons, elsewhere into the same group. The designation of all Proterozoic volcanic and related volcanogenic sedimentary rocks to a single stratiraphic unit of group status – tentatively retained in this report – may prove to be inconsistent with the protracted nature and variable character of Neoproterozoic volcanism on the central and eastern Avalon Peninsula.

Several major faults divide the central area into lithologically, and in part temporally distinct volcano-plutonic blocks. The most prominent of these are (from west to east) the Marysvale, Gasters, Peak Pond, Peter's River, Holyrood and Topsail faults. Although these structures are defined by late brittle movements, in some cases of Paleozoic age, their spatial association with the distribution of plutonics, hydrothermal alteration and volcanic facies boundaries implies an earlier, more fundamental role during development of the volcano-plutonic massif.

Avalon High-Alumina Belt, West to the Peter's River Fault

The oldest known rocks in the Harbour Main Group occur in the extensive area east of the Peter's River Fault, including the Avalon High-Alumina Belt (Hayes and O'Driscoll, 1990). Volcanic rocks in this volcano-plutonic block are associated with rhyolite porphyry, dated at 631 ± 2 Ma (U–Pb zircon; Krogh *et al.*, 1988), and intruded by 620 ± 2 Ma granite of the Holyrood Intrusive Suite (Krogh *et al.*, 1988), as well as by undated monzonite and diorite plutons assigned to the same suite. This block is transected by the north-northwest-trending Holyrood Fault.

The area is characterized by thick ash flows and related pyroclastic and related breccia, and to a lesser degree, by rhyolitic domes and subvolcanic porphyry bodies (Plate 1). The volcanic rocks are typically grey and green, locally variegated, and primarily felsic to intermediate (rhyolite–rhyodacite–dacite) in composition. They host extensive zones of syn-volcanic hydrothermal alteration and brecciation, locally accompanied by epithermal-style gold and pyrophyllite mineralization (*see below*). The reader is referred to detailed descriptions of various aspects of the geology of the

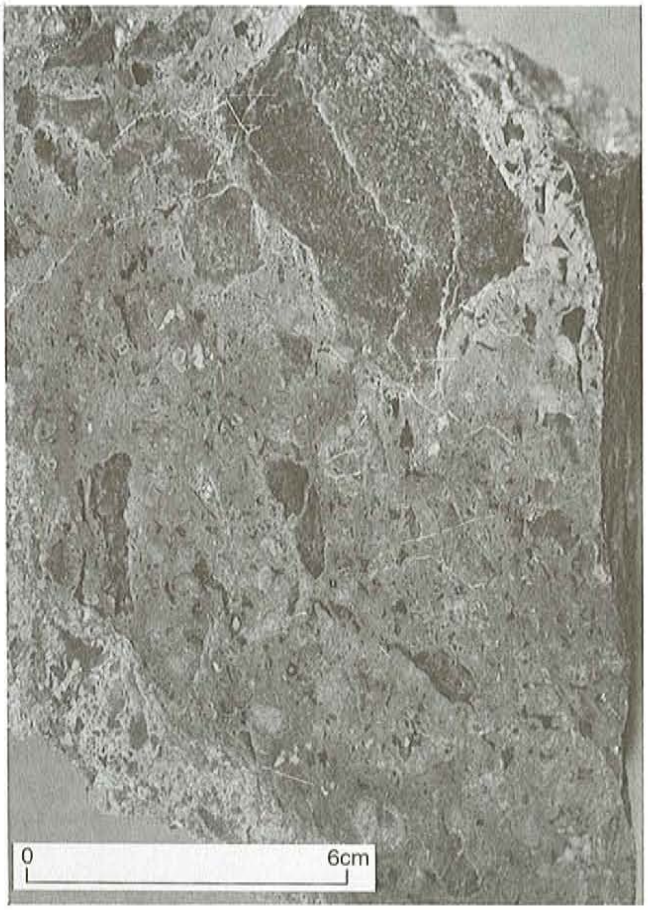

Plate 1. *Ash-flow tuff, Avalon High-Alumina Belt of the Harbour Main Group, near Manuels.*

belt given in Buddington (1916), Vhay (1937), Keats (1970), Papezik (1974), Papezik and Hume (1984), Hayes and O'Driscoll (1990, 1994) and Hayes (1997). Other more detailed descriptions of rocks occurring farther west in this block are given by Jacobs (1984) and O'Brien and O'Driscoll (1996b), and are not repeated here.

Areally restricted subaerial basalt flows occur stratigraphically above the felsic to intermediate pyroclastic rocks in the north half of the area. Mafic volcanic rocks, including pillow-like breccias, are more widespread south and west of the Inside Hawke Hills, where they lie at the top of a distinctive and extensive succession of dark-grey crystal-rich ash flows. The latter has been mapped in a continous belt extending approximately 20 km southward from Conception Bay (Figure 2). The distribution and great thickness of the ash flows and related breccia facies within this block are consistent with volcanicity proximal to volcanic centres, one of which may be sited along the axis of the Hawke Hills.

Exposures west of the Holyrood Fault in the southern part of the area (e.g., south of the Inside Hawke Hills) are broadly similar in terms of volcanic facies, and are predominantly of

felsic pyroclastic origin. Mafic rocks are volumetrically minor and include pillow-like breccia similar to those farther north in the block. In the area southwest of Mount Carmel Pond, however, ash flows are interlayered with thick units of variegated tuffaceous sedimentary rocks and red conglomerate (Mullins, 1970; Thornhill, 1981). Such a facies association is atypical of this block but similar to that seen west of the Peter's River Fault. The highest stratigraphic levels of the Harbour Main Group in this area are occupied by variegated pyroclastic breccia and a distinctive, pale-green fragmental rock of either pyroclastic or hydrothermal origin. The latter is characterized by a highly siliceous, chert-like matrix, having positive relief relative to the breccia clasts.

Peter's River Fault to the Gasters Fault

The Harbour Main Group from the Peter's River Fault as far west as the Gasters Fault is characterized by much greater thicknesses of subaerial mafic flows and volcanogenic sediments than seen in deeper stratigraphic levels farther east. Rhyolites from this block have been dated at 622 ± 2 Ma (Krogh *et al.*, 1988). The stratigraphic section in the northern part of the area, west of the Peak Pond Fault, is described in O'Brien and O'Driscoll (1996b).

Red, densely welded tuff is the dominant lithofacies in the western part of this block (e.g., south of Avondale), where it is capped by a basaltic agglomerate unit, which is in turn succeeded, to the south, by lower Conception Group rocks. Farther northeast, a stratigraphically lower succession of interlayered rhyolite, basalt and basaltic to andesitic breccia, passes up into a 1- to 2-km-thick succession of interstratified volcanogenic sediment and bedded tuff.

The basaltic rocks in this succession may be correlated with those east of the Peak Pond Fault. There, basaltic and andesitic flows and breccia are interstratified with red, pebble to boulder conglomerate. These rocks pass upward into a rhyolite unit containing thin, discontinuous, volcanogenic sediment layers, overlain by basaltic and andesitic flows, which occupy the core of an open periclinal fold near Old Sea. Still farther south, rhyolitic flows reappear and continue southwards into the Avalon Wilderness Reserve, where they are separated by faults from either the Conception Group or post-Conception intrusions.

Gasters Fault to the Marysvale Fault

The northwestern block of the Harbour Main Group, between the Gasters and Marysvale faults, is characterized by thick, interbedded units of ash-flow tuff and red volcanogenic sandstone and conglomerate. A small area of similar rocks, faulted with the Conception Group, occurs near the head of Gasters Bay, between the Gasters Fault and a splay of this structure trending southwestward through Middle Gull Pond. The latter fault is one of several parallel structures that juxtapose upper and lower Conception Group strata, locally defining the Harbour Main–Conception group boundary.

The ash-flow tuffs in the northwestern part of the study area, particularly on the peninsula between Colliers and Gasters bays, are the most well preserved of all such facies within the Harbour Main Group (Plate 2), and are described in detail in Nixon (1974) and Ford (1977). One ash-flow unit from the Weavers Hill sequence (Nixon, 1974) has been dated by Krogh *et al.* (1988) at 606 ± 3 Ma. Three composite ash-flow sequences, from 250 to 500 m thicknesses, are separated by terrestrial sedimentary rocks; all are intruded by subvolcanic plagioclase porphyries (Nixon, 1974). This part of the Harbour Main Group is capped by a 300- to 600-m-thick succession composed primarily of thick vesicular basalt flows. These rocks are well exposed south and west of Colliers Bay, and reappear in an anticlinal outlier at Brigus Junction. In both areas, the basalts are locally associated with mafic sills, and are interstratified with red sandstone and thin discontinuous units of mafic breccia.

The bimodal volcanic–terrestrial sedimentary succession in this fault block postdates the stratigraphic section exposed east of the Peter's River Fault by more than 20 Ma and was erupted more than 10 Ma after emplacement of the main granite phase of the Holyrood Intrusive Suite (Krogh *et al.*, 1988; O'Brien and O'Driscoll, 1996b).

East of the Avalon High-Alumina Belt

Most of the volcanic rocks between the Avalon High-Alumina Belt and the Topsail Fault, and between the Topsail and Dogberry Hill faults along northeastern Conception Bay (King, 1990), although historically assigned to the Harbour Main Group, bear little resemblance to exposures of the group farther west, in the type area. This eastern block comprises submarine mafic flows, pillow lavas and hyaloclastites, which are interbedded on outcrop scale with units of fine-grained, in many cases cherty, marine siliciclastic rocks. Reconnaisance mapping of that part of the block west of the Topsail Fault suggests that the unit retains its distinctive and homogeneous lithologic character from north to south across the entire study area. Its boundary with volcanic rocks in the Avalon High-Alumina Belt is, in most instances, unexposed but is also intruded by later mafic plutons, or is faulted. The interbedding of the mafic volcanic rocks with marine sediments suggests a gradational relationship with the Conception Group, unlike that seen elsewhere in the study area. Along northeastern Conception Bay, similar mafic rocks lie stratigraphically below lower Conception Group strata or are locally intercalated with them (King, 1990). A thin, discontinuous unit of pillow basalt and breccia in the Conception Group on the west shore of Holyrood Bay, described below, may be related to this volcanism.

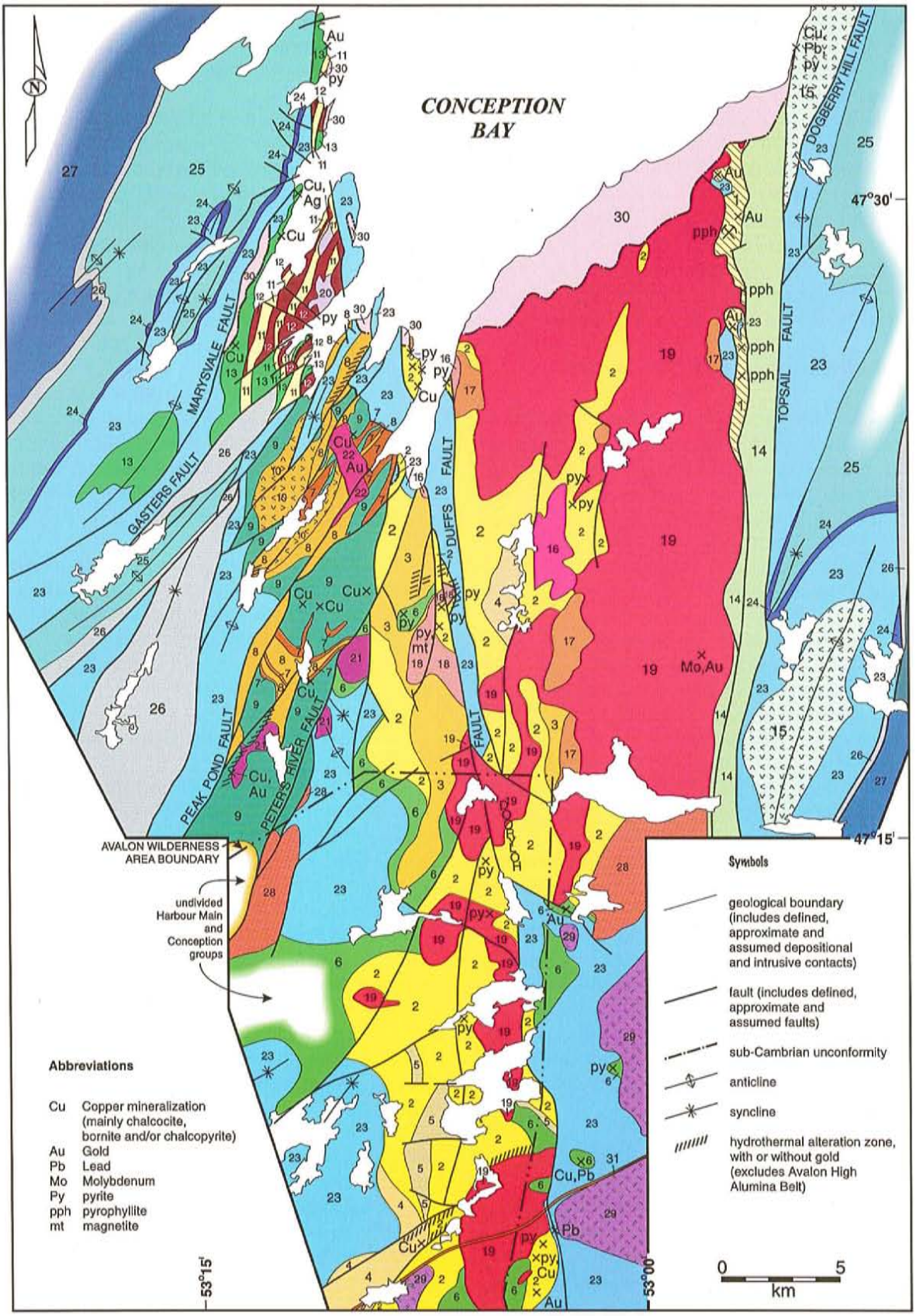

Figure 2. *Geology of the central Avalon Peninsula, Newfoundland.*

LEGEND

MESOZOIC
LATE TRIASSIC AND/OR EARLY JURASSIC
31 *Diabase dyke(s)*

PALEOZOIC
EARLY AND MIDDLE CAMBRIAN
30 *Red and green shale, pink limestone, black and grey shale, and manganiferous shale of the unseparated* Adeyton *and* Harcourt groups

unconformable on Harbour Main and Conception groups and on Holyrood Intrusive Suite

PRECAMBRIAN
LATE NEOPROTEROZOIC
WHALESBACK GABBRO and related mafic intrusions
29 *Unseparated fine- to medium-grained dark-green and grey equigranular gabbro; minor diabase; minor coarse-grained gabbro; includes gabbro and unseparated screens of Conception Group sedimentary rock*

not in contact

UNNAMED POST-CONCEPTION GROUP INTRUSIONS
28 *Unseparated equigranular quartz monzonite and granodiorite; quartz-rich granite and minor granite, felsite and monzonite; quartz-feldspar porphyry*

intrusive contact with the Conception Group

ST. JOHN'S GROUP
27 *Unseparated* Fermeuse *and* Trepassey formations: *dark-grey to black sandstone and shale, locally having slump structures*

UPPER CONCEPTION GROUP
26 Mistaken Point Formation: *green to grey siliceous turbiditic sandstone, siliceous siltstone, mudstone, porcellanite and tuff; non-siliceous, green, red and purple mudstone, siltstone and tuffaceous sandstone*

25 Drook Formation: *white to yellowish-green- and yellow-brown-weathering, thin- to medium-bedded grey and green siliceous sandstone, siltstone, chert and graded tuffaceous sandstone*

24 Unnamed Mixtite Unit: *massive green mixtite; glaciogenic debris flows*

LOWER CONCEPTION GROUP
23 *Unseparated grey and green, thin-bedded siliceous siltstone and sandstone; minor crossbedded sandstone; locally contains red sandstone, red laminated tillite or volcanic rocks near the base; basal conglomerate*

not in contact

WOODFORDS MONZONITE
22 *Fine-grained equigranular monzonite; rare felsite*

UNNAMED INTERMEDIATE INTRUSIONS (may include rocks that postdate the Conception Group)
21 *Dark-grey and green equigranular, magnetic monzonite; medium-grained, green to grey, altered pyroxene-bearing magnetic monzonite; minor quartz monzonite and granodiorite*

20 *Plagioclase porphyritic intermediate intrusions*

not in contact or intrusive contact

HOLYROOD INTRUSIVE SUITE
19 *Fine- to medium- and locally coarse-grained, quartz-rich biotite–hornblende granite; unseparated pink microgranite and quartz monzonite; may include minor, unseparated, post-*Conception Group *granite plutons*

18 *Granophyre; fine-grained granite and aplite having pegmatitic phases; very minor coarse-grained granite*

17 *Fine- to medium-grained equigranular diorite and monzonite, and associated hybrid phases mixed with granodiorite and granite; unseparated gabbro*

16 *Granite containing plugs of quartz-feldspar porphyry*

intrusive contact with 635 to 620 Ma rocks

HARBOUR MAIN GROUP (numbering may not reflect stratigraphic order in all instances)
15 *Unseparated volcanic rocks east of the* Topsail Fault

14 *Mixed mafic volcanic and marine sedimentary rocks; may include minor unseparated felsic volcanic rocks*

ca. 610 to 600 and earlier
13 *Mainly green subaerial vesicular basalt flows and breccia*

12 *Mainly red sandstone and related volcanogenic sediments*

11 *Ash-flow tuffs*

ca. 620 to 610 Ma (may include minor older rocks)
10 *Red welded ash-flow tuff*

9 *Mainly subaerial basalt flows and breccia*

8 *Rhyolite flows and related, altered and unaltered felsic to intermediate volcanic rocks*

7 *Variegated tuffaceous sedimentary rocks; includes minor red sandstone and boulder conglomerate layers*

ca. 635 Ma and earlier (may include rocks as young as 620 Ma)
6 *Basalt flows (locally contains pillow forms); mafic tuffs and breccia*

5 *Minor grey and green volcanogenic sediment and red conglomerate*

4 *Felsic to intermediate breccias*

3 *Dark-grey, welded ash-flow tuff and related rocks*

2 *Unseparated rhyolitic, rhyodacitic and dacitic flows,ash-flow tuffs and minor breccia*

Unseparated volcanic rocks of the Avalon High Alumina Belt

Figure 2. *Continued.*

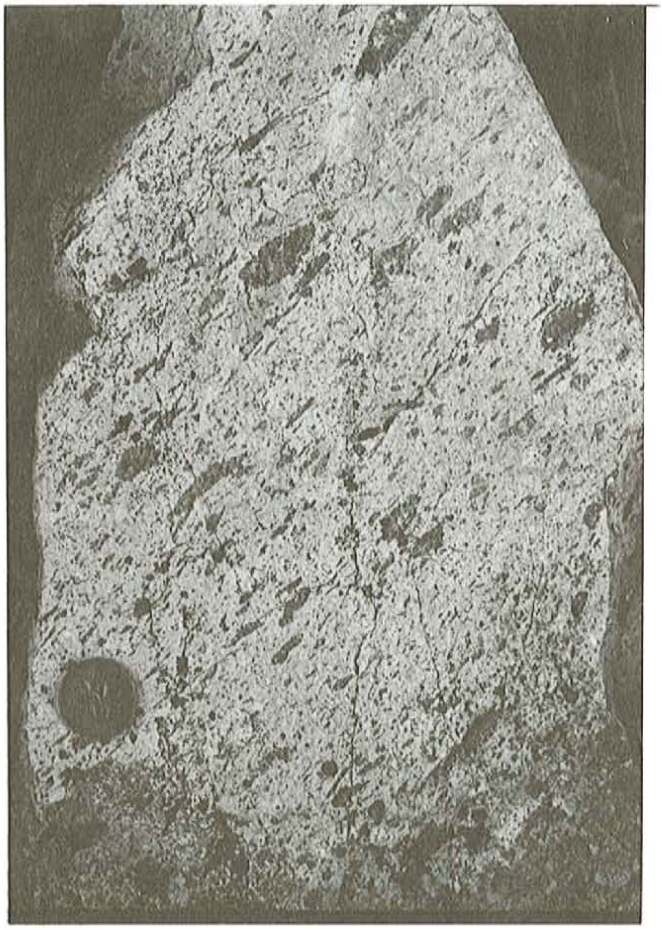

Plate 2. *Welded ash-flow tuff of the Harbour Main Group at Colliers.*

A separate outlier of Harbour Main Group occurs east of the Topsail Fault, between Mobile First Pond and the Witless Bay Line. A brief reconnaisance of this area indicated the presence of subaerial vesicular basalts, unlike those farther north. These basalts are assumed to be overlain by mixtite and/or lahars, that may be intercalated with Conception Group turbidites.

HOLYROOD INTRUSIVE SUITE AND RELATED ROCKS

The Harbour Main Group is intruded by gabbroic, monzonitic and granitic[5] rocks that, in most previous accounts, are interpreted as lithodemic units within the Holyrood Intrusive Suite (e.g., King, 1988a). Within the study area, the suite forms an essentially continuous body extending from the vicinity of Mobile Big Pond, northward to Conception Bay, where it is unconformably overlain by Cambrian cover. The eastern half of the main body of the Holyrood Intrusive Suite is composed primarily of granite. It is intrusive into the Avalon High-Alumina Belt to the east; the granite's boundary with volcanic rocks south of the Avalon High-Alumina Belt is unexposed. In the western half of the main body of the suite, the same granite occurs together with gabbro, diorite, monzonite and related hybrid intrusions, as well as granite porphyry phases. These rocks are intrusive into that part of the Harbour Main Group east of the Peter's River Fault. A network of volcanic roof pendants occurs along the suite's western margin; in the same area, subvolcanic, quartz- and quartz-feldspar porphyry bodies are common. This boundary has a highly irregular shape, reflecting – in part – shallower erosion levels into the suite in this area, a view further supported by the presence of granophyre bodies along this margin (Hughes, 1971; O'Brien and O'Driscoll, 1996b). Descriptions of aspects of the geology of northern parts of the suite have been presented by O'Brien and O'Driscoll (1996b) and are not repeated here.

Early phases of the Holyrood Intrusive Suite are fine-grained equigranular diorite and monzonite, which are extensively mixed with granodiorite and granite. These intrusions host an extensively developed magma-mixing phenomenon, and locally contain magmatic fabrics. They occur as centimetre- to decametre-scale xenoliths and larger, regionally mappable enclaves within later granite.

Buff to pale-orange, grey-weathering granite is the predominant phase of the intrusive suite. The granite, which has been dated at 620 ± 2 Ma (Krogh *et al.*, 1988) is quartz-rich, fine- to medium-grained, and biotite–hornblende bearing. Epidote–chlorite alteration is variably developed; chloritic fractures and tuffisite veins are widespread (Plate 3). Hydrothermal magnetite veinlets and narrow, magnetite-bearing and molybdenite-bearing quartz veinlets occur in a few localities, spatially associated with tuffisite and/or graphic or pegmatitic granite. The quartz-rich, equigranular granite phase is transitional into sub-porphyritic and quartz porphyritic variants. It is intruded by a younger phase of pink aplitic granite and, rarely, by feldspar porphyry. In a number of areas, the granite (adamellite) exhibits a distinctive pale-pink- and green-weathering; in many instances this facies has not been affected by the gas brecciation common elsewhere.

Many of the granitic bodies sited on or west of the Holyrood Fault in the southern part of the area resemble the main granitic phase of the Holyrood Intrusive Suite. The amount of monzonite in this area appears to be significantly less than previously thought (e.g., Mullins, 1970).

[5] Nomenclature is tentative, and may be changed on the basis of petrographic and chemical data, not available at the time of writing.

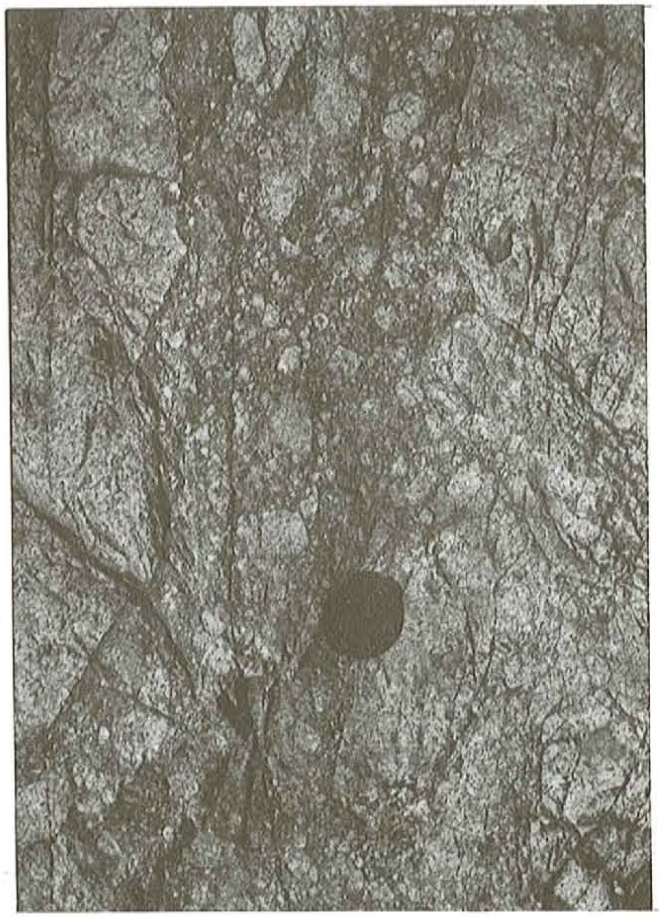

Plate 3. *Tuffsite breccia in granite of the Holyrood Intrusive Suite, near Soldiers Pond.*

Monzonitic Intrusions

Small bodies of monzonite intrude the Harbour Main Group adjacent to, and west of, the Peter's River Fault. These isolated plutons are composed of medium-grained, equigranular green to grey, altered pyroxene-bearing monzonite. Minor quartz monzonite and granodiorite phases also occur. Hybridization of diorite and mafic monzonite with a pink granite has been described in one of the plutons (Woodfords Monzonite: O'Brien and O'Driscoll, 1996b). The absolute age of these monzonites is unknown. Most occur within the Harbour Main Group and thus their relationship with the Conception Group is unclear (*see* discussion in O'Brien and O'Driscoll, 1996b). One small monzonite about 2 km south of Velvet Horn Pond occupies an antiformal core surrounded by Conception Group; the monzonite–sediment contact is unexposed. Conglomerate outcrops near a separate monzonite pluton at Velvet Horn Pond contain clasts of a texturally similar, albeit more granitic, rock.

A discontinuous belt of monzonite to gabbroic plutons extends northward from Mobile Big Pond, along the western edge of the main granite pluton of the Holyrood Intrusive Suite. The plutons contain more mafic material than those exposed farther west, and exhibit mixing with typical Holyrood phases.

CONCEPTION GROUP

The Conception Group (Rose, 1952) occurs throughout the Avalon Peninsula, where it comprises a 3- to 5-km-thick succession of green to grey siliceous sandstone, siltstone and mudstone. The group has been divided into five formations (Williams and King, 1979). In ascending order, these are: Mall Bay (>800 m thick, base unexposed), Gaskiers (300 m), Drook (1500 m), Briscal (<100 m in north, 1200 m in south), and Mistaken Point (400 m). A thin tuff bed near the top of the Mistaken Point Formation has yielded a radiometric U–Pb date of 565 ± 3 Ma (G.R. Dunning, 1988, unpublished data; Benus *in* King, 1988b). The absolute age of the remainder of the succession is unconstrained. The Conception Group within the study area is more argillaceous than that in the eastern and southern Avalon Peninsula, its type area[6].

Much of the Conception Group in the study area is disposed in broad, internally faulted, and openly folded belts on the east and west flanks of the Harbour Main Group. The Conception Group is also infolded with the volcanic rocks, either as broad, open periclinal outliers, such as seen immediately west of the Bosun, or in tighter, north-plunging structures, like those south of Gasters Bay, or between Big Island Pond and Holyrood Bay (Figure 2). In the eastern and western parts of the study area, lower Conception Group strata are folded into broad kilometre-scale anticlines cored by inliers of Harbour Main Group basalts. In the southeastern part of the region, an essentially homoclinal Conception Group is thermally altered in the aureole of the Proterozoic Whalesback Gabbro. The succession dips and youngs westward up to the Holyrood Fault, and the adjacent Harbour Main Group. Composite profiles of the group between Colliers Bay and Bay Roberts indicate a minimum exposed thickness of 3 km.

The contact of the Conception and Harbour Main groups, in most localities, is either faulted or unexposed; a depositional boundary is preserved on Holyrood Bay and near Harbour Main. In many instances, the regional strike of Conception strata parallels that in the underlying Harbour Main succession. A significant exception occurs between Holyrood Bay and Harbour Main, where steeply dipping Harbour Main Group beds strike perpendicularly into basal

[6] The argillaceous nature of the siliciclastic succession around Conception Bay was first noted by Walcott (1899), who designated these strata the 'Conception slate'.

conglomerates and stratigraphically higher turbidites of the overlying Conception Group (Figure 2; *see* also McCartney, 1954, 1967). The boundary of the Conception Group and the Holyrood Intrusive suite is typically a fault. A depositional boundary between the Conception Group and granite is exposed at Holyrood.

The Lower Conception Group strata in the map area are provisionally correlated with the Mall Bay and Gaskiers formations, and the upper units are correlative with the Drook and Mistaken Point formations, which have been traced northward from their type localities. Within that part of the study area, west of and including the Avalon High-Alumina Belt, the onset of Conception Group sedimentation marks the end of prolonged and extensive volcanic activity. In the area between the Avalon High-Alumina Belt and the Topsail Fault, however, Conception Group beds are interlayered with mafic volcanic units; similar intercalation of mafic flows and siliciclastic sediments have been described from the area east of the Topsail Fault (King, 1990). The Conception Group exposures in the latter area are described in detail by King (1990); the reader is referred to this work for further details of the lithostratigraphy of the Conception Group in the north-eastern Avalon Peninsula.

Lower Conception Group

Basal Conglomerates

The basal beds of the Conception Group are typically conglomerate of variable compositions. Their thickness ranges from ca. 1 to 25 m. Clasts vary in size from granule to boulder and are set in a sandy to muddy matrix; clast-supported and matrix-supported fabrics occur. The basal Conception Group on eastern Holyrood Bay is unique in that its basal (red and green) polymict conglomerate is interstratified with a thin silicic volcanic unit (*see* O'Brien and O'Driscoll, 1996b).

Within the Avalon High-Alumina Belt, hydrothermally altered felsic volcanic rocks of the Harbour Main Group are unconformably overlain by boulder conglomerate. In the Oval Pit Mine, basal Conception conglomerate is derived from altered (pyrophyllitized and silicified) rocks; the succeeding sediments are unaltered (e.g., Hayes and O'Driscoll, 1990; Hayes, 1997). Farther west, along the east shore of Conception Bay, the basal boulder conglomerate unconformably overlies and is erosive into the Harbour Main Group, and also samples the underlying Holyrood Intrusive Suite. The Harbour Main–Conception group boundary is exposed approximately 3 km south of Duffs Hydro Station; there, the conglomerate contains rounded volcanic clasts derived from the Harbour Main basement, as well as a variety of rock types found in the Holyrood Intrusive Suite. Of particular note, is the presence in the conglomerate of a distinctive quartz-feldspar porphyry (Plate 4). The same rock is exposed nearby in this coastal section, beneath the unconformity, where it is gradational into more typical, quartz-rich granite of the Holyrood Intrusive Suite, and intrusive into the Harbour Main Group. Approximately 4 km to the south, conglomerate and grit containing subrounded granite clasts lie directly on the granite, within a small outcrop area of Holyrood Intrusive Suite rocks, situated along the trace of the Holyrood Fault.

Plate 4. *Clasts of quartz-feldspar porphyry and granite (both part of the Holyrood Intrusive Suite) in basal Conception Group conglomerate on the east shore of Holyrood Bay.*

Between the Peter's River and Gasters faults, quartz-rich basal conglomerate of the Conception Group lies with pronounced angular discordance across several stratigraphic levels of the Harbour Main Group (O'Brien and O'Driscoll, 1996b). The conglomerate is matrix-supported, and contains abundant pebble- and cobble-sized clasts of a variety of felsic and mafic volcanic rocks in addition to white vein quartz and red jasper or chert. Detrital magnetite lenses, up to 15 cm thick, locally occur in foresets in the conglomerate.

West of the Gasters Fault, the basal contact of the Conception Group is erosional but concordant with the strike of underlying basaltic flows. The basal conglomerate is best exposed at Turks Gut, Marysvale, where coarse-grained conglomerate, composed of well-rounded boulders of basalt, overlies subaerial vesicular basalt flows of the Harbour Main Group (Plate 5).

Overlying Siliciclastic and Related Rocks

The basal conglomerate of the Conception Group is abruptly overlain by about 700 m of rhythmically inter-bedded, fine-grained siliceous sandstone, siltstone and mudstone (Plate 6). On the east side of Holyrood Bay, for example, thin- to medium-bedded silty sandstone–mudstone couplets (turbidites) show typical Bouma-sequence features

Plate 5. *Basal Conception Group boulder conglomerate at Turks Gut, Marysvale.*

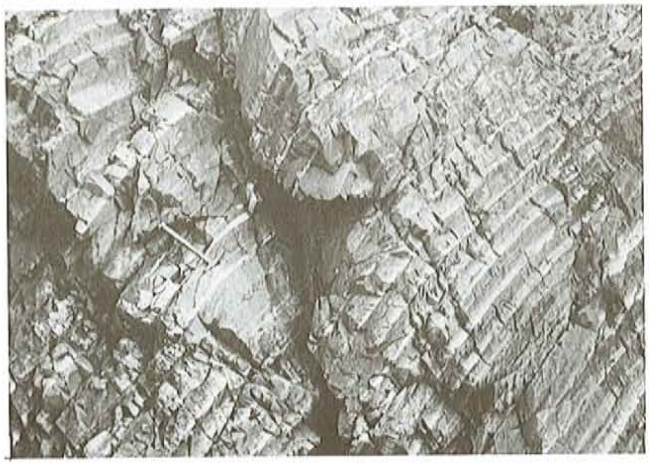

Plate 6. *Thin- to medium-bedded, graded sandstone and siltstone of the Conception Group at Harbour Main.*

such as sole marks, rip-up clasts, grading, parallel- and crosslaminations and structureless mudstone (*see* O'Brien and O'Driscoll, 1996b). These features are comparable with facies in the Mall Bay Formation of the southern Avalon Peninsula. On the west side of Holyrood Bay, the lower Conception Group contains a thin (≤50 m) mafic volcanic unit, characterized by the presence of large pillows, with well-developed radial fracture patterns, and by pillow breccia, having a calcareous matrix.

The basal Conception Group conglomerate in the Avalon High-Alumina Belt passes upward into rhythmically interbedded, siliceous siltstone and sandstone referred to as the 'Black Hill' sequence by Dawson (1963). In the western part of the area, basal Conception beds are succeeded by a thin unit of red sandstone, associated with planar- and cross-laminated green sandstone. These are overlain by thin- to medium-bedded, green siliceous siltstone, which passes up into a distinctive grit and overlying, massive green mixtite unit of glaciomarine origin.

Conception Group Mixtites

Mixtites or diamictites characterized by polymict pebble- to cobble-size clasts in a matrix of mud, silt and sand, form distinctive stratigraphic units between the lower and upper Conception Group turbidites. Although comparable with facies in the Gaskiers Formation (Williams and King, 1979; Anderson and King, 1981) and the Bauline Line Member of the Drook Formation (King, 1990), their precise stratigraphic position and correlation are uncertain.

One mixtite unit, approximately 100 m thick, forms a regional marker bed that extends from Whalens Pond to Brigus, separating between 200 and 700 m of lower Conception Group strata from that of the upper Drook and Mistaken Point formations. This mixtite is characterized by nonsorted and randomly oriented, subrounded to subangular clasts (ca. 1 to 10 cm diameter), set in a nonlaminated, green and grey mud or sand matrix. Clasts of felsic and mafic volcanic rocks, siltstone, sandstone, chert and quartz predominate and granite, granophyre and diorite clasts comprise up to 10 percent of the mixtite, locally. The clast/matrix ratios are extremely variable, even in a small area. The proportion of matrix ranges from 25 to 95 percent, but is generally about 80 percent and in the northern part of the area the mixtite is finer grained that it is in the south. Slumped sandy beds and thin-bedded siltstone and mudstone (rhythmites) of the overlying Drook Formation are locally associated with this mixtite facies. The mixtite is interpreted as a submarine debris flow with a possible glaciogenic component; the coarser grained deposits were probably restricted to submarine fan channels.

A separate, lithologically distinct internally laminated, red mixtite occurs east of the Gasters Fault. Exposures of this facies along the Avondale access road and at Bacon Cove (and nearby coastal cliffs) are situated several hundred metres above the basal Conception Group. This mixtite is characterized by subrounded clasts (1 to 20 cm diameter) of volcanic, granitoid and siliciclastic sedimentary rocks within a well-stratified or laminated mud–silt–sand matrix; these relatively outsize clasts are interpreted as glacial dropstones. In the Harbour Main area, the same red and green, laminated mixtite is capped by a metre-thick limestone layer (Plate 7). There, the mixtite occurs within metres of the faulted Conception–Harbour Main group contact. McCartney (1967) has mapped similar limestone close to the base of the Conception Group, near a depositional (unconformable) boundary with underlying volcanic rocks.

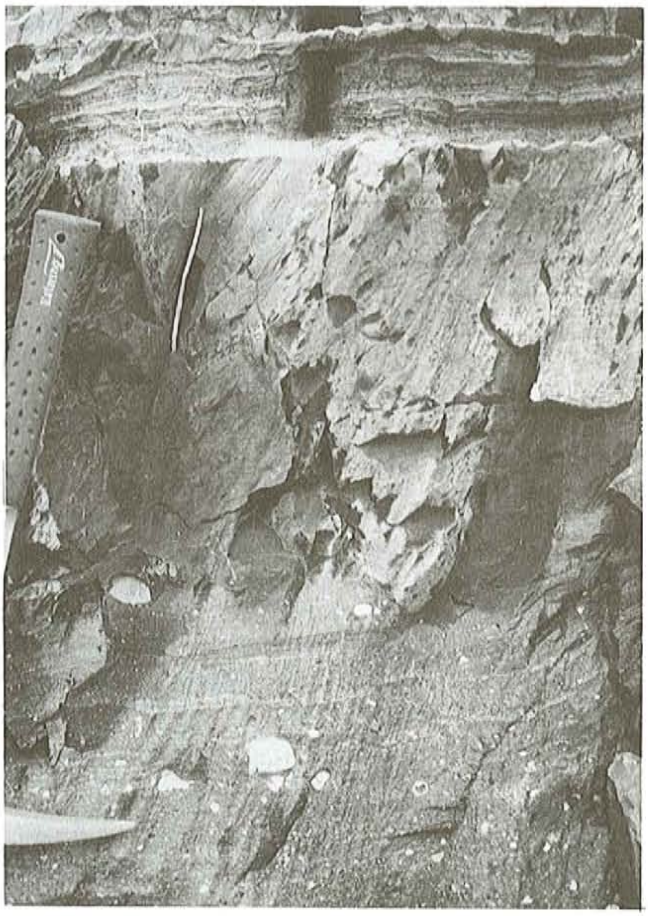

Plate 7. *Laminated mixtite containing dropstones, overlain by limestone; Conception Group at Harbour Main.*

Upper Conception Group

Drook Formation

Siliceous sandstone, siltstone, chert and graded tuffaceous sandstone, here assigned to the Drook Formation (Williams and King, 1979), define much of the map area east of the Topsail Fault and northwest of the Gasters Fault. In the central part of the map area, the formation is exposed in roadcuts along the Trans-Canada Highway. It also forms the core of a large antiform between Middle Gull Pond and Lockyers Waters. White to yellowish-green- and yellow-brown-weathering beds are commonplace in the Drook Formation.

Sedimentary structures that are common in this turbiditic succession include: parallel-sided, medium to thick beds, graded bedding, convolute lamination, small-scale ripple crosslaminations, rip-up clasts, and sole and load marks. Beds of tuff and chert are present in a many areas.

In the northwestern part of the map area (approximately 6 km north on Roaches Line), the Drook Formation is capped by a thin unit of gritty (2 to 4 mm) green sandstone. The latter is comparable in facies – although not thickness – to the Briscal Formation of the southern Avalon Peninsula (Williams and King, 1979).

Mistaken Point Formation

In the western part of the study area, the Drook Formation passes conformably upward into red and green siliceous siltstone and overlying red argillaceous siltstone, all correlative of the Mistaken Point Formation of Williams and King (1979). The formation is also exposed in a fault-bounded synclinorium passing between Middle Gull Pond and Southwest Pond, and in smaller scale, faulted structures located nearby.

The Mistaken Point Formation in this area, as elsewhere on the eastern Avalon Peninsula, is divided into two units. A lower 100- to 200-m-thick unit, consists of green to grey siliceous turbiditic sandstone and interbedded siliceous siltstone, mudstone, cherty porcellanite (*cf.*, Hughes, 1976) and tuff. These beds are equivalent to the Middle Cove Member of King (1990). An upper unit consists of 100 to 200 m of interbedded non-siliceous, green, red and purple mudstone, siltstone and tuffaceous sandstone, equivalent of the Hibbs Cove Member of King (1990). A late Neoproterozoic (*Ediacaran*) fauna, (*cf.*, Anderson and Conway Morris, 1982) similar to those at Mistaken Point (southern Avalon Peninsula), were found immediately north of the study area at Spaniards Bay, and immediately south of the study area, on the Salmonier River (A. King, unpublished 1984 data); their locations are shown in King (1988a).

The most complete profile of the Mistaken Point Formation in the study area is exposed in a large quarry adjacent to, and south of the Trans-Canada Highway, at its intersection with the Avondale access road. Approximately 100 m of strata of the Middle Cove and Hibbs Cove members are well exposed on the steeply dipping east limb of the aforementioned syncline. The Hibbs Cove Member is well exposed in roadcuts and rivers south of Makinsons.

ST. JOHN'S GROUP

In the northwest and southeast parts of the study area, the variegated rocks at the top of the Conception Group are overlain conformably by grey sandstone, siltstone and black shale, equivalent to parts of the St. John's Group (Williams and King, 1979). The group, an extensive, 2-km-thick sequence of marine shales and interbedded sandstones, was deposited in a pro-deltaic to shallow-marine coastal plain environment (King, 1980).

The St. John's Group exposed in the northwestern part of the map area consists of three units, which remain unsepa-

rated on the accompanying map (Figure 2). Argillaceous sandstone and black shale, which are transitional into the underlying Mistaken Point Formation, are equivalent to the Trepassey Formation of Williams and King (1979). Overlying black shales, equivalent to the Fermeuse Formation (Williams and King, 1979), are typified by the presence of slumped and resedimented features. The stratigraphically highest parts of the St. John's Group in this area can be correlated with the Renews Head Formation (Williams and King, 1979). These are thin, lenticular-bedded rusty-brown-weathering sandstone, containing dark shale laminae, overlain by thin, irregular beds, showing ripple-drift crosslamination.

POST-CONCEPTION GROUP (PROTEROZOIC?) INTRUSIONS

Small bodies of equigranular monzonite and related porphyritic intrusions of intermediate to granitic composition occur mainly (but not exclusively) in the area west of the Holyrood Fault. The youngest of these are mapped to intrude across the Harbour Main–Conception group boundary (McCartney, 1954). A large gabbroic pluton in the southern part of the map area, between the Topsail and Holyrood faults has been correlated by King (1988a) with the Whalesback Gabbro of the southern Avalon Peninsula (Williams and King, 1979). It is composed primarily of green and grey, fine-grained and equigranular, slightly magnetic gabbro. The gabbro intrudes moderately dipping to vertical Conception Group strata. Millimetre- to centimetre-scale tight folds of a local cleavage in the Conception Group along its contact with the gabbro are interpreted as intrusion-related phenomena. Smaller, isolated stocks of medium- to coarse-grained gabbro near Butlers Pond and Gibbons Pond are likely related to the Whalesback Gabbro; in the first instance, the gabbro is intrusive into the Conception Group, in the second instance the gabbro intrudes the Harbour Main Group.

Two felsic plutonic bodies include phases that are intrusive into well-defined Conception Group strata. The first of these, exposed near Butlers Pond, consists primarily of quartz-rich granodiorite locally transitional into quartz monzonite. Outcrops of this pluton are typified by either sericitic or chloritic alteration and minor disseminated sulphides – mainly pyrite. The pluton contains zones of aplite and pink quartz-feldspar pegmatitic patches. The main body is spatially associated with pink quartz-feldspar porphyry. Both the main granitoid and the porphyry host fine-grained tuffisite-like breccias, some of which may be hydrothermal in origin.

Another pluton, exposed approximately 2 km south of Old Sea, includes a granitic phase that is intrusive into the Conception Group. The granite in contact with Conception strata is part of a coarse-grained, equigranular and quartz-rich body. Farther south in the same pluton, the granite occurs together with fine- to medium-grained, hornblende-rich monzonite and minor diorite.

HYDROTHERMAL ALTERATION AND MINERALIZATION

Epithermal-style alteration, with or without gold and copper mineralization, occurs in a number of areas in the Harbour Main Group, typically in close proximity to the overlying Conception Group. In several instances, there is a spatial, and inferred genetic, association with mafic to intermediate and granitic plutons of the Holyrood Intrusive Suite, as well as with elements of a later suite of Proterozoic plutons, intrusive into the Conception Group strata. The plutonic rocks are locally affected by silicic, sericitic and, locally, K-silicate alteration, and contain anomalous gold concentrations. The Avalon High-Alumina Belt represents the most widespread area of hydrothermal alteration; this belt contains some of the most extensive and highest grade gold mineralization in the region. Highly anomalous gold concentrations are also found in bedrock and float along the western margin of the Harbour Main Group (Triangle Belt: *see* O'Brien and O'Driscoll, 1996b), and associated with granite near Butlers Pond (Crocker, 1993).

A brief description of some hydrothermally altered and mineralized outcrops in parts of the northern half of the area, given in O'Brien and O'Driscoll (1996b), is expanded upon here, where new data have become available. The reader is referred to several previous accounts of alteration and pyrophyllite mineralization in the Avalon High-Alumina Belt (Hayes and O'Driscoll, 1990, 1994 and references therein).

AVALON HIGH-ALUMINA BELT

The Avalon High-Alumina Belt (Hayes and O'Driscoll, 1990) refers to a ca. 15-km-long zone of advanced argillic and silicic alteration that occurs within pre-620 Ma rocks of the Harbour Main Group. The extensive hydrothermal alteration system contains several deposits of pyrophyllite, including Armstrong World Industry Canada Limited's Oval Pit Mine, and recently discovered examples of vein- and breccia-hosted epithermal gold mineralization (e.g., Saunders, 1991; O'Brien and O'Driscoll, 1996a). The geology of the Oval Pit Mine has been been studied and described by various authors, most recently, by Hayes (1997). Papezik (1974) describes typical ore as a very fine-grained assemblage of quartz, sericite and pyrophyllite in varying proportions, together with minor rutile, diaspore and barite.

At many localities within the Avalon High-Alumina Belt, silica alteration and pyrophyllitization are developed parallel to primary layering in felsic flows and pyroclastic successions. Preliminary observations support the view that silicification and pyrophyllitization are genetically related

events that, in most instances, overlap in time. The alteration occurred prior to much of the regional deformation, preceeding deposition of the overlying marine sediments (Black Hill sequence – Conception Group – of Dawson, 1963). In areas of the Avalon High-Alumina Belt where silicic alteration is less extensive, primary layering is replaced, on scales ranging from a few millimetres to several metres, by chlorite, pyrophyllite and silica. In areas of more intense hydrothermal alteration, irregular restite-like zones of such material, appear to "float" in extensively silicified material (Plate 8). In one area, near Manuels, a 5-m-wide zone of hydrothermal alteration occurs within a thick composite ash-flow unit. The stratigraphically lower half of the zone is predominantly pyrophyllite alteration; its upper half is mainly silica alteration. The zone is capped by variegated siltstones that are interlayered with coarse-grained beds containing pebbles of pyrophyllite and silica-altered rocks. The altered zone, one of many within the Avalon High-Alumina Belt, is overlain and underlain by unaltered rhyolitic ash flows and breccia.

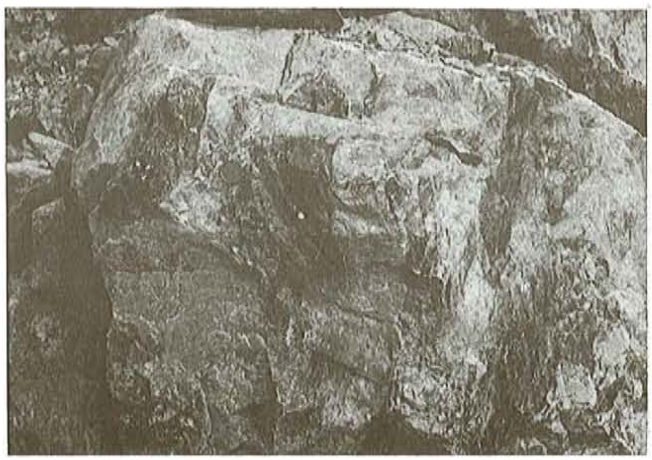

Plate 8. *Remnant blocks of less silicified (but altered), layered volcanic material in a silica-rich hydrothermal alteration zone, Avalon High-Alumina Belt, Route 1.*

The hydrothermally altered Harbour Main sequence is unconformably overlain by the Conception Group at Black Hill (Dawson, 1963) and farther south in the Oval Pit Mine (Hayes and O'Driscoll, 1990; Hayes, 1997). To the north, Cambrian shales lie unconformably upon the same alteration zone. The altered rocks, which include parts of the Holyrood Intrusive Suite, are truncated to the south and west by the main 620 ± 2 Ma phase of the suite. Deeper levels of the same hydrothermal alteration may reappear farther south, in the vicinity of Butlers Pond (Figure 1; *see below*).

Within the northern half of the Avalon High-Alumina Belt, elevated gold values occur within pyritic and non-pyritic silicified and/or hematitized hydrothermal breccias and in banded, quartz–K-feldspar–hematite veins (*see* O'Brien and O'Driscoll, 1996a). A good example of breccia-hosted mineralization occurs in a roadcut on the Trans-Canada Highway (Route 1), immediately east of the Foxtrap access road (Saunders, 1991). Much of this exposure, which has been cut perpendicular to strike, consists of massive grey to pale rose-coloured rock of volcanic protolith that has been affected by intense silicic alteration. This silicified rock is locally a breccia, the matrix of which is highlighted by chlorite and red hematite. Elevated gold values occur in a 8-m-wide zone of breccia consisting of dark-grey to black pyritic, and light-grey, less pyritic, more sericite-rich variants. An assay of 10.2 g/t Au was obtained from a breccia consisting of rounded to angular fragments of silicified or intensely pyritic wall rock having a dark-grey to black, chloritic matrix, rich in subhedral pyrite grains up to 1mm (O'Brien and O'Driscoll, 1996a; Plate 9).

Plate 9. *Auriferous (10.2 g/t Au) hydrothermal breccia, Avalon High-Alumina Belt, Route 1.*

Examples of vein-hosted gold mineralization occur in the north end of the belt, near Manuels. Vein bundles, locally containing up to 30 percent screens and selvages of altered wall rock, have been mapped in zones up to 7 m wide. The veins occur in a number of different wall rocks, including red to variegated hydrothermal breccias and massive silica-rich altered rock. The host breccias show evidence of multiple stages of brecciation, and are typically fine- or medium-grained and angular. Values up to 2 g/t Au have been obtained in grab samples from one of these veins (O'Brien and O'Driscoll, 1996a, unpublished data). Nearby rocks display advanced argillic alteration, including pyrophyllitization, and locally contain minor pyrite, as well as dumortierite and/or lazulite. Veins consist of interbanded quartz, K-feldspar and (red) hematite, displaying cockade structure and rhythmic crustiform banding (Plates 10 and 11). The veins are similar in character and appearance to gold-bearing veins in low sulphidation or adularia–sericite styles of epithermal systems (e.g., Heald *et al.*, 1987; Bonham, 1987; Izawa *et al.*, 1990). Isolated, centimetre-scale crustiform

Plate 10. *Auriferous (2 g/t Au), banded quartz–K-feldspar–hematite ("low-sulphidation"-style) veins, Avalon High-Alumina Belt, near Manuels.*

Plate 11. *Auriferous veins from the same locality as Plate 10; banded vein cuts hydrothermal breccia and is itself brecciated.*

veins, similar to the mineralized veins, occur distal to the vein complexes; they are associated with simple quartz veins and zones of calcedonic silica, and locally contain elevated (ca. 100 ppb) gold values.

In several parts of the same belt, granites assigned to the Holyrood Intrusive Suite display extensive hydrothermal alteration. New roadcuts along the CBS by-pass road at Manuels expose extensively altered granite and volcanic rocks that have been overprinted by metre-scale zones of moderate- to high-strain deformation, and by later brittle faults. Where the granite–volcanic contact is intrusive, the observed alteration in the granite is characterized by chlorite and pyrite, and the presence of narrow vuggy quartz veins. The country rocks in this instance contain narrow quartz–hematite–K-feldspar–pyrite veins. Elsewhere in the same area, the granite is affected by a ca. 100-m-wide zone of grey silica–pyrite alteration, associated with traces of molybdenite and chalcopyrite, and zones of late hydrothermal biotite. This granite, which is intensely silicified in places, is cut by zones of tuffisite-like breccia, and contains irregular, subhorizontal hydrothermal quartz veins. Here, the granite–volcanic boundary is a fault, and the alteration is crosscut by weakly metamorphosed mafic dykes. Elsewhere in the belt, the granite contains narrow cupriferous quartz veins.

OTHER ALTERATION AND MINERALIZATION EAST OF THE PETER'S RIVER FAULT

Volcanic rocks of similar facies and presumably correlative stratigraphic position to the hydrothermally altered rocks in the Avalon High-Alumina Belt reappear on the west side of the Holyrood Intrusive Suite. The Harbour Main Group in that area contains less widely developed and more sulphide-rich examples of advanced argillic alteration, with or without elevated gold concentrations (O'Brien and O'Driscoll, 1996b). Such alteration zones are exposed near the Duffs and Holyrood faults, and can be traced discontinuously southward to the edge of the study area. Mineralization is spatially related to the boundary area between Harbour Main and Conception groups, and is locally remobilized by later movement along the Holyrood Fault and related structures.

Similar rocks in the southern part of the study area, west of the Holyrood Fault, host extensive zones of silicification, quartz veining and hydrothermal brecciation, with or without pyrite, hematite and chalcopyrite. Alteration is typically (but not everywhere) sited near the contact with the Conception Group and, in places, is parallel to the boundary of the Holyrood Intrusive Suite. Variably developed rusty zones of silicic alteration associated with disseminated pyrite within felsic flows and ash flows occur in outcrop and as float in several areas: e.g., west of Paradise Pond, south of Cape Pond and west of Mount Carmel Pond. Granite in the latter area contains pyrite as disseminations and, with magnetite, in veinlets. Outcrop and float of rusty mafic volcanic rocks containing disseminated pyrite and minor copper sulphide-bearing quartz veins occur between Butlers Pond and the Horsechops Road. These vesicular mafic rocks occur as small inliers within the band of Conception Group between the Holyrood Fault and the Whalesback Gabbro. One such basaltic exposure hosts the Oxley Prospect (Mullins, 1970; *see below*).

An area of hydrothermally altered granite and volcanic float, presumably derived from nearby granite and adjacent country rocks, occurs at Butlers Pond. Granodiorite and quartz monzonite boulders having sericitic alteration and hydrothermal brecciation, contain chalcopyrite as disseminations and veinlets. Assays up to 12.2 g/t Au[7] have been obtained from similar boulders in this area (Crocker, 1993, written communication, 1996). Other boulders in the area are of highly altered (silica + sericite) chalcopyrite-bearing rock, of either volcanic or intrusive origin, cut by zones of hydrothermal breccia with a magnetite-rich matrix. The nature of the alteration and mineralization sampled by these boulders is similar to that in porphyry–gold–copper systems (e.g., Sillitoe, 1979, 1993). Glacial dispersion patterns from distinctive outcrops in the region (e.g., bull quartz at the 'Glazy Rocks') are consistent with a very local derivation for the mineralized and altered boulders.

Extensive quartz veining is developed in Harbour Main Group volcanic rocks at the boundary of a granite pluton in the vicinity of South West Pond (NTS 1N/3). The granite, which is also veined, is similar to the main body of the Holyrood Intrusive Suite around Soldiers Pond to the northeast. Quartz veins occupy up to 50 percent of a 40-m-wide, steeply dipping to subvertical zone, in which massive, white and mainly unidirectional quartz veins overprint fine quartz network structures. The veins are internally brecciated in some instances. The larger veins are locally stained dark orange or brown and contain disseminated pyrite, which is locally tarnished to black; minor chlorite and K-feldspar are also present. One pyrophyllite-bearing quartz vein was noted in granite near the main vein complex. The earlier network complexes consist of multidirectional veinlets between ≤1 mm to approximately 1cm. Wall-rock rhyolite and basalt are affected inhomogeneously by silica and sericite alteration; the latter is locally intense and can extend for several metres away from the vein contact. The veins strike east–west, parallel to the granite boundary and can be traced discontinously for about 1.5 km. They lie along the strike from the Oxley Prospect, located approximately 2.5 km to the east. This occurrence consists of disseminated chalcopyrite and galena in a ca. 30-cm-thick quartz vein within basalt. Howse (1934b) refers to an early assay report of 1.8 dwt (ca. 3 g/t) Au from samples collected from the vein by local prospectors. During the course of this study sampling of the South West Pond veins did not yield anomalous gold values.

Variously altered Harbour Main Group rocks form a broad, poorly exposed, northeast-trending zone between South West Pond and Gibbons Pond (Figure 1) in the southern part of the map area. The zone locally extends to the boundary with the Conception Group, although altered rocks are found more than 1km from Harbour Main–Conception group contact. Andesite, and rhyolite flows, tuffs and breccias have been affected by extensive silicic alteration, and cut by barren and pyrite-bearing, orange-brown quartz veins. A distinctive area of cherty-matrix (hydrothermal?) breccia occurs within the zone of intense silicification, and contains traces of copper sulphide. The breccia is associated with narrow zones of vuggy silica alteration. The alteration zone coincides with anomalous concentrations of gold in lake-bottom sediment (36 ppb; Davenport *et al.*, 1990). Volcanic and hypabyssal rocks affected by potassic, sericitic and silicic alteration and containing anomalous gold (up to 650 ppb) occur in the same regional stratigraphic position and occur southeast of South West Pond (Mullins, 1970; Sparkes, 1986).

ALTERATION AND MINERALIZATION BETWEEN THE PETER'S RIVER AND GASTERS FAULTS

An extensive, albeit discontinuous, zone of advanced argillic and silicic alteration is developed near the western boundary of the Harbour Main Group. The zone is disrupted by faults, but can be traced from Conception Bay, at least as far as the northern boundary of the Avalon Wilderness Reserve. Alteration in this belt is in most cases, proximal to exposed Conception Group strata.

A poorly exposed belt of felsic to intermediate rocks displaying argillic and propylitic alteration, silicification and brecciation is associated with small monzonitic intrusions in the local area north and west of Old Sea (Triangle Belt; *see* O'Brien and O'Driscoll, 1996b and references therein). Within

[7] Assay result reproduced with permission of P. Crocker.

this belt, mineralized float (up to 36 g/t Au) and gold-bearing till (0.5 to 2 g/t Au) occurs over a several-hundred-metre-wide linear zone, striking northeast from the Salmonier Nature Park for approximately 4 km (Rennie, 1989; Beischer, 1991). Diamond drilling of the property by Ace Developments Limited in 1995 identified gold values up to 10.2 g/t, over 0.6 m along a strike length of 1200 m, as well as quartz-rich breccias yielding gold values of 1.2 g/t over 10 m and 0.5 g/t over 10 m (Ace Developments Limited, press release, June 16, 1995). Within one exposure of altered rocks, a marginal zone is defined of weakly silicified, intermediate material, containing coarse-grained pyrite and rare chalcopyrite, cut by irregular quartz veins. The intensity of wall rock alteration and of network quartz veining increases toward a central zone of fine-grained and massive, pale-green to grey, silica-altered rock. Smaller zones of silica breccia occur within the network-veined areas.

Hydrothermal breccias and zones of silicic alteration with or without copper mineralization occur in or near at least three other areas of monzonite farther north in this block. Alteration and mineralization occurs within the monzonites and the country rocks (basalt, rhyolite and volcanogenic sedimentary rocks).

At Triangle Pond, vesicular basalt contains small pods of massive chalcocite in carbonate veins and breccias; similar veins occur in tuffaceous sedimentary rocks and monzonite in nearby roadcuts west along Route 1. Narrow quartz–epidote–bornite veins occur in volcanogenic sandstone at the margin of the Woodfords Monzonite near North Arm, Holyrood Bay. One such vein returned an assay of 845 ppb Au (O'Brien and O'Driscoll, unpublished data). The regional magnetic field over this area may indicate the presence at shallow depth of similarly magnetic monzonites in the poorly exposed area north of the Trans-Canada Highway, and east of the Salmonier Line.

The top of the Harbour Main Group exposed on a regional fold closure at Southwest Pond (NTS 1N/6) hosts a zone of strong silicic alteration, with or without pyrite and sericite, together with traces of dumortierite and/or lazulite. Similar alteration is exposed in outcrop or as float along strike on both flanks of the same structure, along Black Ridge and in the Skibbereen area. Farther north, the altered rocks and/or their protolith are spatially associated with monzonite.

Similar alteration can be traced discontinuously along a 2-km-long zone striking southwestward from Harbour Main. Exposures of the zone near Holden's Road, include a small shaft (dating to the last century), sunk along narrow pyrite–galena-bearing quartz–calcite veins in silicified and pyritic mafic and felsic flows. Nearby exposures of mafic flows are malachite-stained and pyrite-bearing, and contain elevated gold values (170 ppb; O'Brien and O'Driscoll, unpublished data). Elsewhere in the same zone, bleached and vuggy, lithophysae-rich felsic rocks and quartz–feldspar porphyry have been altered to an assemblage of pyrite, silica, sericite and epidote, and are cut by a network of quartz veinlets. The altered rocks locally have elevated gold values (100 ppb; O'Brien and O'Driscoll, unpublished data).

ALTERATION AND MINERALIZATION WEST OF THE GASTERS FAULT

Mineralization in the northwestern block of the Harbour Main Group includes a large number of basalt-hosted, cupriferous calcite–quartz–chlorite veins, which locally carry slightly elevated gold values, but are typified by high silver contents (up to 110 ppm; O'Brien and O'Driscoll, unpublished data). The veins resemble parts of the alteration system in the easterly adjacent Harbour Main Group (east of the Peak Pond Fault) in terms of their mineralogy and overall character. It is possible, however, that the veins northwest of the Gasters Fault are related to a slightly younger, silver-rich epithermal system.

Near Colliers, uppermost Harbour Main Group vesicular mafic flows and breccias host narrow stringers and fractures containing bornite, chalcopyrite, chalcocite and pyrite. The wall rocks are chloritized, epidotized and locally silicified. A shaft (now filled) was sunk in the main occurrence, located near Colliers River. A smaller shaft, about 3 m in depth, situated nearby, exposes oxidized and silicified basaltic breccia, cut by a steep, ca. 15- to 30-cm-wide quartz vein containing minor chalcocite and chalcopyrite.

At Turks Gut Ridge, near the coast at Marysvale, several copper occurrences are located in vesicular basalt of the Harbour Main Group. Mineralized rocks lie near the unconformable boundary with the overlying Conception Group. An adit and shaft, dating back to the mid-eighteenth century are developed in breccia veins, veinlets, and disseminations of bornite, chalcocite and chalcopyrite in association with calcite and/or quartz. Some of the veins are composite and multiply brecciated, and contain fine-grained silica. The wall rocks – green, grey and locally red basalt – are typically chloritized and epidotized, and in places silicified.

Quartz veins, ranging from millimetres to metres in width, cut both the Harbour Main Group and overlying Conception Group in the northwestern part of the area, particularly between Bay de Grave and Brigus. In some instances, they are multiply emplaced and internally brecciated; locally drusy cavities are preserved. Alexander Murray (*in* Murray and Howley, 1881a) reported that a small number of these veins contain visible gold, in several different localities (e.g., Brigus Lookout, Shea's Hill, and Fox Hill: *see* maps in Murray and Howley, 1881, and Howse,

1934a), however, published results of later studies have not confirmed these reports. Two grab samples of quartz–chlorite–K-feldspar vein material collected from the dump at Hennessey's shaft and adit, Brigus, did not yield gold (O'Brien and O'Driscoll, 1996a). Murray and Howley, in their 1881 account, also reported the presence of minor pyrite, galena and barite in these veins.

In the same area, quartz veins also occur in the Harbour Main Group, which lies immediately east of, and in fault contact with, the Conception Group; locally these contain disseminated chalcopyrite. One such vein, which occurs within basalt, is exposed along the coast for more than a kilometre southward from Burnt Head (Figure 1); it has returned assays from several localities between 150 to 464 ppb Au[8] (O'Brien and O'Driscoll, 1996a; J. Snow, written communication, 1996). Disseminations and stringers of pyrite, together with minor copper sulphide, are developed in several zones within felsic to intermediate breccias associated with, and overlying the basaltic unit. The pyritic breccias and the basalt locally contain elevated concentrations of gold (from 40 to 284 ppb Au; O'Brien and O'Driscoll, 1996a; J. Snow, written communication, 1996).

Farther south, in a similar part of the Harbour Main Group succession near Kitchuses, porphyritic andesitic intrusions, interpreted to be coeval with volcanism (Nixon, 1974) are associated with hydrothermal alteration of volcanic and interlayered sedimentary rocks. A pyritic silicified zone, cut by ribbon-like pyritic quartz veinlets is exposed near the boundary with a plagiophyric porphyry body along the north shore of Gasters Bay. The porphyry intrusions are affected by pyrite–silica–sericite alteration in nearby exposures.

A NOTE ON MINERALIZATION AND EXPLORATION POTENTIAL OF THE CONCEPTION AND ST. JOHN'S GROUPS

Within the boundaries of the study area, pyrite is the most common sulphide in either the Conception Group or the overlying St. John's Group. Pyrite commonly occurs along fractures, in quartz veins, and as millimetre-scale laminae. The stratabound pyrite locally occurs in association with silica-rich (silicified?) or cherty beds. These likely represent distal facies of more extensive exhalative-style mineralization, which elsewhere may contain elevated base metal or gold values. The sedimentary rocks have potential for hosting Au–As–Sb mineralization, perhaps in the vicinity of faults and/or porphyry dykes, such as suggested by the model of Sillitoe and Bonham (1990). Exploration of sedimentary rocks in areas where they have been intruded by granitic stocks – particularly those intrusions with hydrothermal alteration – should also be considered. It should be further noted that Proterozoic turbidites, coeval with and of similar facies to parts of the Conception Group, are host to gold mineralization (Ridgeway Mine) within equivalent rocks to the Avalon Zone in the Carolina Slate Belt of the southeastern Appalachians, USA (*see* also O'Brien and O'Driscoll, 1996b).

Galena occurs with pyrite in Conception Group mudstone and related siliciclastic rocks (Rusty Fault Zone of Cant, 1974), several kilometres south of Mount Carmel Pond, along the trace of the Holyrood Fault. To the north and south, the same units coincide with anomalous values for arsenic in lake-bottom sediment (Davenport *et al.*, 1990). These rocks may be viewed as favourable exploration targets for sediment-hosted sulphide and/or gold mineralization.

The stratigraphically highest parts of the Proterozoic succession in the study area are equivalent to the sulphide-bearing strata of the lower St. John's Group, exposed several kilometres farther north, in the vicinity of Carbonear. Mineralization within the St. John's Group occurs near the boundary of the Renews Head and Trepassey formations and consists of 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 silt–shale-dominated succession, and bear some affinities with stratabound, Sedex-style mineralization (*cf.*, Carne and Cathro, 1982; Goodfellow *et al.*, 1993). The same prospective stratigraphic horizons occur in the northwestern corner of the study area, and continue across the western half of the Holyrood (NTS 1N/6) map area.

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[8] Assay result reproduced with permission of J. Snow.

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