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THE GEOLOGICAL SETTING, GEOCHEMISTRY AND AGE OF LATE PROTEROZOIC INTRUSIVE ROCKS AT THE BUTLERS POND Cu–Au PROSPECT (NTS 1N/3), AVALON PENINSULA, NEWFOUNDLAND

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ABSTRACT

The Butlers Pond Prospect, located in the central Avalon Peninsula of southeast Newfoundland, has been the focus of intermittent exploration activity for intrusive-hosted, copper–gold mineralization since its discovery in the early 1990s. This interest stems from the occurrence, around Butlers Pond, of outcrops of iron oxide-rich magmatic breccias, hydrothermally altered granite and volcanic rocks, and glacially derived boulders of copper–gold-bearing granites, intrusion breccia, and volcanic rocks. This mineralization has been characterized previously in terms of differing models of both "classic" porphyry copper–gold and iron oxide copper–gold (cf. "Olympic Dam") styles of mineralization.

The property lies near an east–west embayment in the Holyrood Horst, and is underlain primarily by late Neoproterozoic (ca. 630 to 620 Ma) volcano-plutonic rocks, part of the Avalonian belt of the Newfoundland Appalachians. The oldest rocks outcropping on the property are pre-620 Ma flows and volcaniclastic rocks of the Harbour Main Group. These felsic to mafic, primarily subaerial units are intruded by three phases of the 625 to 620 Ma Holyrood Intrusive Suite, including the metallogenically significant 622 ± 2 Ma Butlers Pond porphyry. The 620 Ma and earlier magmatic rocks are overlain by coarse- to fine-grained marine siliciclastic rocks, which may be correlated with either post-570 Ma sedimentary facies of the Conception Group found east of the Topsail Fault, or older rocks of similar facies that occur as outliers elsewhere in the Holyrood Horst. The marine sedimentary rocks are intruded by a small pluton of diorite and gabbro, related to the Whalesback Gabbro.

The restricted areal extent of hematite-rich brecciation, the negative geochemical signatures (i.e., low U, Cu, Au, Ag and REE's) of the iron-oxide breccia in the Butlers Pond porphyry, and the nature and mineralogy of host intrusions, coupled with known geophysical signatures, argue against origins tied to a larger iron oxide Cu–Au system. The potassic alteration and the style of copper–gold mineralization in the granite breccia boulders at Butlers Pond are most consistent with an origin tied to a porphyry copper–gold style, magmatic hydrothermal system. Discrete zones of phyllic (silica–sericite–pyrite) alteration observed in outcrop (and in boulders) are also consistent with this style of mineralization, as is the geochemical signature of the associated intrusions. Existing evidence points to the mineralized and brecciated boulders being of local origin.

The protolith of the copper–gold mineralized breccia, which is indistinguishable from equigranular phases of the Holyrood Intrusive Suite widely developed north of the Butlers Pond region, coupled with the new 622 ± 2 Ma age of the Butlers Pond porphyry, further highlights the potential for mineralization elsewhere in the largely coeval Holyrood Intrusive Suite. These new data, however, confirm that this plutonism cannot be directly related to formation of the 580 to 570 Ma magmatic arcs hosting the extensive late Proterozoic high- and low-sulphidation Avalonian epithermal systems in the Hickey's Pond, Hope Brook and Manuels areas of southern and eastern Newfoundland.

[1] Regional Geology

INTRODUCTION

The Butlers Pond Prospect is located in late Proterozoic rocks of the Newfoundland Avalon Zone, approximately 45 km south–southwest of St. John's (Figure 1). The area around Butlers Pond (NTS map area 1N/3) has been the focus of intermittent exploration for gold and base metals following the discovery of copper- and gold-rich, hydrothermally brecciated granite boulders in the early-mid 1990s. The most recent activity in the area has focussed on granite-hosted, hematite-rich breccias that outcrop at Butlers Pond and the possibility of the area's potential to host iron-oxide–copper–gold (“Olympic Dam”) style of mineralization.

Although a significant amount of exploration has been conducted to evaluate the property, the nature of mineralization, as well as its local and regional geological setting, have remained largely equivocal. This study was undertaken to address these issues, in order to establish regional correlations with magmatic rocks and intrusion-related gold systems elsewhere in the Avalonian belt, and in doing so, identify prospective areas for similar mineralization in other parts of the region. A limited amount of major-, trace- and rare-earth-element geochemistry on representative sample suites was carried out in an attempt to classify mineralized and brecciated rocks, and to test if various intrusive rocks in the Butlers Pond area (including mineralized units) are genetically linked to each other and/or to other, more extensive phases mapped elsewhere in the Holyrood Intrusive Suite. The U–Pb dating of the Butlers Pond porphyry was carried out to test its possible links with other dated parts of this suite.

The following account is based primarily on work conducted by the senior author as a B.Sc. (Honours) thesis (Sparkes, 2001[2]), based on mapping carried out during a larger mapping and metallogeny project on the Avalon Peninsula, undertaken by the Geological Survey of Newfoundland and Labrador. The following report summarizes data presented in Sparkes (*op. cit.*) and also incorporates the results of work carried out by the authors, independent of that thesis, as part of the Geological Survey's larger scale investigations in the Proterozoic rocks of the central Avalon Peninsula.

PREVIOUS INVESTIGATIONS

The region north and east of Butlers Pond was included in 1:250 000 systematic bedrock mapping surveys carried out by McCartney (1967) and Rose (1952); rocks south of the area were mapped at the same scale by Williams and King (1979). The first detailed mapping of rocks at Butlers Pond was carried out during a survey of the east half of the St. Catherine's map area by Mullins (1970); systematic mapping of the entire region at 1:50 000 has been carried out by O'Brien *et al.* (1997, 2001a).

Chalcopyrite-bearing granite boulders exhibiting extensive brecciation and hydrothermal alteration were discovered at Butlers Pond by Cape Broyle Exploration Limited in 1992. These returned assays as high as 6% Cu, 12.8 g/t Au and 0.23 oz/t Ag (Crocker and Dalton, 1994). Mineralized mafic and felsic volcanic boulders containing up to 4.2% Cu, 376 ppb Au and 2.5 oz/t Ag were also discovered at this time, in an area approximately 400 m west of the mineralized granite boulders. Both the granite and volcanic boulders were interpreted to be of local origin. Mafic volcanic rocks about 500 m west of Butlers Pond were subsequently found to contain stringer-type chalcopyrite and chalcocite. Grab samples returned values of up to 1.06% Cu, 7.81 g/t Au and 7.9 g/t Ag (Crocker and Dalton, *op. cit.*).

Subsequent exploration from 1994 to 1995 by Avalon Mines Limited included prospecting, line cutting, geological mapping, soil geochemistry, ground geophysics (VLF-EM, magnetics and time-domain IP) and seven diamond-drill holes, totalling 1002 m (Pickett, 1995, 1996). Diamond drilling of geophysical targets did not identify the bedrock source of the high-grade copper–gold-bearing boulders. The Butlers Pond property has been held by Altius Minerals Corporation from 1999. Much of the area of granitic rocks in the area to the north of Mobile Big Pond (ca. 3 km north of Butlers Pond) has been recently (post-1999) explored by Phelps Dodge Corporation.

REGIONAL SETTING

The Butlers Pond Prospect lies within a complex assemblage of late Neoproterozoic, mainly subaerial volcanic and plutonic rocks, traditionally assigned to the Harbour Main Group and Holyrood Intrusive Suite, near the east side of a broad, north–south elongated periclinal dome, known as the Holyrood Horst (e.g., McCartney, 1967, 1969; King, 1988; Figure 1). Recent mapping and geochronological studies of this part of the Appalachian Avalon Zone have documented a geological record of protracted and episodic volcanicity, having varied composition, lithofacies, and depositional environments, spanning a period of almost 160 million years in the Neoproterozoic (O'Brien *et al.*, 2001a).

[2] The reader is referred to Sparkes (2001) for more detailed presentations and discussions of petrography, mineralogy and geochemistry from the Butlers Pond area, as well as a more comprehensive review of previous exploration.

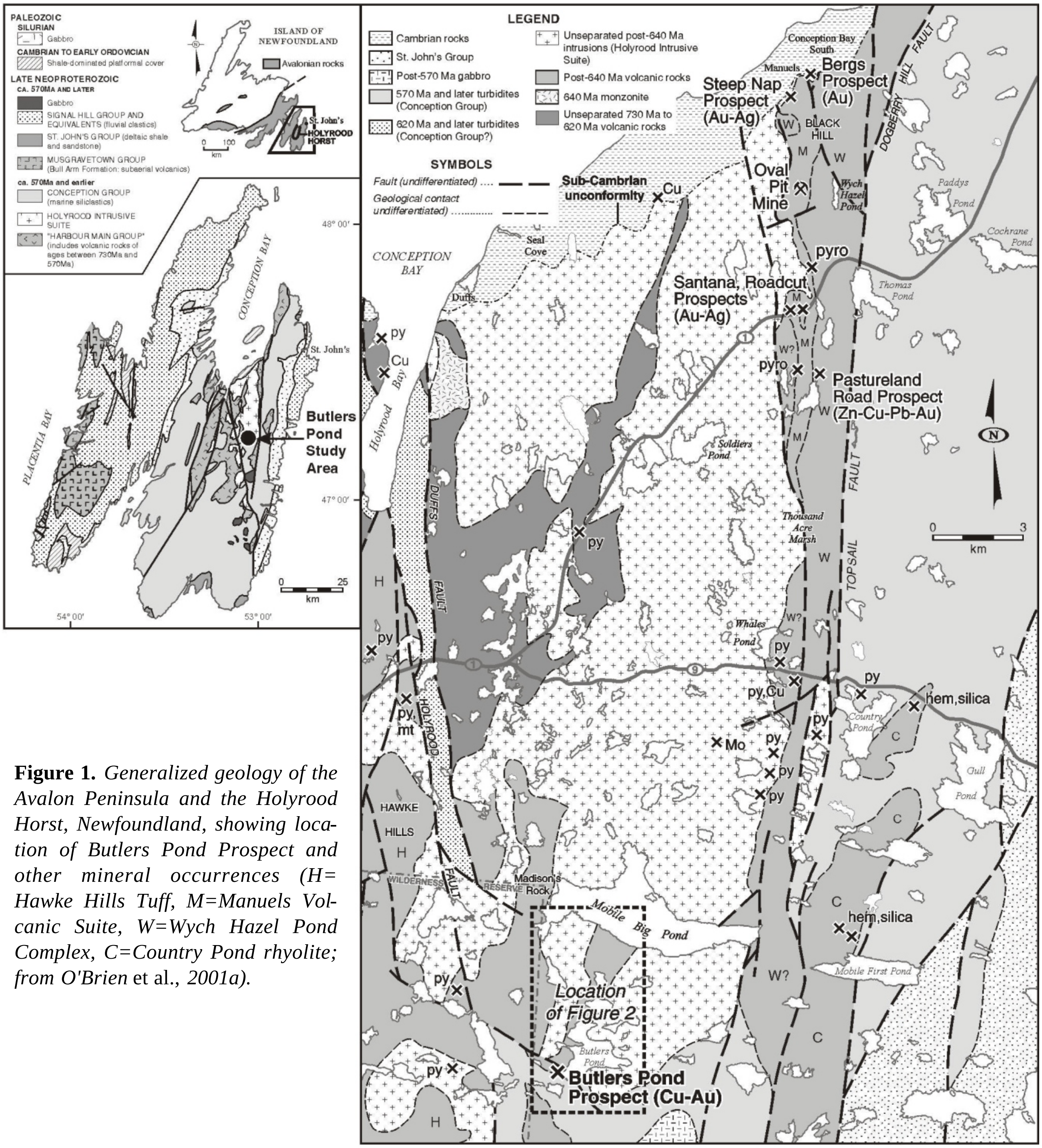

Figure 1. *Generalized geology of the Avalon Peninsula and the Holyrood Horst, Newfoundland, showing location of Butlers Pond Prospect and other mineral occurrences (H= Hawke Hills Tuff, M=Manuels Volcanic Suite, W=Wych Hazel Pond Complex, C=Country Pond rhyolite; from O'Brien* et al.*, 2001a).*

Deposition of disparate volcanic successions was punctuated by both marine and terrestrial sedimentation, and by the emplacement, uplift and erosion of intrusive suites of widely differing age and composition.

The Harbour Main Group as delineated by McCartney (1967) includes rocks now known to be as old as 730 Ma (Israel, 1998) and as young as approximately 580 Ma (O'Brien *et al.*, 2001a, b). These compositionally diverse volcanic rocks include subaerial felsic ash-flow tuffs, coarse-grained, red siliciclastics, andesites, rhyolite to rhyodacite dome complexes, and less extensive (and in some cases, significantly younger), shallow-marine mafic flows and pyroclastic rocks. The Holyrood Intrusive Suite represents several spatially and lithologically separate, and in part, genetically unrelated plutons. Quartz-rich, hornblende–biotite granite forms the largest pluton that extends from Conception Bay southward to the Butlers Pond area. This batholith-scale exposure of the Holyrood Intrusive Suite has been dated at 620 ± 2 Ma (Krogh *et al.*, 1988) and 622 ± 3 Ma (*see* O'Brien *et al.*, 2001a). Other plutons, including significantly younger Neoproterozoic granite, together with a variety of variably altered and mineralized granite, diorite, quartz–feldspar porphyry and hybrid rocks have been mapped along the eastern side of the Holyrood Horst, near Manuels, and southward into the area northeast of Mobile Big Pond (O'Brien *et al.*, 1997, 2001a). Outliers of marine siliciclastic sedimentary rocks, historically assigned to the Conception Group (e.g., McCartney, 1967; King, 1988), but of at least two potentially separate ages, overlie volcanic and plutonic rocks within and adjacent to the Holyrood Horst.

GEOLOGY OF THE BUTLERS POND REGION

Rocks in the area surrounding Butlers Pond, as far north as Mobile Big Pond, are assigned here to seven map units, all of which are of either known or presumed Neoproterozoic age (Figure 2). The plutonic rocks, which belong to the Holyrood Intrusive Suite, are divided into three map units: i) granite typical of the quartz-rich (625 Ma to 620 Ma) main phase of the Holyrood Intrusive Suite (O'Brien *et al.*, 1997, 2001a), ii) a porphyritic granite pluton, locally dated at 622 ± 2 Ma (*see below* Age of the Butlers Pond Porphyry), and iii) smaller, coeval intrusions of granodioritic to tonalitic composition. The last two units (ii and iii) are herein informally named the Butlers Pond porphyry. Each of the three units intrudes primarily subaerial and locally shallow-marine volcanic rocks of the unseparated Harbour Main Group (cf. McCartney, 1967), having an age greater than or equal to 620 Ma. Marine siliciclastic sedimentary rocks of the Conception Group in this area contain a unit of boulder-to-pebble polylithic conglomerate at the base, and are interpreted to disconformably overlie both the Harbour Main Group and Holyrood Intrusive Suite. The youngest rocks in the map area are mafic to intermediate plutonic rocks of the Whalesback Gabbro, which are intrusive into the Conception Group.

HARBOUR MAIN GROUP (UNITS 1 AND 2)

The oldest rocks in the map area are volcanic flows and volcaniclastic rocks belonging to the Harbour Main Group, as outlined by McCartney (1967) and King (1988). These rocks are divided into lithologically distinctive units of primarily felsic to intermediate and, to a lesser degree, mafic composition. All are intruded by the Holyrood Intrusive Suite.

Felsic to Intermediate Flows and Tuffs (Subunits 1a and 1b)

Unit 1 is divided into two principle lithofacies. The first consists of grey–green flows and fine-grained tuffs of rhyodacitic to dacitic composition that are depicted as subunit 1a on the accompanying map (Figure 2). The second, shown as subunit 1b on Figure 2, is a more homogeneous unit characterized by red–purple to grey, crystal-lithic tuff.

Grey–Green Rhyodacite–Dacite Flows and Tuffs (Subunit 1a)

The rocks of subunit 1a outcrop in the north-central part of the area south of Mobile Big Pond (Figure 2), and in smaller areas north and south of the eastern end of Butlers Pond, where they have been intruded to the east and west by the main granite phase of the Holyrood Intrusive Suite and both phases of the Butlers Pond porphyry. The rhyodacite–dacite unit is grey- to white-weathering, grey–green and locally purple on fresh surfaces, plagioclase-crystal-rich, and variably flow-banded. Along intrusive contacts with adjacent granite, the rhyodacite–dacite has been recrystallized to a dark grey to black hornfels, having a hackly cleavage. The crystal-rich rhyodacite–dacite exposed in a syncline southeast of Butlers Pond has a well-defined eutaxitic foliation and contains coarse-grained (≤15 cm) lithic fragments. These locally display primary flattening, and have length-to-width ratios that vary from approximately 5:1 to15:1.

Dyke-like bodies of granite intrude the rhyodacite–dacite unit parallel to and across subvertical flow-banding. Metre-scale blocks and rafts of thermally metamorphosed rhyodacite–dacite are common within each of the intrusions, particularly near their contacts.

Red–purple to Grey, Crystal-lithic Tuff (Subunit 1b)

The tuff of subunit 1b is well exposed in the west part of the study area and along the western and northwestern shores of Butlers Pond. On a regional scale, these tuffs form part of the 630 to 620 Ma red-to-grey crystal-rich facies of the much more extensive Hawke Hills Tuff, which is well exposed north and west of the study area (O'Brien *et al.*, 2001a; G. Dunning, unpublished data). Subunit 1b is intruded by all three phases of the Holyrood Intrusive Suite.

The tuff weathers pale pink to white, and is distinctly red–purple on fresh surfaces. It is characteristically crystal-

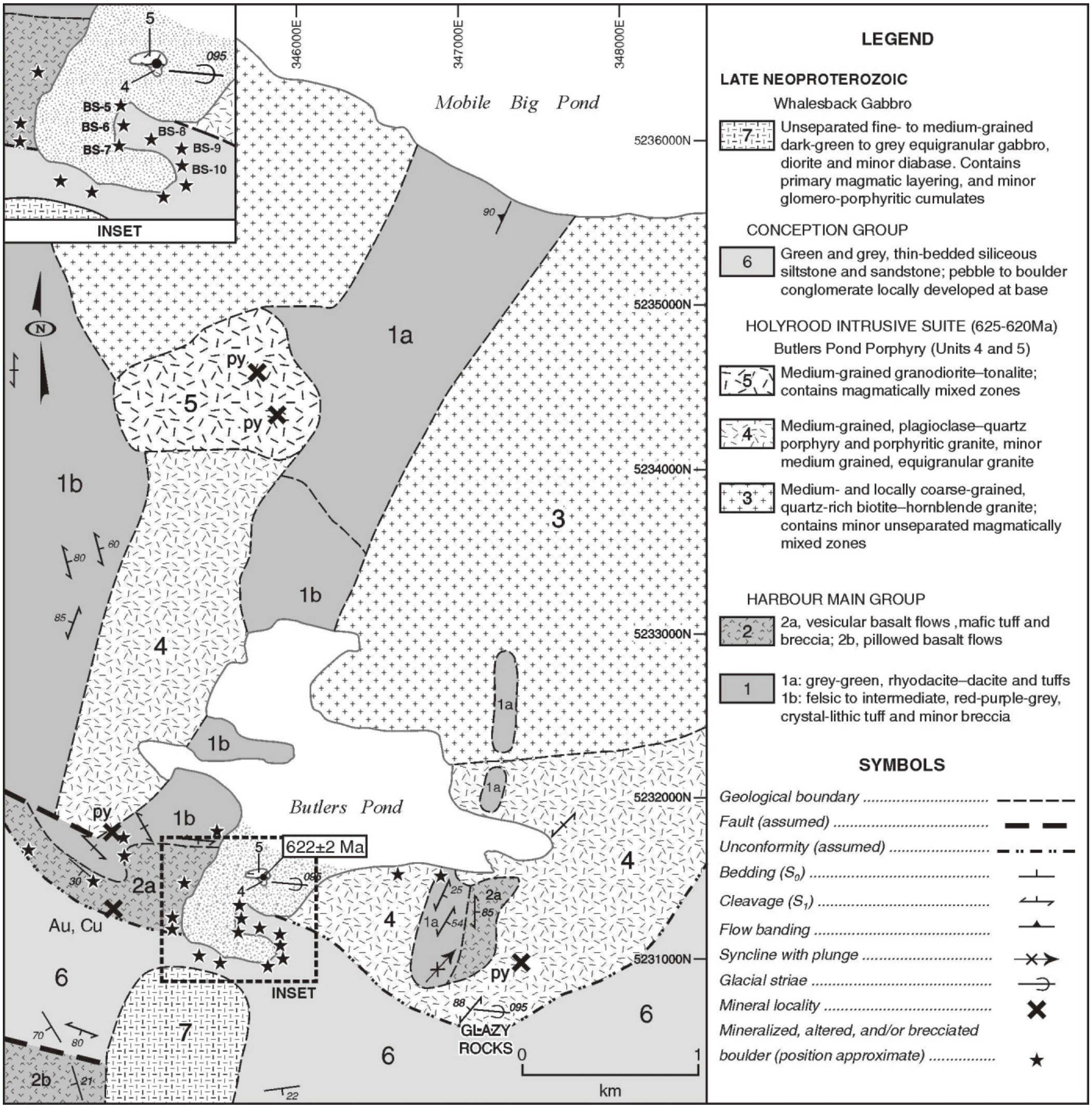

Figure 2. *Geology of the area around Butlers Pond (after Sparkes, 2001).*

rich (K-feldspar and plagioclase) and contains lithic fragments and pumice, flattened parallel to a variably developed and variably orientated eutaxitic foliation (length-to-width ratios from 2:1 to 7:1). Adjacent to the Butlers Pond porphyry, tuffs of this unit are deformed by narrow, subvertical, generally north-trending shear zones. These rocks typically lack pervasive hydrothermal alteration, although crosscutting, millimetre-scale chlorite and sericite veinlets are locally developed. One exception is the tuffs exposed on a high hill immediately north of Butlers Pond, where discontinuous, one-metre-scale zones of silica–pyrite alteration are developed very locally.

Mafic Flows and Pyroclastic Rocks (Subunits 2a and 2b)

Mafic volcanic rocks (Unit 2) are exposed in the south of the study area, where they are in assumed depositional contact above Unit 1 felsic to intermediate volcanic rocks. The contact of Units 1 and 2 is presumed to be conformable. Coarsely vesicular, hematite-rich basalts (subunit 2a) outcrop adjacent to Butlers Pond, where they have been intruded by the granite phase of the Butlers Pond porphyry. A separate area of mafic rocks, which includes an areally-restricted unit of pillowed mafic flows, are preserved in the southwestern-most part of the map area (subunit 2a).

Hematite-rich Vesicular Flows (Subunit 2a)

The basalt of subunit 2a weathers pale grey and is grey-green and locally purple on fresh surfaces. It is typically coarsely vesicular, and contains amygdales ($\leq$1 cm) filled with epidote, chlorite, quartz and calcite. Massive or non-vesicular flows are less extensive. The coarse-grained amygdaloidal basalt contains macroscopic, plagioclase laths in the groundmass, forming an ophitic texture. The basalts contain abundant crosscutting veinlets and fractures, containing epidote with or without hematite. The vesicular basalt intersected in diamond drilling by Avalon Mines near Butlers Pond in 1995 includes dark grey to red–purple, fine- to medium-grained, and ophitic-textured units, locally rich in amygdales ($\leq$2 cm) filled by calcite and/or quartz, K-feldspar and epidote, and containing lesser amounts of chlorite and hematite. Zones of hematite-rich basalt are common in drill core and have a distinctive red colouration.

The basalt contains widespread hematite and locally epidote alteration near intrusive contacts with granite phase of the Butlers Pond porphyry at Butlers Pond. The hematite and epidote occur as millimetre-scale veinlets, as vesicle fillings and locally as a pervasive groundmass phase. The altered mafic rocks contain sulphide mineralization and, locally, significant copper and gold values (*see below* Description of the Mineralized Rocks).

Massive to Pillowed Flows (Subunit 2b)

In the southwest corner of the study area, the basalt flows of subunit 2b are pillowed and contain abundant, fine-grained, thinly layered yellow-green siltstone as inter-pillow material. The pillows have coarsely vesicular cores and fine-grained, chilled rims; individual pillows range from 10 cm to 1.5 m in width. Filled vesicles contain epidote, chlorite, quartz and calcite.

Exposures of pillow basalt within the Holyrood Horst are uncommon. An areally restricted pillow basalt unit overlies crystal tuff of the Hawke Hills Tuff near the Bosun, near the Inside Hawke Hills (NTS map area 1N/6), where it is overlain by a thin pebble conglomerate unit at the base of the Conception Group.

HOLYROOD INTRUSIVE SUITE (UNITS 3 to 5)

All felsic to intermediate intrusive rocks in the Butlers Pond area are asssigned to the Holyrood Intrusive Suite, a large, compositionally and texturally composite, primarily felsic plutonic unit, characterized by an abundance of quartz-rich, hornblende–biotite granite (O'Brien *et al.*, 1997). The latter lithology represents one of three intrusive phases mapped within the exposures of the suite between Butlers Pond and Mobile Big Pond. The remaining two intrusive units represent a hybrid, high-level stock, here referred to informally as the Butlers Pond porphyry. The age of the most extensive granite phase of the suite has been determined elsewhere at 620 ± 2 Ma (Krogh *et al.,* 1988) and 623 ± 3 Ma (see O'Brien *et al.,* 2001a). New data, presented below, indicate that the Butlers Pond porphyry is coeval with the extensively developed granite (Unit 3).

Medium- to Coarse-grained, Hornblende–Biotite Granite (Unit 3)

The most widespread plutonic rock in the study area is hornblende–biotite granite (Unit 3) that is typical of much of the Holyrood Intrusive Suite exposed between Mobile Big Pond and the Trans-Canada Highway (Route 1) (O'Brien *et al.,* 2001a; *see* Figure 1). Unit 3 is exposed in the area north of Butlers Pond and extends to Mobile Big Pond and eastward to the Topsail Fault zone, east of the map area. The granite clearly intrudes and contains numerous rafts of subunit 1a volcanic rocks near Mobile Big Pond. Variably oriented mafic dykes, up to 3 m wide, intrude the granite in several exposures around Mobile Big Pond.

Typical Unit 3 granite is medium to coarse grained, equigranular to quartz-subporphyritic in appearance and largely homogeneous in texture and composition. The granite has a distinctive "quartz-knobby" weathered texture in many outcrops, where quartz phenocrysts have significant positive relief. This distinctive texture is characteristic of outcrops of dated 625 to 620 Ma granite of the Holyrood Intrusive Suite elsewhere in the Holyrood Horst (*see* O'Brien *et al,* 1997, 2001a).

The granite is composed of quartz (25 to 40 percent), K-feldspar (30 to 40 percent), plagioclase (20 to 25 percent), and generally between 5 and 15 percent chloritized hornblende and/or biotite. Quartz forms large (2 mm to 1 cm), variably strained, primary euhedra to anhedra and late interstitial grains. Minor myrmekitic patches occur as intergrowths of quartz and K-feldspar, interstitial to all of the other minerals, particularly chloritized biotite and/or hornblende. The K-feldspar anhedra and subhedra (2 to 8 mm) display microperthite exsolution, simple twinning, and rare microcline twinning. Locally, K-feldspar grains exhibit growth zoning, and contain inclusions of plagioclase, chloritized hornblende, and minor epidote. Plagioclase (An_{30-35}) occurs as blocky to tabular, subhedral to anhedral grains (2 to 8 mm) that exhibit lamellar albite twinning, pericline twinning, and sector growth zoning; plagioclase contains rare inclusions of chloritized hornblende and opaques. Mafic minerals occur as subhedral to anhedral grains (0.1 up to 4 mm). The mafic minerals have been completely (or nearly so) altered to an assemblage of chlorite, with or without epidote, pumpellyite, sericite, rutile and opaques. Chloritized mafic minerals (mainly hornblende) commonly display anomalous blue birefringence. Biotite occurs as smaller anhedral flakes, in subordinate amounts to hornblende. Apatite, rutile, epidote, sericite and opaques occur as accessory phases.

Hydrothermal Alteration

The most prominent of these hydrothermal alteration effects includes late stockwork/veinlet-style hydrothermal brecciation of the granite; a more subtle, yet widespread alteration is feldspar saussuritization. Zones of alteration within Unit 3 granite are located mainly near the contact with the granite phase of the Butlers Pond porphyry. Metre-scale zones of hydrothermal breccia, which are particularly common northeast of Butlers Pond, contain pyrite, chlorite, sericite, epidote, silica and, in some cases, carbonate. Granitic fragments within the hydrothermal breccia are similar to surrounding granite and appear to be very locally derived. Pyrite forms up to 5 percent of the rock in some localities, where accompanied by chlorite–silica alteration, and forms small, localized gossanous zones in outcrop. Within the least altered samples, late, microscopic-scale hairline veinlets of sericite, silica and calcite commonly invade along grain boundaries and locally cut across mineral grains. Replacement of feldspars by a mixture of sericite and minor epidote is ubiquitous and of moderate intensity (ca. 5 to 30 percent replacement).

Butlers Pond Porphyry (Units 4 and 5)

The Butlers Pond porphyry is a new, informal name used to designate distinctive porphyritic to subporpyritic granite, granophyre and associated and locally comingling, intermediate plutons within the Holyrood Intrusive Suite in and around Butlers Pond. Two phases have been recognized.

Porphyritic Granite Phase (Unit 4)

The granite of Unit 4 forms two separate lobes, separated by red crystal tuffs of subunit 1b (Figure 2). The western lobe is a compositionally uniform, medium- to coarse-grained, plagioclase subporphyritic granite, whereas the eastern lobe includes quartz–feldspar porphyry and local zones of granophyric granite and aplite, particularly in its eastern parts. The granite weathers a distinctive pinkish red colour, due to hematite dusting of feldspars. East of Butlers Pond, hematite alteration is less pronounced, and the granite weathers orange-pink to white and locally brown. The granite is quartz rich but lacks the "quartz knobby" texture seen in Unit 3.

The granite intrudes Units 1 and 2 of the Harbour Main Group and contains xenoliths (cm-scale) and larger rafts (up to 3 by 10 m) of these volcanic rocks. The spatial association of alteration and hydrothermal breccias within Unit 3 granite with the contact of the Butlers Pond porphyry, coupled with the formation of intrusion breccias focussed at the contact of the Butlers Pond porphyry, is consistent with an intrusive, possibly cogenetic relationship between Unit 3 granite and the later porphyry. The eastern margin of Unit 4 is unexposed but is assumed to be coincident with structures related to the Topsail Fault zone, located approximately 3 km east of the map area (Figure 1).

The granite of the Butlers Pond porphyry is composed of quartz (30 to 50 percent), K-feldspar (25 to 35 percent), plagioclase (20 to 35 percent), and generally between 5 and 15 percent chloritized hornblende and/or biotite. Quartz occurs as 3- to 5-mm, ovoid to lobate, subporphyritic grains (locally with K-feldspar and plagioclase inclusions) and as interstitial myrmekitic intergrowths with K-feldspar. Anhedral to euhedral plagioclase (An_{30-35}) forms albite- and tartan-twinned, sub-porphyritic grains (3 to 7 mm). Dusting of plagioclase by hematite and K-feldspar is common (*see below* Hydrothermal Alteration). K-feldspar occurs as myrmekitic intergrowths with quartz and also as 1 to <4 mm, interstitial, anhedral grains, which are commonly microperthitic. Chloritized hornblende and lesser amounts of biotite occur as small (1 to 3 mm), anhedral to subhedral, interstitial grains and patches. Apatite occurs as tiny pale-green, euhedral needles as overgrowths on other phases, particularly quartz. Allanite is only locally present in the granite, apparently being restricted to zones adjacent to hematite-rich breccia. It occurs as rare, brown-yellow, euhedral to subhedral, broken interstitial grains (typically ≤ 1 mm), most of which exhibit growth zoning. Trace amounts of zircon are also present.

Hydrothermal Alteration

In the area southeast of Butlers Pond, the granite contains localized zones of silica–sericite hydrothermal alteration, associated with local development of chlorite and hematite. Plagioclase and K-feldspar is typically moderately to intensely (20 to 80 percent) replaced by sericite. Sericite also occurs in fracture-controlled, veinlets and vein bundles (locally up to 5 percent of an individual sample) that invade along grain boundaries and cut across grains. Hornblende and biotite grains are altered to an assemblage of chlorite, epidote, sericite, opaques and rutile. Hematite commonly occurs as a dusting along feldspar grain boundaries.

The silica–sericite alteration is manifested as small hydrothermal breccia zones (up to 3 m wide) and is locally pervasive on a submetre scale. The granite clasts commonly range from 1 mm to 2.5 cm and are rounded to subrounded, medium-grained and equigranular. Importantly, the granite clasts within the silica–sericite-altered breccias are compositionally similar to the auriferous, brecciated granite boulders found as float around the southern end of Butlers Pond. In addition, the silica–sericite alteration is of a style visually similar to the first-stage alteration observed in the brecciated granite boulders in the southern Butlers Pond (*see below* Description of the Mineralized Rocks).

Several localized zones of stockwork-style alteration and brecciation occur close to the margins of the granite in the area east and northeast of Butlers Pond. Chlorite is the prominant alteration phase; sericite and silica are less extensive, and are associated with pyrite (up to 5 percent). Hydrothermally brecciated granite was also observed immediately east of the hematite-rich breccias at Butlers Pond, where chlorite is again predominant. Minor silica–sericite alteration, associated with traces of pyrite, was noted in granite exposures north of Butlers Pond. Crosscutting veinlets of chlorite were observed in the same area.

Granodiorite–Tonalite Phase (Unit 5)

Unit 5 of the Butlers Pond porphyry is characterized by medium- to coarse-grained rocks of granodioritic to tonalitic composition that display a macroscopic, subophitic texture. At the southern end of Butlers Pond, Unit 5 intrudes and is intermingled with the porphyry's granite phase; both are extensively altered, and crosscut and brecciated by a hematite-rich, hydrothermal breccia. The granodiorite–tonalite exhibits chilled margins against the granite, but both display variously inter-tonguing contacts (Plate 1), suggestive of a comagmatic relationship. West of Butlers Pond, Unit 5 clearly intrudes silica–sericite–pyrite-altered felsic volcanic rocks (subunit 1b of the Harbour Main Group). North-northwest of Butlers Pond, it is intrusive into grey-green rhyodacite–dacite of subunit 1a. The northern contact of the granodiorite–tonalite in this area is unexposed, but is inferred to be intrusive into Unit 3 granite.

The granodiorite–tonalite body that hosts the hematite breccia at Butlers Pond is compositionally and texturally similar to that found north of Butlers Pond (and is thus cor-

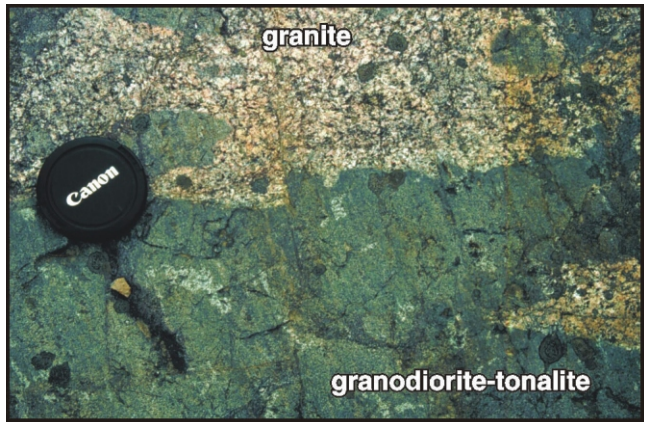

Plate 1. *Inter-tonguing of granite and granodiorite–tonalite phases of the Butlers Pond porphyry (Holyrood Intrusive Suite) at Butlers Pond.*

related with it), although in the latter area, silica–sericite alteration and associated pyrite mineralization is locally extensive. The northern exposures of the granodiorite–tonalite phase tend to be coarser grained and contain segregations of more leucocratic and more melanocratic material.

Typically, Unit 5 is composed of quartz (20 to 40 percent), plagioclase (45 to 55 percent), hornblende (10 to 20 percent) and K-feldspar (5 to 12 percent). Quartz occurs exclusively as angular interstitial grains ($\leq$ 0.5 mm) containing inclusions of plagioclase, K-feldspar and ferromagnesian minerals. Plagioclase occurs as blocky to tabular, euhedral to subhedral grains (0.2 to 0.7 mm), that are affected by intense sericite and lesser epidote alteration (*see below*). Anhedral K-feldspar is interstitial to plagioclase, untwinned and typically dusty-brown. Brown hornblende occurs as acicular, lath-like subhedral-to-anhedral grains (5 to 7 mm long and 1 mm wide) exhibiting a distinctive subophitic texture (intergrown with plagioclase) and are extensively altered (*see below*). Accessory minerals include rutile, opaques, sericite, epidote, apatite, zircon and allanite. Apatite is abundant and occurs as late overgrowths, particularly on quartz and plagioclase grains. The apatite crystals are mainly euhedral and acicular, measuring up to 0.5 mm in length; they have a distinctive pale green colouration. Allanite occurs as euhedral grains to broken anhedra (1.2 mm long and 0.3 mm wide) having prominent growth zoning and simple twinning. Allanite grains exhibit distinct colour zoning, including medium brown (inclusion-bearing) cores and lighter brown (inclusion-free) rims.

Hydrothermal Alteration

Several zones of extensive silica–sericite–chlorite alteration in Unit 5 granodiorite–tonalite are exposed in an area of about 0.5 km^2, north of Butlers Pond. Mineralization consists of up to 5 percent pyrite and forms discontinuous rusty zones of variable width and up to 10 m in length. At the south end of Butlers Pond, rocks of this phase are extensively altered and locally brecciated. Replacement of feldspars by a mixture of sericite and epidote is ubiquitous, and is generally intense (approximately 50 to 85 percent replacement). Hornblende is altered to an assemblage of chlorite, opaques, epidote, rutile and sericite. Allanite is commonly rimmed by epidote and crosscut by sericite-filled fractures. Hematite-rich brecciation and alteration is apparently restricted to the outcrop at the south end of Butlers Pond, where it has affected approximately 15 percent of the exposure. Both the feldspar–quartz-porphyritic granite and granodiorite–tonalite phases of the Butlers Pond porphyry are affected by the hematite-rich alteration.

Age of the Butlers Pond Porphyry

A sample of porphyritic granite from the Butlers Pond porphyry was collected from the outcrop that hosts hematite-rich hydrothermal breccia (Figure 2). This sample yielded a large amount of coarse-grained euhedral prismatic zircon. Three fractions composed of 10 to 20 zircons each were selected for analyses. These clear and crack-free grains were abraded prior to analysis to remove outer surfaces that might have undergone fluid alteration and Pb loss. The resultant data points are all concordant within the two sigma uncertainties (0.5 to 0.7 percent discordant). As the three analyses have $^{207}Pb/^{206}Pb$ ages of 623 to 621 Ma, an age and uncertainty of 622 ± 2 Ma is considered the best estimate of the age of crystallization of this rock (Figure 3, Table 1).

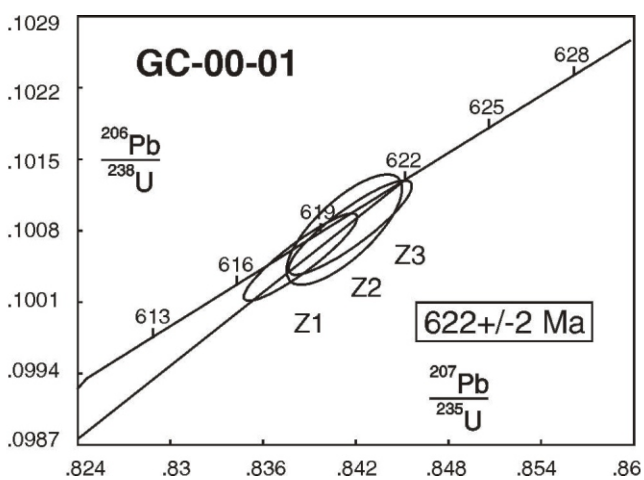

Figure 3. *Conchordia diagram for a sample from the granite phase of the Butlers Pond porphyry (Holyrood Intrusive Suite).*

Table 1. U–Pb zircon data for Butlers Pond granite

Fraction	Weight (mg)	Concentration U (ppm)	Concentration Pb rad	Total common Pb (pg)	Measured $^{206}Pb/^{204}Pb$	Corrected Atomic Ratios $^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	±	$^{207}Pb/^{235}U$	±	$^{207}Pb/^{206}Pb$	±	Age (Ma) $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
Z1 10 lrg clr euh abr	0.043	171	18.3	5	9688	0.1794	0.10054	34	0.8384	30	0.06048	10	618	618	621
Z2 20 lrg euh abr	0.047	232	25.0	26	2619	0.1846	0.10083	38	0.8416	32	0.06054	12	619	620	623
Z3 20 euh lrg abr	0.024	211	22.8	2	13794	0.1849	0.10081	44	0.8413	30	0.06052	18	619	620	622

Notes: lrg = large, clr = clear, euh = euhedral crystals, abr = abraded. Uncertainties reported after isotopic ratios are 2 sigma and refer to the final digits

CONCEPTION GROUP

A poorly exposed succession of siliceous siltstone and sandstone belonging to the Conception Group occupies a region of topographically low relief in the southern part of the study area (Figure 2), where it is interpreted to disconformably overlie the Butlers Pond porphyry and the Harbour Main Group. A cobble to boulder conglomerate unit, containing clasts of locally derived volcanic rocks and hematite-altered granite porphyry, is locally developed at the base.

The Conception Group in this area is primarily composed of grey and green, buff-yellow-weathering, thin- to medium-bedded and thinly laminated, siliceous siltstone and fine-grained sandstone. Thin (<5 cm) cherty beds are locally present. Granule to pebble conglomerate occurs as a thin unit at the base of the siliceous siltstone–sandstone sequence. Clasts in the basal conglomerate include large ($\leq$ 1.5 m) boulders of vesicular basalt, clearly derived from the underlying volcanic rocks, and felsic plagioclase porphyry pebbles and cobbles; together they constitute about 90 percent of the total clasts. The pebbles and cobbles are subangular to subrounded and average 10 cm in diameter. A number of large angular float blocks (up to 3 by 2 m) of polylithic conglomerate are located along the projection of the unconformity along the southern shore of Butlers Pond. The blocks contain clasts of geological units exposed nearby, including locally hematite-altered and brecciated plagioclase porphyritic granite and quartz–feldspar porphyry of the Butlers Pond porphyry, as well as crystal-lithic tuff and basalt of the Harbour Main Group. The boulders measure up to 35 cm in diameter and are set in a red, hematite-bearing sandy matrix.

Petrographic studies revealed no evidence of thermal metamorphism in sedimentary rocks proximal to the Butlers Pond porphyry.

WHALESBACK GABBRO

A small body of mafic to intermediate plutonic rocks, here included with the larger Whalesback Gabbro of Williams and King (1979), outcrops immediately south of Butlers Pond (Figure 2). No contacts were observed within the map area, but farther south, the Whalesback Gabbro is observed to be intrusive into Conception Group sedimentary rocks (Williams and King, 1979), and volcanic rocks of the Harbour Main Group (O' Brien *et al.*, 1997). Exposures in this area are mostly massive, medium- to coarse-grained, equigranular, grey-green and locally grey and white gabbro and diorite. Igneous layering, which ranges from a few centimetres to a few decimetres thickness, is preserved in several outcrops, and dips moderately to steeply to the west and southwest. The glomeroporphyritic cumulate layers contain intensely altered pyroxene and plagioclase grains up to 7 mm in length. The gabbro is plagioclase- and pyroxene-rich and commonly displays a felted, ophitic texture. Trace amounts of pyrite occur throughout.

DESCRIPTION OF THE MINERALIZED ROCKS

Hydrothermally Altered and Brecciated Granite Boulders

Hydrothermally altered and brecciated granite boulders that contain copper–gold–silver mineralization are found primarily in the southern part of Butlers Pond; the location of many of the larger boulders is given in Figure 2. The boulders range in size from less than 0.5 up to 3 m, are subrounded to angular, and exhibit a distinctive rusty-brown-weathering surface. The sample suite examined in this study includes both mineralized and unmineralized, variably altered and brecciated granite.

The brecciated rock (Plate 2) is a medium- to coarse-grained, pink, equigranular quartz-rich granite; granite fragments within the breccias range from less than a millimetre to several tens of centimetres. The granite clasts contain quartz (30 to 40 percent), K-feldspar (30 to 40 percent), plagioclase (An_{30-35}; 15 to 25 percent), chloritized hornblende (5 to 15 percent) and trace minerals including apatite, rutile, pyrite, sericite, chlorite and carbonate. K-feldspar shows microcline twinning, and plagioclase shows lamellar albite twinning, carlsbad twinning, cross-hatch twinning and complex sector growth zoning. Quartz and K-feldspar occur, in many cases, as myrmekitic intergrowths. The feldspars are only weakly saussuritized. The granite clasts are similar to equivalents of Unit 3 of the Holyrood Intrusive Suite found north of Mobile Big Pond as well as brecciated and commonly pyritic granites east of Butlers Pond (Plate 3; *also see* Sparkes, 2001).

The sulphides are associated with two distinct stages of hydrothermal alteration and brecciation (Plate 2). The first stage of alteration has a characteristically light green to cream colour, and is preserved within and around brecciated granite clasts and is locally pervasive, replacing the original granite clasts. Only minor disseminated chalcopyrite is associated with this phase. Material affected by the second stage of alteration is dark greenish grey and occurs as a fracture-related, stockwork-style of brecciation that contains up to 15 percent chalcopyrite (with or without pyrite) in the breccia matrix.

The first stage of alteration consists of a very fine-grained mixture of silica and sericite, together with trace amounts of epidote and rare euhedra and subhedra of mag-

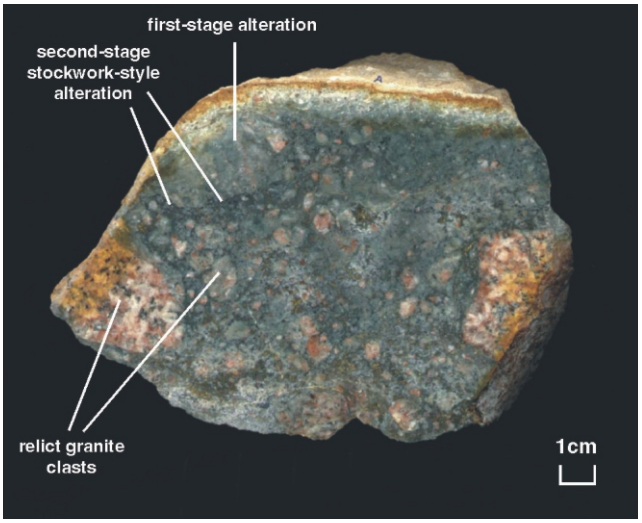

Plate 2. *Sample from gold-bearing chalcopyrite-rich granite boulder from the shore of Butlers Pond showing first- and second-stage alteration, and illustrating nature of granite clasts.*

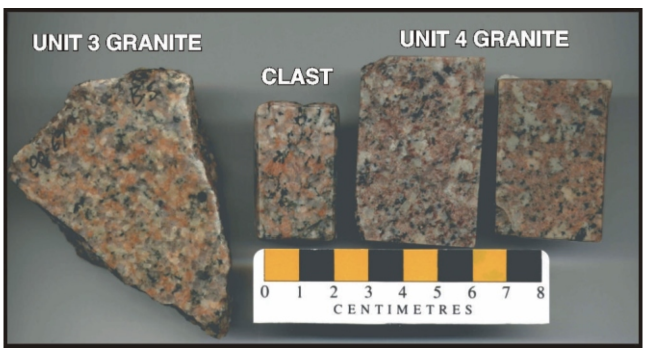

Plate 3. *Representative samples of Units 3 and 4 of the Holyrood Intrusive Suite at Butlers Pond and granite clast from the gold-bearing chalcopyrite-rich granite boulder in Plate 2.*

netite. The silica is very fine-grained and the sericite occurs as network-like veinlets and vein-bundles. This alteration phase contains up to 3 percent total sulphides; chalcopyrite is predominant and locally associated with traces of bornite (as exsolution rims), and minor pyrite. Sulphides are anhedral and commonly isolated, whereas rare grains of magnetite are euhedral to subhedral.

The second (or stockwork) stage of alteration style is manifested as a fine-grained assemblage of K-feldspar and silica, in association with minor amounts of hydrothermal biotite, sericite, chlorite, epidote and magnetite. Broken to finely milled fragments of granite are incorporated into the hydrothermal matrix and partially to completely pseudomorphed by K-feldspar. Locally, the fine-grained breccia and associated sulphides occur along fractures in the granite clasts. Sulphides constitute up to 15 percent of the breccia matrix in select samples; chalcopyrite is predominant and is associated with lesser pyrite. Chalcopyrite occurs as a sulphide–silicate mixture as disseminations and clots reaching 1 cm in diameter. It is spatially associated with (and replaces) pyrite, in fracture-controlled veinlets that are in-turn, truncated by blebs of magnetite (Plate 4). Hydrothermal biotite occurs as irregular patches and veinlets associated with chalcopyrite in the breccia matrix (Plate 5).

Source of Mineralized Granite Boulders

No bedrock source for the mineralized boulders has been identified, although a number of lines of evidence point to a relatively local origin. The boulders are predominantly angular in nature, and appear to be clustered in a small area. Altered and mineralized volcanic boulders found in the same area have likely outcrop sources 500 m west of

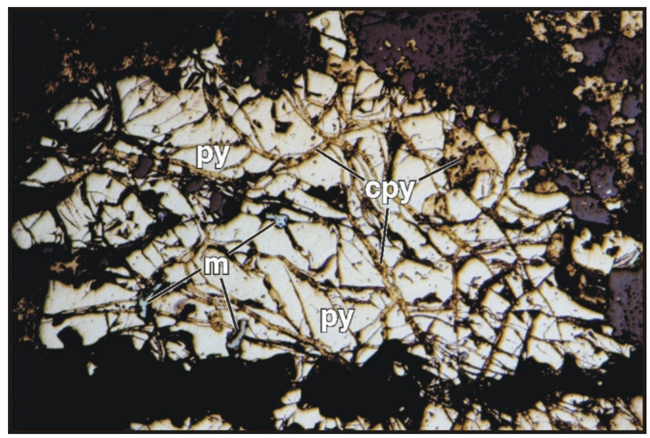

Plate 4. *Photomicrograph of chalcopyrite (cpy), pyrite (py) and magnetite (m) in gold-bearing (3.85 g/t) granite boulder from the shore of Butlers Pond (sample BS-10).*

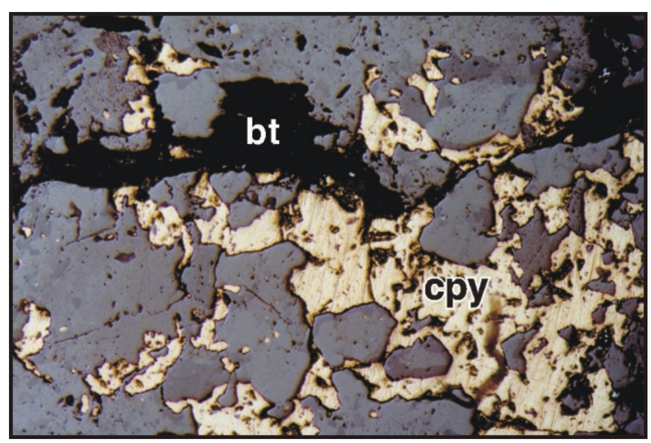

Plate 5. *Photomicrograph of biotite (bt) and chalcopyrite (cpy) in gold-bearing (3.85 g/t) granite boulder from the shore of Butlers Pond (sample BS-10).*

Butlers Pond. Glacial striae at Butlers Pond match those in the nearby "Glazy Rocks" quartz vein outcrop, where a distinctive and locally derived vein-quartz boulder train extends less than 1 km beyond the quartz-rich outcrop. Measurements from both areas give similar ice-movement direction (toward 090° to 105°). The orientation of these glacial features agrees with the suggested ice transport of the mineralized volcanic boulders described above and would thus imply that the brecciated granite boulders would have been transported a similar distance.

Hematite-rich Breccia

Hematite-rich breccia is well exposed on a 16 by 7 m glacially polished outcrop in the once-flooded, southern part of Butlers Pond. This outcrop contains plagioclase porphyritic granite and granodiorite–tonalite phases of the Butlers Pond porphyry; both are crosscut by a hematite-rich hydrothermal breccia (Plate 6). The granite phase is crosscut by, and is locally inter-tongued with the granodiorite–tonalite phase prior to brecciation. Hematite-rich breccia is found only at this exposure, where it comprises approximately 10 to 15 percent of the outcrop. The area affected by brecciation has a maximum width of 4 m and length of 12 m, and a general trend of about 120 degrees. Clasts are variably rounded and sized, varying from finely milled grains to clasts reaching 20 cm in diameter. The matrix of the breccia consists of milled fragments of granite and granodiorite–tonalite, hematite, sericite and minor chlorite (*see below*).

The breccia is mainly matrix-supported (up to 50 percent matrix) except in areas where *in situ* fragmentation of granite and granodiorite–tonalite has occurred. Both granite and granodiorite–tonalite wall rock adjacent to the breccia zone contain hairline fractures that are filled with matrix material.

The matrix of the breccia consists of red hematite, sericite, chlorite, epidote, biotite, specular hematite, and trace amounts of chalcopyrite, together with quartz and milled fragments of both granite and granodiorite–tonalite phases of the Butlers Pond porphyry. The assemblage of minerals can be separated into two classes, *viz.*, those incorporated during brecciation of the wall rocks and those of hydrothermal (fluid-derived) origin.

Biotite, specular hematite and quartz are locally derived from the adjacent wall rocks (i.e., primary), and in some sections, both primary biotite and specular hematite were found to be partially brecciated, incorporated into, and stable within the hydrothermal matrix material. Hydrothermal alteration mineralogy in the hematite-rich breccia is dominated by hematite and sericite, the latter occurring as hairline veinlets and veinlet bundles within the breccia matrix, and found

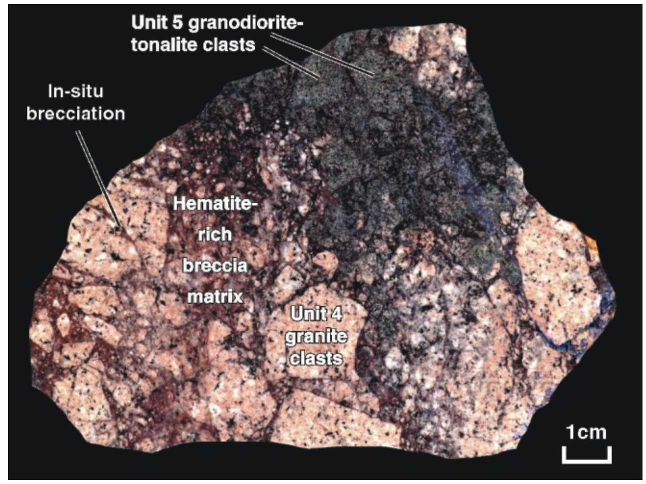

Plate 6. *Hematite-rich breccia from the main breccia outcrop at the south end of Butlers Pond showing both phases of Butlers Pond porphyry and* in situ *brecciation.*

where *in situ* brecciation of wall rock has occurred. Minor amounts of very fine-grained chlorite and trace amounts of very fine-grained, anhedral chalcopyrite grains have also been observed. The sericite–hematite veinlets appear to preferentially rim larger granite clasts in areas of mainly *in situ* brecciation.

OTHER MINERALIZED ROCKS

West of Butlers Pond, hydrothermal alteration and associated pyrite mineralization occur in internally brecciated subvolcanic felsic porphyry dykes within mafic volcanic rocks. The dykes are extensively silicified and sericitized and may contain up to 5 percent pyrite cubes ($\leq$ 4 mm). The felsic fragments are pink where unaltered but are grey-brown where silicified. The breccia contains anomalous metal values, *viz.*, 65 ppb Au, 667 ppm Cu, 427 ppm Pb, 672 ppm Zn and 62 ppm Mo; comparable values from similar rocks in the same area were reported by Pickett, (1995, 1996). In thin section, pyrite occurs as mainly euhedral and broken cubes, up to 4 mm across, with trace chalcopyrite occurring along pyrite grain boundaries and as intergrowths with the pyrite. The pyrite and chalcopyrite are intergrown and associated with fine-grained, anhedral and interlocking, intense mosaic-textured, stockwork silicification. The silica-flooded rock is cut by minor, coarser grained quartz veinlets. Trace amounts of epidote and sericite accompany the early silica–pyrite stockwork-flooding.

Pickett (1996) noted zones of epidote, with or without silica, carbonate alteration and quartz–carbonate veining in basalt in drill core west of Butlers Pond (Avalon Mines drillholes BP-95-A1 and BP-95-A2), locally associated with stringer-type sulphide mineralization. Assay data include up to 1820 ppm Cu, 5100 ppm Zn, and 1975 ppm Pb for these sections of sulphide stringers in the two drill cores (Pickett, 1996). Crocker and Dalton (1994) noted that chalcopyrite and possibly chalcocite stringers cut the basalt about 500 m west of Butlers Pond. Assay values from grab samples from this area returned results up to1% Cu and 7.8 g/t Au.

GEOCHEMISTRY OF THE INTRUSIVE ROCKS

Geochemical data from intrusive rocks of the Holyrood Intrusive Suite in the Butlers Pond area are presented in Tables 2, 3 and 4, and include ICP-ES[3] data from the geochemical laboratory of the Newfoundland and Labrador Geological Survey and INAA[4] data from Activation Laboratories Limited (including REE's and Au). Tables outlining detection limits of both major- and trace-element analysis, along with preparation and determination procedures for the ICP-ES technique are given in Finch (1998); procedures and detection limits for the INAA technique are outlined in Davenport (1988). These major-element, trace-element and rare-earth-element data are treated in detail in Sparkes (2001) and only a brief summary of some pertinent aspects is given below.

MAJOR AND TRACE ELEMENTS

The major- and trace-element data help identify first-order geochemical characteristics of the intrusive phases as identified by field mapping and petrography, which aid in determining the geological setting and mineral-deposit style of the rocks at Butlers Pond. These data are consistent with petrographic data, which together confirm that the felsic plutonic units at Butlers Pond are hornblende–biotite-bearing, I-type granites of calc-alkaline affinity (Sparkes, 2001; Figure 4). These rocks also fall in the field of volcanic-arc granites (cf. Pearce *et al.*, 1984). Mineralization within granite boulders is enriched in Cu, low in Mo and locally Au-rich (up to 3.85 g/t Au in this study and up to 12.8 g/t in previous work). The chemistry of the granites, including that of the mineralized boulders, is consistent with that of rocks known to be associated with gold-rich porphyry deposits (e.g., Sillitoe, 1993). The outcrop exposure of hematite-rich breccia did not return anomalous values for Cu, Au, Ag, Mo or U (Tables 3 and 4), elements commonly enriched in Fe-oxide copper–gold style mineralized systems (cf. Reeve *et al.*, 1990).

Incompatible trace elements are those that favour the melt phase over the solid during melting or crystallization, whereas compatible elements favour the solid phase over the melt/magma (Jenner, 1996). On incompatible versus incompatible trace-element plots, rocks related to one another by simple fractionation generally show trends starting at or near the origin with a positive slope to the right with increasing differentiation (e.g., Y vs. Zr, Figure 5). Compatible versus compatible element plots (e.g., TiO_2 vs. V) generally show fractionation trends from the upper right toward the origin, with increasing differentiation. Compatible versus incompatible element plots (e.g., TiO_2 vs. Zr) generally show fractionation trends from the upper left toward the lower right with increasing fractionation. The Y vs. Zr and Dy vs. Y plots indicate a fractionation trend may exist between granites from Unit 3 and Unit 4, with Unit 4 granite being more fractionated. If Unit 5 granodiorite–tonalite was related by simple fractionaltion to either of the granites, then the mafic rocks would be expected to have lower abundances of Y, Zr and REEs (e.g., Dy) than either of the granites. This is not the case (Figure 5). Whereas the granodiorite–tonalite has higher abundances of compatible elements (e.g., Ti, Sc and V) compared to the granite (features consistent with their mafic composition) the enrichments of incompatible elements (Y, Zr and REEs) in these mafic rocks appear to preclude them being related by simple fractionation to the granite suites.

PRIMITIVE-MANTLE-NORMALIZED ELEMENT PLOTS

Plots of primitive-mantle-normalized elements are consistent with major- and trace-element data in suggesting a possible genetic link between the granites of Units 3 and 4. The primitive-mantle-normalized trace-element plot (Figure 6) was constructed from ICP-ES data and normalized to values obtained from Sun and McDonough (1989). Granites from Units 3 and 4 both have similar, negatively sloping trends between La_N and Dy_N (Unit 4 has slope ~13; Unit 3 has slope ~15), in contrast to the shallower slope (~ 6.7) of the granodiorite–tonalite. The steep slope between La_N and Dy_N indicates an overall calc-alkaline trend for the granites. Both granite fields have low Li_N values (~0.7 to 4), elevated Ba_N and K_2O_N values (~100 to 180), slightly negative Nb_N, P_2O_{5N} and TiO_{2N} anomalies, and negatively sloping trends toward the lower right of the diagram, suggesting a genetic link. The granodiorite–tonalite has a lower slope from La_N and Dy_N, higher Li_N values than the granite, and lacks the latter's prominent P_2O_{5N} anomaly, suggesting that the intermediate rocks are not related to the granite through fractionation, and have a unique source.

[3] ICP-ES = Inductively Coupled Plasma-Emission Spectrometry; [4] INAA = Instrumental Neutron Activation Analysis

Table 2. Major-element analyses of representative plutonic rocks form the Butlers Pond area

Sample Number	Map Unit	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	MnO %	P_2O_5 %	L.O.I. %	Total
OB-00-094	3	74.54	12.44	1.57	0.78	0.84	3.71	3.26	0.190	0.07	0.05	0.97	98.42
OB-00-095	3	74.52	12.70	1.53	0.61	0.49	3.58	4.16	0.176	0.04	0.08	0.92	98.81
OB-00-123	3	73.56	13.74	1.51	0.46	0.83	3.79	3.97	0.146	0.06	0.03	1.06	99.17
OB-00-124	3	75.63	13.19	1.06	0.38	0.28	3.81	4.32	0.112	0.04	0.03	0.75	99.62
OB-00-125	3	73.03	14.35	1.74	0.77	0.54	4.29	3.76	0.174	0.06	0.04	0.99	99.75
OB-00-127	3	71.79	14.84	1.97	0.76	0.87	4.12	3.99	0.203	0.07	0.06	1.09	99.77
OB-00-257	3	72.62	14.32	2.01	0.74	0.65	4.17	3.68	0.210	0.08	0.05	1.24	99.76
OB-00-258	3	73.29	13.85	1.88	0.60	1.12	3.75	3.90	0.187	0.07	0.06	1.02	99.72
OB-00-261	3	75.41	13.00	0.95	0.29	0.39	3.70	4.36	0.108	0.03	0.01	0.85	99.08
OB-00-262	3	76.89	13.20	0.85	0.18	0.31	4.30	3.62	0.083	0.04	0.01	0.95	100.40
OB-00-266	3	72.89	13.81	2.01	0.85	1.04	4.19	3.26	0.210	0.08	0.06	1.42	99.82
OB-00-103	4	73.23	13.78	1.77	0.53	0.39	3.77	4.55	0.181	0.05	0.06	0.88	99.20
OB-00-103	4	74.26	13.06	1.59	0.51	0.30	3.45	4.57	0.164	0.05	0.03	0.82	98.82
OB-00-115	4	72.83	13.90	1.93	0.53	0.33	4.13	4.19	0.204	0.05	0.05	0.88	99.01
OB-00-115	4	74.18	14.08	1.69	0.48	0.27	3.94	4.59	0.173	0.05	0.04	0.81	100.30
OB-00-159	4	70.20	14.95	2.40	0.74	0.77	4.49	3.70	0.256	0.05	0.08	1.10	98.73
OB-00-159	4	72.21	13.88	1.90	0.57	0.54	3.87	4.35	0.198	0.04	0.05	0.89	98.50
OB-00-304	4	73.03	13.67	1.91	0.57	0.51	4.42	3.80	0.214	0.06	0.05	1.08	99.32
BS-2	5	63.21	16.74	5.25	2.08	1.60	3.32	4.12	0.539	0.12	0.28	2.14	99.41
OB-00-160	5	59.24	17.93	5.67	2.47	1.19	3.27	4.89	0.626	0.14	0.32	2.55	98.29
OB-00-162	5	61.56	17.31	5.99	2.64	1.12	3.78	3.97	0.629	0.15	0.37	2.47	99.99
BS-9CGM	sulphide boulder	77.33	10.98	1.44	0.49	0.09	3.62	3.31	0.143	0.03	0.04	0.78	98.25
BS-9GRC	sulphide boulder	76.37	12.04	1.49	0.54	0.10	3.86	3.80	0.166	0.04	0.05	0.82	99.28

The normalized REE plot of INAA data for Units 3, 4 and 5 of the Holyrood Intrusive Suite (Figure 7) was constructed using primitive-mantle values obtained from Sun and McDonough (1989). All three units are enriched in LREE (La_N, Ce_N, Nd_N and Sm_N); they have similar, steep, negatively sloping trends (Unit 4 ~ 11.5, Unit 5 ~ 6.7 and Unit 3 ~ 10) from La_N to Sm_N and, relatively flat trends from Eu_N to Lu_N. The trends and negative slopes in both INAA and ICP-AES data are similar, both suggesting calc-alkaline affinities and possible genetic links between the two granite phases. The pronounced difference in slope between Units 4 and 5 again argues against a genetic link through fractionation. The data are relatively well clustered, with the exception of Eu_N values; the spread in these data likely represents modal abundances of plagioclase.

SUMMARY AND CONCLUSIONS

1. The late Proterozoic geological record as preserved in rocks at Butlers Pond is one of mainly subaerial, pyroclastic and locally subaqueous volcanism of felsic through intermediate to mafic composition, followed by the emplacement at high crustal levels of a composite, metallogenically important plutonic suite, between 625 and 620 Ma. Tilting, exhumation, erosion and submergence of the volcano-plutonic rocks occurred prior to emplacement of a later spatially restricted suite of mafic intrusive rocks of presumed late Proterozoic age.

2. The data support a co-magmatic relationship between granite typical of the main, areally extensive, hornblende–biotite granite phase of the Holyrood Intrusive Suite, dated elsewhere at 620 ± 2 Ma and 623 ± 3 Ma, and the newly dated 622 ± 2 Ma Butlers Pond porphyry.

3. Integration of these new data with that from regional mapping and geochronological studies elsewhere in the central Avalon Peninsula, allows for the correlation of subaerial explosive volcanism recorded in the Butlers Pond area with volcanism dated between 630 to 620 Ma in nearby parts of the Holyrood Horst (e.g., southern parts of the Hawke Hills tuff, Figure 1). Plutonism and volcanism are

Table 3. Table of trace elements for representative samples of plutonic rocks from the Butlers Pond area

Sample Number	Map Unit	Cr ppm	Zn ppm	Pb ppm	Co ppm	Ni ppm	Fe %	Cd ppm	Ti ppm	V ppm	Be ppm	Nb ppm	Cu ppm	Dy ppm	Sc ppm	Y ppm	Zr ppm	Mn ppm	Sr ppm	La ppm	Ce ppm	Ba ppm	Li ppm	As ppm
OB-00-094	3	2	60	13	3	2	1.08	0.5	1328	13	1	8	41	1	5	12	77	677	168	21	29	1043	3	4
OB-00-095	3	1	31	3	2	2	1.05	0.5	1261	9	1	7	1	2	4	17	121	418	125	27	37	1002	4	2
OB-00-123	3	1	32	8	2	2	1.02	0.5	1073	6	2	7	1	2	3	13	91	551	185	22	30	833	7	4
OB-00-124	3	1	27	5	1	1	0.68	0.5	847	2	2	10	1	1	3	10	74	460	106	20	30	1048	3	3
OB-00-125	3	1	37	1	2	2	1.19	0.5	1237	8	2	8	1	2	4	18	106	564	151	26	37	923	5	5
OB-00-127	3	1	43	2	3	2	1.35	0.5	1427	10	2	9	1	2	4	17	104	692	217	28	38	1047	5	1
OB-00-257	3	1	44	4	3	2	1.50	0.5	1512	13	2	10	1	2	4	14	120	717	195	31	43	1056	6	5
OB-00-258	3	1	42	14	3	2	1.35	0.5	1353	12	2	8	2	2	4	16	130	671	202	28	41	1091	8	2
OB-00-261	3	1	27	14	1	1	0.65	0.5	833	4	1	10	1	1	3	11	94	353	109	22	33	954	5	4
OB-00-262	3	1	25	12	1	1	0.54	0.5	607	1	1	9	1	1	2	10	64	444	100	19	31	980	3	1
OB-00-266	3	1	43	17	4	2	1.37	0.5	1455	18	2	9	2	2	5	16	93	717	195	25	35	796	4	1
OB-00-103	4	1	35	5	3	3	1.20	0.5	1300	11	1	8	4	2	4	14	139	527	121	23	36	917	4	3
OB-00-103	4	1	35	15	2	2	1.03	0.5	1208	11	1	6	3	2	4	13	138	483	115	22	32	944	3	3
OB-00-108	4	1	79	1	5	4	2.55	0.5	2465	18	2	10	14	3	6	19	n.d.	974	237	14	29	878	7	4
OB-00-115	4	1	32	1	3	2	1.32	0.5	1429	9	2	10	2	4	5	26	170	507	100	37	51	1049	4	4
OB-00-115	4	1	32	5	2	2	1.09	0.5	1301	8	2	10	4	3	4	19	159	456	93	26	50	985	3	2
OB-00-159	4	1	38	1	3	2	1.68	0.5	1777	17	2	9	16	3	5	19	225	489	214	37	56	960	5	4
OB-00-159	4	1	29	8	3	2	1.27	0.5	1417	13	1	8	16	3	4	20	172	381	162	31	45	1164	4	4
OB-00-304	4	1	42	2	3	2	1.37	0.5	1612	10	2	12	2	2	5	19	174	603	138	20	35	939	3	3
OB-00-305	4	1	64	384	1	2	1.26	0.1	1572	12	1	11	9	1	5	8	n.d.	247	99	9	13	946	1	29
BS-2	5	1	83	8	8	4	3.52	0.5	3616	42	2	8	27	3	11	21	153	979	204	29	43	904	12	3
OB-00-160	5	1	93	1	8	4	3.85	0.5	4014	49	2	8	3	4	13	23	178	1157	163	28	46	1097	15	6
OB-00-162	5	1	97	1	8	4	4.05	0.5	4079	57	2	8	2	3	14	22	139	1260	191	25	43	907	17	5
OB-00-300	5	1	120	4	7	4	3.98	0.5	3774	51	2	9	5	3	12	26	n.d.	1885	280	31	48	600	13	4
BS-9CGM	boulder	1	26	5	2	2	0.92	0.5	1095	3	1	6	2700	1	3	11	131	367	67	8	13	939	3	4
BS-9GRC	boulder	1	29	6	2	2	0.95	0.5	1273	3	1	7	3504	1	3	15	146	400	74	8	12	1068	3	4
OB-00-161	4 Hem-bx	10	50	13	2	33	1.32	0.5	1298	9	1	7	13	2	4	17	n.d.	365	127	27	43	1025	3	6
OB-00-165	1b Bx	5	672	427	10	9	3.69	8.3	1118	18	1	3	667	1	4	7	n.d.	65	27	16	25	510	1	3

n.d. - not determined

Table 4. Table of trace and rare-earth-elements determined by INAA for representative plutonic rocks from the Butlers Pond area

Sample Number	Map Unit	Au ppb	Ag ppm	As ppm	Ba ppm	Br ppm	Co ppm	Cr ppm	Cs ppm	Hf ppm	Mo ppm	Na %	Rb ppm	Sb ppm	Sc ppm	Ta ppm	Th ppm	U ppm	Zn ppm	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Tb ppm	Yb ppm	Lu ppm
OB-00-094	3	2	b.d.	1	720	b.d.	2	b.d.	b.d.	2	b.d.	2.65	78	0.2	3.9	b.d.	6.5	1.8	63	20	29	10	1.9	0.5	0.7	1.4	b.d.
OB-00-095	3	4	b.d.	1.5	750	b.d.	2	b.d.	1	3	b.d.	2.51	79	0.3	3.4	b.d.	8	1.4	b.d.	22	32	15	2.7	0.6	b.d.	2	b.d.
OB-00-123	3	1	b.d.	1	660	b.d.	2	b.d.	1	3	2	2.77	96	0.2	2.8	b.d.	7.9	1.3	b.d.	20	28	15	2	0.6	b.d.	1.5	b.d.
OB-00-124	3	b.d.	b.d.	b.d.	870	b.d.	1	b.d.	b.d.	3	b.d.	2.95	93	b.d.	3.1	1.3	11	1.6	b.d.	23	33	14	2	b.d.	b.d.	1.7	b.d.
OB-00-125	3	b.d.	b.d.	1.8	720	b.d.	1	b.d.	b.d.	3	b.d.	3.07	90	b.d.	3.2	1.2	9.1	1.7	b.d.	24	34	16	2.5	0.6	b.d.	1.9	b.d.
OB-00-127	3	4	b.d.	1.2	750	b.d.	2	b.d.	2	3	2	2.83	74	b.d.	3.3	b.d.	7.5	1.6	b.d.	24	33	14	2.2	0.7	b.d.	1.8	b.d.
OB-00-103	4	b.d.	b.d.	1.6	770	b.d.	2	b.d.	1	4	b.d.	2.72	140	b.d.	3.7	0.8	11	3.1	90	26	38	19	2.8	0.5	0.5	2.3	b.d.
OB-00-159	4	b.d.	b.d.	1.8	780	b.d.	2	b.d.	1	5	b.d.	3.35	70	b.d.	4.5	b.d.	8.1	1.3	b.d.	32	50	23	3.6	1.1	b.d.	2.1	b.d.
OB-00-160	5	3	b.d.	1.7	820	b.d.	7	b.d.	2	4	2	2.40	170	0.2	11	b.d.	5.5	1.7	81	26	40	23	4	1.3	b.d.	2.6	b.d.
OB-00-162	5	3	b.d.	1.5	760	b.d.	6	b.d.	3	4	b.d.	2.78	120	0.1	12	b.d.	5.9	1.4	69	24	37	18	3.8	1.1	0.6	2.8	b.d.
BS-9CGM	boulder	b.d.	b.d.	b.d.	960	0.8	2	b.d.	b.d.	4	b.d.	2.90	71	0.3	3.1	1.1	7.6	2.3	b.d.	8.2	16	b.d.	1.2	b.d.	b.d.	2	b.d.
BS-9GRC	boulder	b.d.	b.d.	2.2	1000	b.d.	2	b.d.	1	4	b.d.	2.98	67	0.2	3.3	0.8	9.5	1.9	b.d.	7.5	18	b.d.	1.3	b.d.	0.7	2.7	b.d.
BS-5	boulder	b.d.	b.d.	1.8	950	0.8	2	b.d.	2	6	13	3.05	130	0.6	6.4	0.9	12	1.9	b.d.	14	25	9	2.2	0.5	b.d.	2	b.d.
BS-6	boulder	b.d.	b.d.	1.9	500	b.d.	3	8	2	5	29	1.65	160	0.4	11	0.7	11	2	b.d.	17	33	10	2.7	0.7	0.7	5.5	0.82
BS-7	boulder	30	b.d.	4.8	2400	b.d.	15	25	2	2	43	3.37	77	0.1	15	b.d.	1.2	b.d.	b.d.	2.2	8	b.d.	1	b.d.	b.d.	1.1	b.d.
BS-8	boulder	52	b.d.	1.6	890	b.d.	3	b.d.	b.d.	4	b.d.	2.60	110	0.2	4	b.d.	11	1.3	b.d.	15	27	9	1.6	b.d.	0.7	2.4	b.d.
BS-10	boulder	3850	43	2.1	850	b.d.	2	b.d.	b.d.	3	b.d.	2.39	86	0.4	3.2	b.d.	9.1	1.8	b.d.	24	41	9	2.1	0.6	b.d.	2.1	b.d.
OB-00-161	4 hem Bx	2	b.d.	1.3	830	b.d.	3	b.d.	1	4	4	3.54	38	0.2	3.6	0.8	8.3	1.1	b.d.	27	46	19	3.3	0.8	b.d.	2.3	b.d.
OB-00-165	1b h-bx	65	b.d.	1.7	520	b.d.	7	b.d.	b.d.	2	62	0.96	30	b.d.	3.5	0.2	2.4	0.7	673	15	29	8	1.5	b.d.	b.d.	1.1	b.d.

b.d. = below detection limit

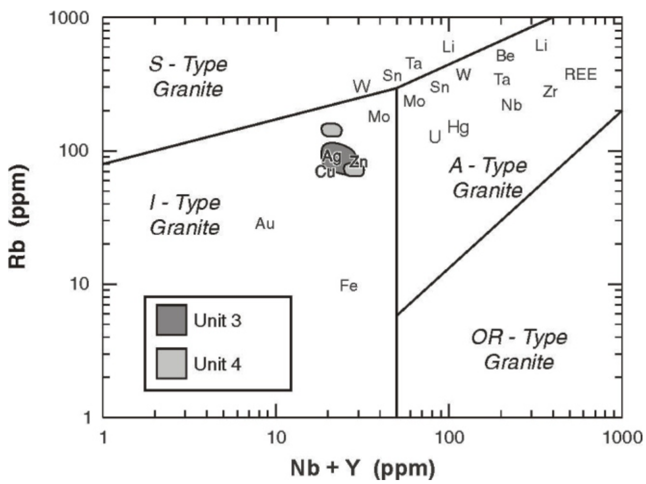

Figure 4. *Rb vs Nb+Y trace-element diagram showing compositions of Units 3 and 4 relative to fields for I-, S-, A- and OR-type granites (modified from Pearce* et al., *1984, Ray* et al., *1995 and Christiansen and Keith, 1996).*

thus considered coeval. Furthermore, observed contact relationships consistently indicate that all volcanic sequences in the study area (including mineralized units) are older than 620 Ma, and thus unrelated to 580 Ma and younger Proterozoic volcanism elsewhere in the Avalon Zone.

4. Following the emplacement of the Holyrood Intrusive Suite between 625 and 620 Ma, a period of uplift and erosion resulted in the unroofing of the plutons and the intruded volcanic pile. Marine sedimentary rocks record a submergence of the volcano-plutonic complex, which has also been documented in other areas, both within and adjacent to the Holyrood Horst (O'Brien *et al.,* 2001a). Existing data do not preclude correlation with 621 +5/-4 Ma marine sedimentary rocks in the northern Holyrood Horst (Israel, 1998; O'Brien *et al.,* 2001a), although such a correlation requires essential contemporaneity of volcanism, plutonism, uplift erosion and submergence. An alternate correlation is with the post-580 and pre-565 Ma, marine, siliciclastic sedimentary rocks of the Conception Group east of the Topsail Fault (King, 1988; O'Brien *et al.*, 2001a).

5. Whole-rock geochemistry indicates a possible genetic relationship, through fractionation, between the main hornblende–biotite granite phase (Unit 3) of the Holyrood Intrusive Suite and the granite phase (Unit 4) of the Butlers Pond porphyry. The similar chemical affinities of Units 3 and 4 are consistent with a contemporaneity that is independently demonstrated by the geochronological data. Both phases are LREE-enriched, calc-alkaline magmas likely related to a subduction-related, volcanic arc. Available data, however, argue against a simple fractionation relationship between the coeval and comingling granodiorite–tonalite and granite phases of the Butlers Pond porphyry.

6. Documented mineralization in the Butlers Pond area shares several characteristics with that found in porphyry copper–gold deposits. The alteration assemblages associated with copper–gold mineralization in locally derived boulders include K-feldspar–biotite–magnetite–silica (potassic) in the second-stage (stockwork) alteration as well as an earlier style of silica–sericite-dominated alteration. Both assemblages are consistent with porphyry-style copper–gold deposits, such as those described by Sillitoe (1979, 1991, 1993), Corbett and Leach (1998) and Titley (1994). Other observations consistent with such a model include the occurrence of silica–sericite alteration zones with associated pyrite mineralization found southeast, west and north of Butlers Pond, and also the calc-alkaline composition, I-type affinity and volcanic-arc-like signature of granite host rocks.

7. The protolith of the copper–gold mineralized breccia is indistinguishable from equigranular phases of the Holyrood Intrusive Suite that are widely developed north of the Butlers Pond region. Similar granite, with comparable silica–sericite–pyrite alteration, also occurs in the area southeast of Butlers Pond. This indicates a potential for such a style of mineralization elsewhere in this region, particularly in areas where phases similar to the Butlers Pond porphyry are present. The 622 ± 2 Ma age of the Butlers Pond porphyry demonstrates that intrusive rocks associated with hydrothermal alteration, brecciation and mineralization at Butlers Pond are not anomalous, *vis-a-vis* age, relative to most of the Holyrood Intrusive Suite. This further demonstrates that the suite has potential to host to porphyry-style Cu–Au deposits at Butlers Pond and possibly elsewhere in the region. These new data, however, confirm that this plutonism cannot be directly related to formation of the 580 to 570 Ma magmatic arcs hosting the extensive late Proterozoic high- and low-sulphidation Avalonian epithermal systems in the Hickey's Pond, Hope Brook and Manuels areas of southern and eastern Newfoundland (e.g., O'Brien *et al.,* 2001a,b). The magmatism recorded at Butlers Pond, however, is approximately coeval with plutonism related to small, intrusion-related copper–gold–molybdenum systems in Avalonian rocks in Cape Breton (e.g., Lynch and Ortega, 1997).

8. Available field, petrographic and geochemical data suggest that the hematite-rich brecciation associated with some areas of the Butlers Pond porphyry pluton is not of the type related to many iron-oxide–copper–gold systems. The restricted extent, negative geochemical signatures of the hematite-rich breccia (i.e., low U, Cu, Au, Ag and REE's) and the I-type affinity and mineralogy (e.g., no fluorine-bearing phases) of the host granite are not consistent with this deposit model. The brecciation is largely *in situ* and may be related to local mechanical brecciation during release of volatile-rich fluids near the interface with country rocks or a

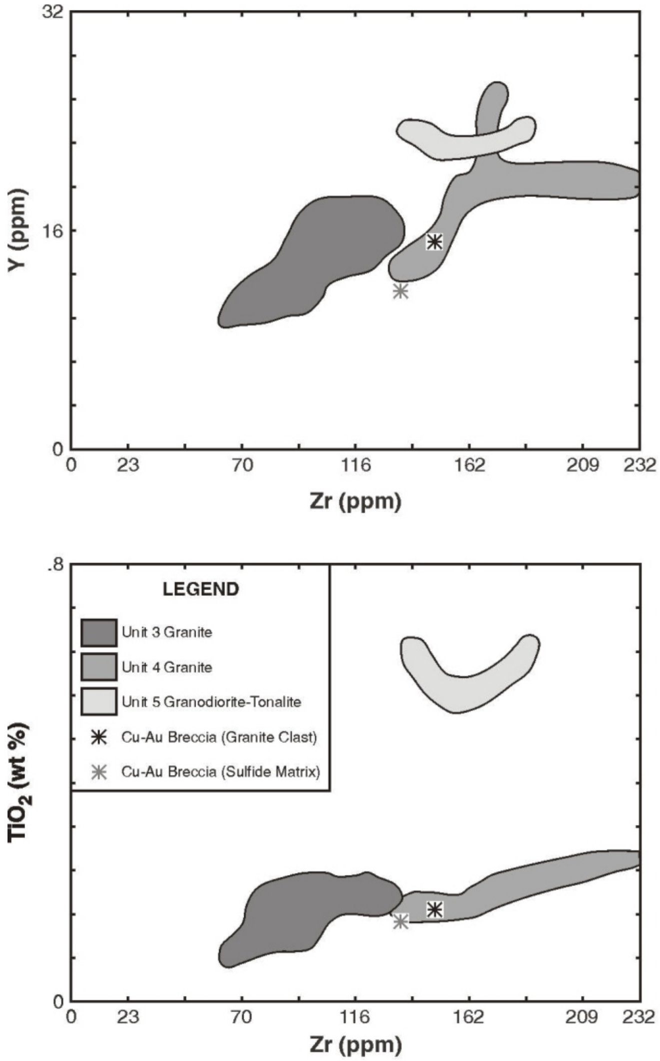

Figure 5. *Bivariate trace-element geochemical plots for Units 3, 4 and 5 of the Holyrood Intrusive Suite in the Butlers Pond area.*

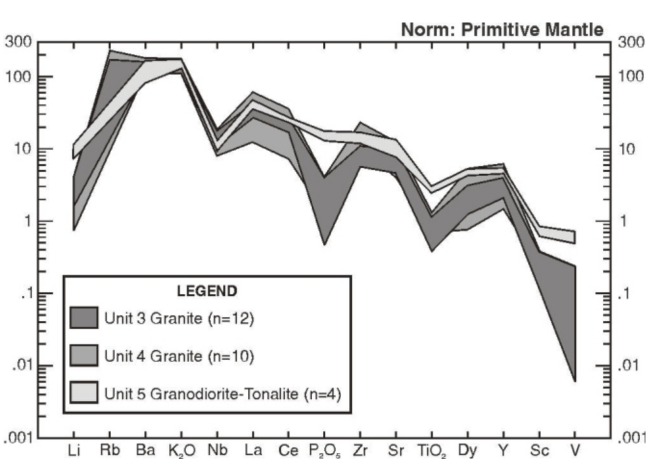

Figure 6. *Normalized multi-element geochemical plots for Units 3, 4 and 5 of the Holyrood Intrusive Suite in the Butlers Pond area.*

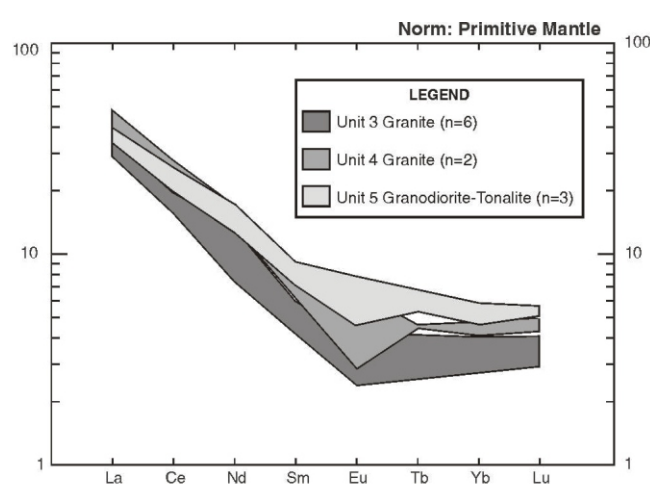

Figure 7. *Normalized rare-earth-element geochemical plots for Units 3, 4 and 5 of the Holyrood Intrusive Suite in the Butlers Pond area.*

chilled magma carapace. The thick pile of oxidized mafic and felsic volcanic rocks adjacent to the west margin of porphyry may be the source of hematite in these breccias.

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