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# LATE NEOPROTEROZOIC GEOLOGY OF THE EAST COAST OF CONCEPTION BAY, NEWFOUNDLAND AVALON ZONE

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## ABSTRACT

*The late Neoproterozoic volcano-sedimentary rocks that host ca. 585 to 570 Ma epithermal precious-metal and, spatially related, zinc–lead–copper mineralization along the eastern margin of the Holyrood Horst continue eastward, across the Topsail Fault, where they are well exposed along the rugged eastern coast of Conception Bay. These, and the other magmatic units described, span the region from Topsail Head to Cape St. Francis, and abut to the east, younger marine siliciclastic rocks of the Conception Group.*

*The most extensive "pre-Conception" units include the pre-620 Ma White Mountain volcanic suite, the ca. 625 to 620 Ma Holyrood Intrusive Suite and the ca. 580 Ma Wych Hazel Pond complex. Other, less extensive units identified in this study, include dyke swarms that have not been described from the Holyrood Horst. Marine sedimentary and volcanic rocks of the Wych Hazel Pond complex represent an aerially extensive portion of the late Neoproterozoic basin-fill that records the rapid transition from a long-lived, primarily subaerial environment into a marine depositional setting. The accumulation of the late Neoproterozoic sedimentary succession is associated with the transition from felsic to mafic-dominated volcanism, and may imply a change in the over-riding tectonic environment.*

*The entire Neoproterozoic succession, including the Conception Group, is affected by deformation of implied late Neoproterozoic age, manifested mainly by open folding and localized thrusting. Folds and faults that affect the Neoproterozoic rocks are locally crosscut by mafic intrusions, which are part of the newly defined Beaver Hat intrusive suite. The emplacement of these intrusions provides a minimum limit to the age of this deformation. The current maximum limit for that deformation, which is based on data from immediately west of the Topsail Fault is 582 Ma (age of the basal Wych Hazel Pond complex); these intrusions were sampled for U–Pb dating. The effects of Paleozoic (or younger) deformation along the margin of the Holyrood Horst are most readily demonstrated in a small outlier of Lower and Middle Cambrian rocks, adjacent to the Topsail Fault.*

*The area between Topsail Head and Cape St. Francis includes fault-related epigenetic base-metal (± gold) mineral occurrences, as well as, at least one low-sulphidation-style epithermal gold prospect. The first type of mineralization includes pyritic gossan zones spatially related to the regional trace of the Topsail Fault. Auriferous, chalcopyrite and galena-bearing quartz veins locally are associated with the fault between the Wych Hazel Pond complex and Conception Group. Low-sulphidation-style, gold-bearing quartz veins occur in northern portions of the map area, and represent the continuance of a regionally extensive epithermal system, best exposed near Manuels, west of the Topsail Fault.*

## INTRODUCTION

This report summarizes preliminary, field-based results of 1:25 000-scale regional bedrock mapping along the eastern coast of Conception Bay during the summer of 2005. This mapping focused upon the late Neoproterozoic geology of the region west of the Conception Group, an area that is dominated by submarine siliciclastic sedimentary rocks and associated mafic volcanic flows, along with minor subaerial felsic volcanic and intrusive rocks. The mapping covered a narrow northeast-trending corridor, approximately 38 km long and up to 6 km wide, between Topsail in the south, and Cape St. Francis in the north. The study was undertaken to examine if the regional geological units west of the Top-

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sail Fault (e.g., *see* O'Brien *et al.*, 2001 and references therein; Sparkes *et al*., 2005; Sparkes, 2005), extended northeast to Cape St. Francis, and if so, whether they were mineralized.

These units include the 625 to 620 Ma and earlier Holyrood Intrusive Suite and White Mountain volcanic suite, the ca. 585 Ma and later Manuels volcanic suite and Wych Hazel Pond complex (O'Brien *et al*., 2001; Sparkes *et al*., 2005). The Conception Group, most of which lies east of the current study area, was previously mapped by King (1988, 1990).

## PREVIOUS WORK

Previous regional-scale mapping of the volcano-plutonic rocks within the region includes work by Hsu (1975) and King (1988, 1990). Further regional mapping in the northern half of the area was completed during recent gold exploration by Rubicon Minerals (Sparkes, 2004). More recently, regional reconnaissance mapping of the entire area was carried out by S. O'Brien (written communication, 2005).

Detailed investigations, including mapping, have been carried out as part of mineral exploration in the Cape St. Francis and the Grog Pond areas. The mineral exploration was carried out by Chislett (1989), Cominco Limited (Rennie and de Carle, 1989), Basha (2000, 2001, 2002) and Rubicon Minerals Corporation (Sparkes, 2003). Other completed work in the area includes unpublished theses (e.g., Maher, 1972; Smith, 1987; Churchill, 1990).

King (1990) subdivided the pre-Conception Group geology into three distinct units: the St. Phillips, Portugal Cove, and Princes Lookout formations (Harbour Main Group). Elements of the St. Phillips Formation have been included here with the newly defined and informally named Horse Cove complex. Both the Portugal Cove and Princes Lookout formations have been tentatively included within the Wych Hazel Pond complex, however the Princes Lookout Formation has been retained as a distinct subunit of that complex. Nomenclature used in this report is preliminary and informal, and where possible, matches that used for equivalent, previously named and dated volcano-plutonic successions recently identified in the adjoining Holyrood Horst (O'Brien *et al*., 2001; Sparkes *et al*., 2005).

## REGIONAL GEOLOGICAL SETTING

Historically, the central Avalon Peninsula has been subdivided into what were believed to be three contrasting lithotectonic blocks (viz., the western, central and eastern blocks of Papezik, 1969, 1970; Figure 1). The distribution of regional geological units in the central part of the peninsula is controlled by a north–south-elongated, southward-plunging, regional uplift, known as the Holyrood Horst (McCartney, 1969; O'Brien *et al*., 2001). At its core are: 1) late Neoproterozoic (730 to 580 Ma) subaerial felsic and mafic volcanic rocks (O'Brien *et al*., 1997, 2001), previously included in the Harbour Main Group, and 2) extensive areas of Neoproterozoic, mainly felsic intrusive rocks belonging to the Holyrood Intrusive Suite (King, 1988) and the broadly co-genetic, less widely developed, 620 Ma and earlier White Hills intrusive suite (Sparkes *et al.*, 2005). The horst structure is flanked by a shoaling-upward sequence of marine, deltaic, and fluviatile facies siliciclastic rocks belonging to the Conception, St. John's and Signal Hill groups, respectively (*see* King, 1988).

Along the eastern flank of the Holyrood Horst, a sequence of younger subaerial felsic volcanic rocks is juxtaposed with the Holyrood Intrusive Suite (O'Brien *et al*., 2001; Sparkes *et al*., 2005). These rocks, assigned to the Manuels volcanic suite by O'Brien *et al*. (2001), represent some of the youngest volcanic activity (ca. 585 to 580 Ma) within the eastern Avalon Peninsula. The felsic volcanic rocks of the Manuels volcanic suite are unconformably overlain by submarine siliciclastic sedimentary rocks and associated mafic volcanic rocks informally designated as the Wych Hazel Pond complex (O'Brien *et al*., 2001). It is this syn- to post-585 Ma magmatism that is associated with the epithermal alteration and associated precious-metal mineralization in felsic rocks, and subsequent base-metal mineralization in the mafic units, in this region (*see* O'Brien *et al*., 1997, 1998, 1999, 2001; Sparkes *et al*., 2005).

The recent mapping shows that several of the major geological units flanking the eastern margin of the Holyrood Horst (White Mountain volcanic suite, Holyrood Intrusive Suite and Wych Hazel Pond complex) continue farther east, across the Topsail Fault, and occupy the region between Topsail Head and Cape St. Francis (Figure 2). The correlation of units across the Topsail Fault, along with the recognition of multiple intrusive events, lends further insight into the complex and episodic late Neoproterozoic magmatic history of this metallogenically important part of the Avalon Zone, and offers further opportunities to establish timing of major tectonic events.

# LATE NEOPROTEROZOIC GEOLOGY OF THE MAP AREA

Correlatives of the aerially extensive felsic volcanic successions found immediately west of the Topsail Fault are preserved primarily as relatively small, fault-bound windows within the study area, and are found mainly between Grog Pond and the Bauline Line (Figure 2). Here, the felsic volcanic rocks occur in close spatial association with, and

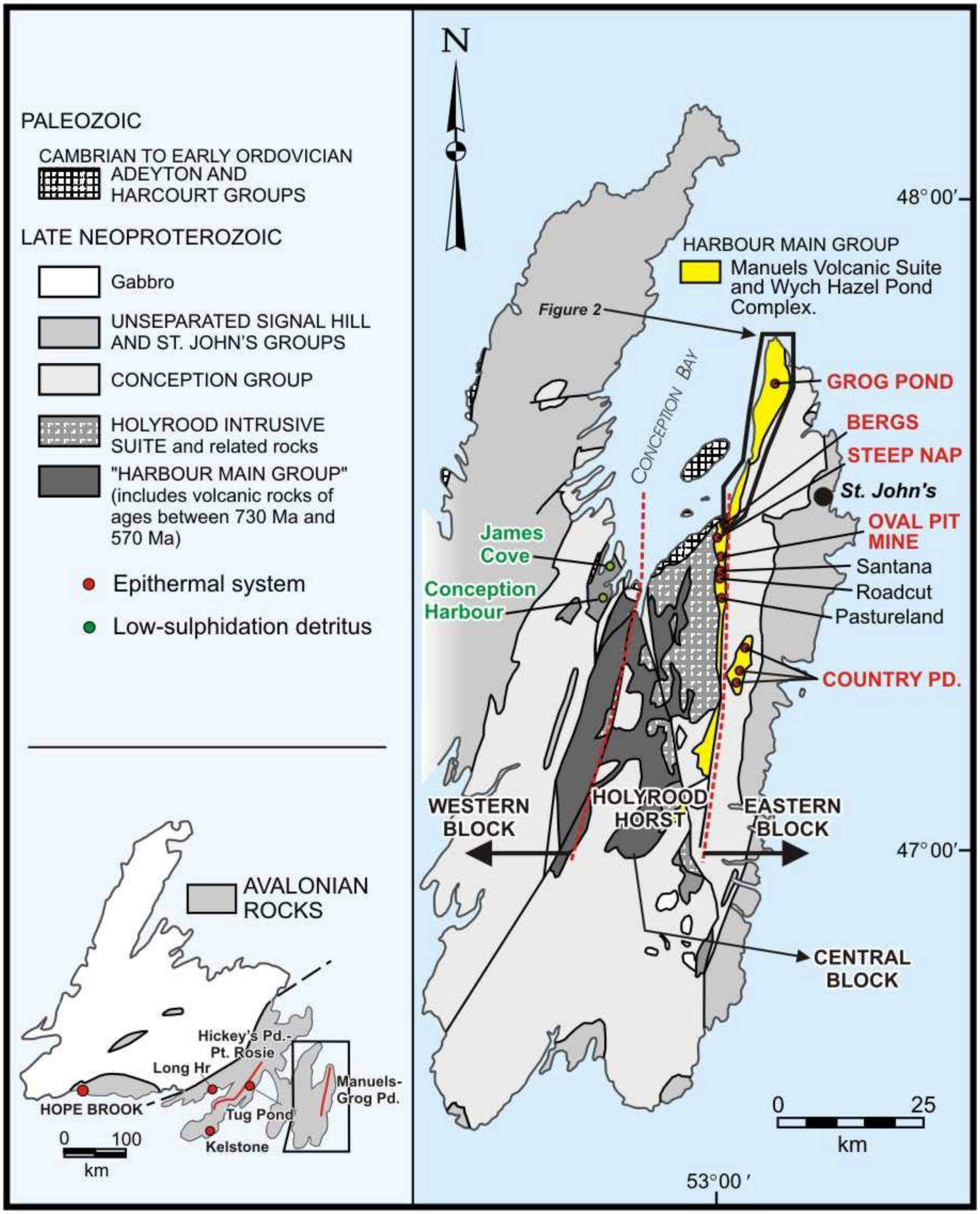


**Figure 1.** *Simplified geological map of the Avalon Peninsula (modified from King, 1988). Shaded area on inset map shows approximate distribution of "Avalonian" rocks, red dots and lines delineate epithermal prospects and/or deposits (modified from O'Brien* et al., *1998).*

locally intruded by, granitic rocks correlated with the Holyrood Intrusive Suite (cf. O'Brien *et al.*, 2001; Sparkes *et al.*, 2005). The pre-620 Ma volcano-plutonic succession is in fault contact with younger (post-580 Ma) siliciclastic sedimentary rocks and associated mafic rocks, which together are mapped as the Wych Hazel Pond complex (cf. O'Brien *et al.*, 2001; Sparkes *et al.*, 2005). In the study area, sedimentary rocks of the complex are the principle host to

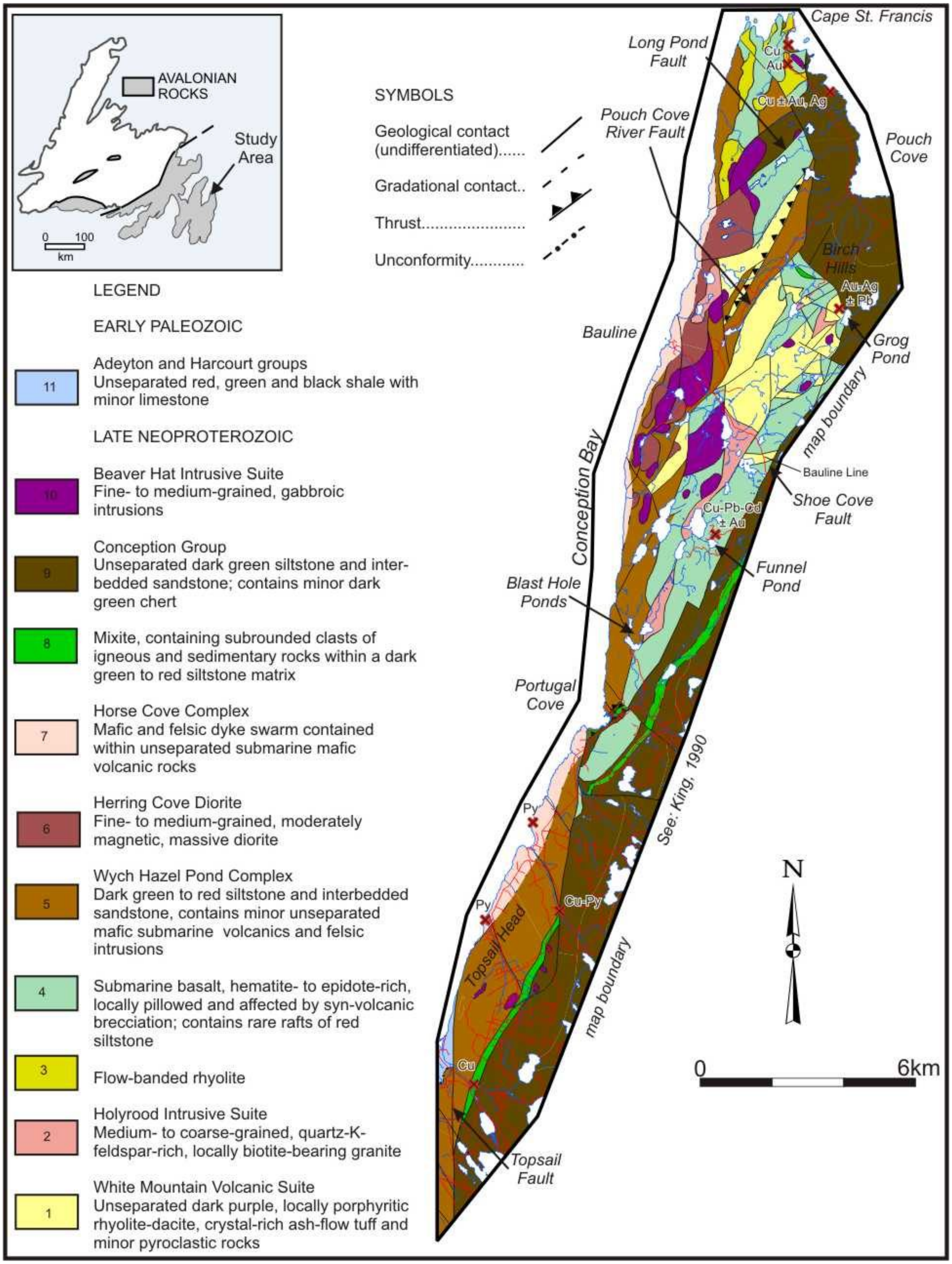


**Figure 2.** *Preliminary map of the regional geology of the eastern coast of Conception Bay, Avalon Peninsula; complied in part from Hsu (1975) and King (1990).*

numerous intrusions including the newly recognized and informally named Herring Cove diorite and Beaver Hat intrusive suite. To the east of this volcano-sedimentary package, external to the map area, lies the Conception Group, which is a conformable, shoaling-upward marine sequence (King, 1990), the deposition of which marks the cessation of volcanic activity within the region.

## 620 Ma AND OLDER ROCKS

### White Mountain Volcanic Suite (Unit 1)

The oldest unit within the map area (Unit 1) includes subaerial crystal-rich ash-flow tuff, massive, locally flow-banded, rhyolite–dacite and minor pyroclastic rocks. These rocks dominate the highlands in the area of Grog Pond south to the Bauline Line, and also occur as discrete outliers in the region south of Bauline. The most distinctive and widely developed rock type within this unit is a massive red, crystal-rich ash-flow tuff that contains mm-scale euhedral crystals of biotite that are locally altered to sericite.

These volcanic rocks are preserved in structural windows bounded to the west by the Pouch Cove River Fault and to the east by the Shoe Cove Fault and/or splays off that structure. The succession is inferred to dip moderately to the west, on the basis of alignment of rare pumice fragments contained within the massive ash-flow tuff. A rare pyroclastic unit, restricted to extreme western exposures of the suite, contains fragments of both felsic volcanic and intrusive rocks, and is similar to that seen in the suite west of the Topsail Fault (Plate 1).

The volcanic rocks are correlated with the White Mountain volcanic suite of Sparkes *et al.* (2005) on the basis of lithology and their intrusive contact with granitic rocks of the Holyrood Intrusive Suite.

**Plate 1.** *Strongly foliated pyroclastic unit of the White Mountain volcanic suite (Unit 1), containing clasts of crystal-rich ash-flow tuff, fine- to medium-grained granite, and dark-purple porphyritic rhyolite.*

### Holyrood Intrusive Suite (Unit 2)

Equigranular biotite granite (Unit 2) shares a close spatial association with, and locally intrudes, the volcanic rocks of Unit 1. The granite, here correlated with the Holyrood Intrusive Suite, is medium to coarse grained, quartz-K-feldspar-rich and contains minor biotite and chlorite. Near intrusive contacts with the volcanic rocks, the granite has been brecciated by tuffisite (Plate 2); this is a common feature developed elsewhere in granites of this suite. Minor quartz-porphyritic phases typically develop a “knobby” quartz weathering, similar to that described in the main body of the suite in the Holyrood Horst. In several outcrops, the granite is a distinctive pink, white and green, typical of the Holyrood Intrusive Suite elsewhere on the Avalon Peninsu-

**Plate 2.** *Well-developed tuffisite brecciation in granite of Holyrood Intrusive Suite (Unit 2), adjacent to an intrusive contact with felsic volcanic rocks of the White Mountain volcanic suite.*

la (e.g., O'Brien *et al*., 2001). Localized float in the area north of Blast Hole Ponds indicates the granite is at least locally affected by intense pyrite-silica hydrothermal alteration.

Although the granite is limited to fault-bounded windows containing volcanic rocks of the White Mountain volcanic suite, or sheets contained within younger intrusive rocks, its distribution is significantly greater than previously noted. Unit 2 is correlated with the Holyrood Intrusive Suite on the basis of similar composition, textures, and the local development of the distinctive pink, white and green alteration.

## Ca. 585 to 580 AND YOUNGER ROCKS

### Wych Hazel Pond Complex (Units 3 to 5)

Most of the map area consists of late Neoproterozoic volcano-sedimentary rocks assigned to the Wych Hazel Pond complex of O'Brien *et al.* (2001). This extensive sequence, which includes widespread volcanic units of typically mafic composition, records the initial infilling of a Neoproterozoic basin subsequent to a protracted period of subaerial, predominantly felsic volcanism. A well-exposed erosional unconformity separates the Wych Hazel Pond complex and the underlying 584 ± 1 Ma subaerial felsic volcanic rocks of the Manuels volcanic suite, west of the Topsail Fault, near Manuels (O'Brien *et al.*, 2001). The age of the base of the Wych Hazel Pond complex, as defined in the same area, is 582 ± 1.5 Ma (Sparkes *et al*., 2005). Thus, the time interval represented by this unconformity is unresolvable within analytical error using U–Pb geochronology. At Manuels, the base of the complex is defined by a localized basal conglomerate overlain by thin-bedded, internally laminated and locally slumped red and green siltstone and interbedded dark-green sandstone.

Previous mapping of the Wych Hazel Pond complex, west of the Topsail Fault by O'Brien *et al*., (2001), recognized three distinct lithofacies: 1) a lower unit of thin-bedded, internally laminated and slumped green and grey and locally red siltstone, sandstone and feldspathic grit, 2) mafic breccias and locally interbedded siliciclastic sediments, and 3) syn-sedimentary feldspar porphyries, locally dated at 585 ± 5 Ma (Sparkes *et al*., 2005).

The new mapping (Figure 2) shows that the above-mentioned lithofacies continue east of the Topsail Fault, where they are associated with several other lithologically distinct units. Generally, sedimentary rocks of the complex east of the Topsail Fault are typically more epidote-rich than those farther west, and display a significant amount of mafic volcanic detritus (Plate 3). At a 1:25 000 scale, the complex has been subdivided into 5 units (G. Sparkes, unpublished data,


**Plate 3.** *Typical volcaniclastic sandstone (Unit 5) of the Wych Hazel Pond complex, containing epidote nodules of a possible volcanic origin.*

2005). For the purposes of simplicity and scale, however, similar rock types have been grouped into three units on the accompanying page-size map (Figure 2). Rhyolites in the north of the map area are tentatively included within the Wych Hazel Pond complex, but further investigation may require their reassignment to older units.

#### *Unit 3*

Several discontinuous belts or elongate domes of rhyolite with well-developed flow banding and localized autobreccia are exposed in the geologically distinctive, extreme northwestern portion of the map area, west of the Long Pond Fault. The rhyolite is weakly to moderately feldspar-phyric, and phenocrysts are supported within a dark purple, to grey-green aphanitic groundmass. These rhyolites closely resemble the flow-banded rhyolite sequence of the Manuels volcanic suite (O'Brien *et al*., 2001), and it is not unrealistic that further data could support their correlation with that suite. Another possibility is correlation with flow-banded rhyolite of the White Mountain volcanic suite. In the region of Cape St. Francis, these rhyolites lie in direct contact with, and underlie, massive and locally pillowed, weakly feldspar-phyric, epidote-rich basalt and associated hyaloclastite deposits of the Wych Hazel Pond complex. The contact between the rhyolite and mafic volcanic rocks is sharp and depositional, without intervening sedimentary material.

#### *Unit 4*

This unit contains two types of basalt that have been grouped as one unit on Figure 2. A hematite-rich pillow basalt division is most prominent of the two, and corresponds in part to flows included in the Princes Lookout Formation (Harbour Main Group) by King (1990). An epidote-rich basalt division is widely developed in the complex west of the study area, west of the Topsail Fault (Sparkes, 2005).

The epidote-rich basalt is dark green, locally feldspar-phyric, massive and locally pillowed, where pillow forms reach 1m in diameter. This basalt sequence is intercalated with a regionally distinctive hyaloclastite unit that consists of irregularly shaped, moderately to highly vesicular, basaltic fragments in a brown to dark green volcaniclastic siltstone to fine-grained sandstone matrix. The epidote-rich basalt is intimately associated with volcaniclastic sandstone facies of Unit 5.

The hematite-rich basalt is readily identified by its dark red-weathering, and the abundance of syn-volcanic, hematite-rich breccia zones that crosscut the basalt. This unit consists of hematite-rich, non- to moderately magnetic, massive to locally pillowed basalt having a locally developed feldspar-phyric texture, containing 1- to 3-mm-long white-weathering feldspar in a dark-green groundmass. The hematite-rich basalt commonly contains rafts of similar siltstone and sandstone facies (Plate 4). West of Grog Pond, this unit is intercalated with variegated sediments containing localized pale green epidote alteration developed along the contact. The hematite-rich basalt is best exposed in an antiform immediately east of Portugal Cove, where it is in sharp contact with overlying sedimentary rocks that are correlated with the Torbay Member of the Conception Group (King, 1990). For this reason, the hematite-rich pillow basalt is viewed as occupying the upper stratigraphic levels of the complex.

The basal Wych Hazel Pond succession west of the Topsail Fault, is not developed in the region around Cape St. Francis, where basalt of the Wych Hazel Pond complex lies directly on rhyolite. However, a similar sedimentary unit is preserved in isolated outcrops elsewhere in the northern portion of the map area, but its isolated nature and faulted contacts makes its stratigraphic position unclear.

In the area south of Birch Hills (Figure 2), sedimentary breccia occurs in close proximity to isolated outliers of red, thinly bedded siltstone and minor interbedded sandstone, which are interpreted to represent the base of the Wych Hazel Pond complex. The presence of rare clasts of crystal-rich ash-flow tuff and rhyodacitic volcanic rocks of the White Mountain volcanic suite in the breccia suggests its original contact with that suite was an unconformity (Plate 5).

***Unit 5***

As depicted on the accompanying map (Figure 2) Unit 5 is a composite unit that includes three main facies. These

**Plate 4.** *Raft of red, thickly laminated siltstone contained within hematite-rich pillow basalt of Unit 4.*

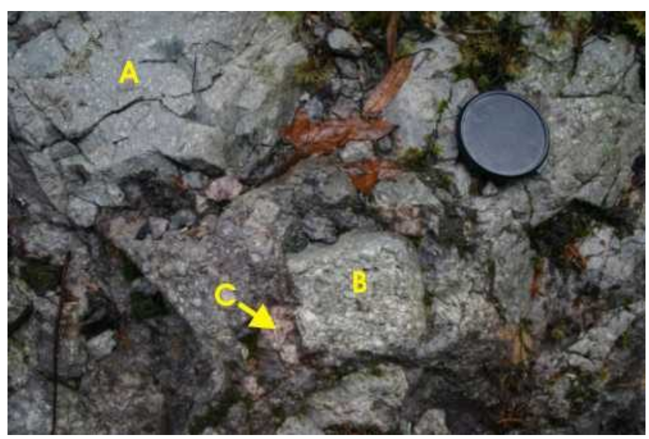


**Plate 5.** *Interpreted basal sedimentary breccia of the Wych Hazel Pond complex. Note the unit contains clasts of feldspar-phyric basalt (A), porphyritic rhyodacite (B), and minor porphyritic intrusive (C).*

are: 1) thin-bedded, internally laminated, locally slumped, variegated red and green siltstone and interbedded dark-green sandstone, 2) brown-weathering, massive, epidote-rich volcaniclastic sandstone , and 3) interbedded thin- to medium-bedded siliceous white-weathering and non-siliceous brown-weathering fine- to medium-grained sandstone.

The variegated siltstone–sandstone facies predominantly occurs in the north of the map area, and is spatially associated with felsic volcanic rocks of the White Mountain volcanic suite. The epidote-rich volcaniclastic sandstone facies occurs mainly in the southern part of the map area, where it is typically associated with minor amounts of unseparated mafic volcanic rocks. The latter are typical of the Unit 4 epidote-rich basalt.

The siliceous sedimentary facies is best exposed between Portugal Cove and Bauline. This unit is predominantly thin to medium bedded and contains interbedded siliceous and non-siliceous sandstone, dark-green siliceous siltstone and minor chert. These rocks were previously assigned to the Portugal Cove Formation (Harbour Main Group) by King (1990) and are host to numerous late Neoproterozoic intrusions.

Unit 5 is in fault contact with most surrounding units, and has been affected by folding and localized thrusting. Major structural boundaries separate the siliceous sedimentary rocks from the hematite-rich pillow basalt to the north of Portugal Cove. The variegated and epidote-rich facies are here interpreted to be intercalated with, and grade laterally into, Unit 4 basalt.

### Herring Cove Diorite (Unit 6)

The Herring Cove diorite (Unit 6) is predominantly hosted within the siliciclastic sedimentary and associated submarine epidote-rich mafic volcanic rocks of the Wych Hazel Pond complex. It is characterized by fine- to medium-grained diorite containing subhedral white feldspar phenocrysts and interstitial dark green minerals, which include chlorite and epidote (Plate 6). The diorite locally contains screens of quartz-K-feldspar-rich granite of the Holyrood Intrusive Suite. The unit is well exposed in the high hills along the eastern coastline of Conception Bay near Bauline, and is bounded to the north by the Long Pond Fault. The Herring Cove diorite is a moderately to strongly magnetic rock; its exposures are locally coincident with regional magnetic highs that form a linear belt along the western coast of the peninsula.

**Plate 6.** *Typical lithology of the intermediate, fine-grained Herring Cove diorite (Unit 6).*

### Horse Cove Complex (Unit 7)

Along the eastern coastline of Conception Bay, the trace of the Topsail Fault is associated with a regional-scale, variably developed high-strain zone, associated with a prominent swarm of mafic and felsic dykes, hosted within submarine volcaniclastic and mafic volcanic rocks of the Wych Hazel Pond complex. The dyke swarm and its host are here collectively designated, in an informal fashion, as the Horse Cove complex (Figure 2). This composite unit corresponds to that shown as St. Phillips Formation (Harbour Main Group) by King (1990). In more northern regions of the map area, mafic and felsic dykes at the margins of the complex are intrusive into the Herring Cove diorite.

The dyke swarm includes feldspar porphyry dykes and multiple generations of mafic dykes (Plate 7). Brown-weathering, epidote-rich, dark green diabase dykes are the

**Plate 7.** *Mafic and felsic dyke swarm of the Horse Cove complex (Unit 7).*

inferred oldest of several within the complex. These are locally crosscut by feldspar porphyry dykes containing 1 to 2 mm, subhedral white feldspar in a purple to grey-green, fine-grained groundmass. The latter are crosscut by feldspar-phyric, epidote-rich mafic dykes, which are, in turn, cut by dark purple, fine-grained, strongly magnetic mafic dykes, inferred to be the youngest intrusions within the complex. All dykes within the complex display sharp intrusive contacts with locally chilled margins. Widths range in size from less than 20 cm to greater than 2 m, and the dykes predominantly trend subparallel to the regional foliation.

The feldspar porphyry dykes of Unit 7 are lithologically indistinguishable from those of the Wych Hazel Pond complex, in particular, the 585 Ma Fowlers Road porphyry of Sparkes *et al.* (2005). A porphyritic rhyolite dyke from the northeastern coast of Conception Bay has a reported U–Pb age of 585 Ma (Krogh *et al*., 1988), similar to that obtained from the Fowlers Road porphyry (Sparkes *et al*., 2005). Locally, the Horse Cove complex contains rare screens of flow-banded rhyolite and rare granitic dykes, the latter may have a co-genetic relationship with the feldspar porphyry. The eastern boundary of this unit is gradational, and is marked by the development of mafic and felsic dykes; the western boundary is unexposed and is interpreted to correspond with the trace of the Topsail Fault.

### Conception Group (Units 8 and 9)

Rocks assigned to the late Neoproterozoic Conception Group lie east of the volcano-sedimentary rocks. Only the westernmost part of the group was investigated during this study; in the area mapped, the following units (in ascending stratigraphic order) were noted: Broad Cove River, Bauline Line, Torbay and Mannings Hill members (cf. King, 1990). On the accompanying map (Figure 2), the Broad Cove River Member has been grouped together with the Torbay and Mannings Hill members, and all are designated collectively as Unit 9. The narrow but regionally continuous and lithologically distinctive mixtite-bearing Bauline Line Member is separated and shown as Unit 8. These units and their contact relationships are described in detail in King (1990), and thus need only a brief description here. The detailed distribution of each of these Conception Group units in the study area will be presented elsewhere (G. Sparkes, unpublished data, 2005). The Conception Group sediments contrast with those elsewhere in the succession in that they contain less mafic detritus, are not interbedded with mafic volcanic rocks, and are not intruded by syn-sedimentary feldspar porphyry dykes.

The basal contact of the Conception Group is not exposed within the field area. The lowest stratigraphic unit is represented by the Broad Cove River Member. This unit typically consists of medium- to thick-bedded dark-green to grey sandstone and interbedded laminated to thin-bedded, dark-green siltstone. The unit also contains rare, dark-red, silty beds and a distinctive, thick-bedded, dark-green chert.

The Torbay Member lies in gradational contact above the Broad Cove River facies, and is characterized by thin- to medium-bedded, dark grey-green silty sandstone having discontinuous lenses of buff- to brown-weathering, medium-grained sandstone. In the Portugal Cove area, thin- to medium-bedded siliceous siltstone and interbedded sandstone are correlated with the Torbay Member (King, 1990). These siliceous sedimentary rocks, which are in sharp contact with the hematite-rich basalt, closely resemble siliceous sedimentary rocks of the Wych Hazel Pond complex that are exposed near Portugal Cove. The Torbay Member and other sedimentary rocks of the Conception Group are separated from the Wych Hazel Pond complex by a fault.

The Bauline Line Member is a variegated mixtite that consists of subrounded to rounded pebble- to cobble-size clasts within a green to red siltstone to fine-grained sandstone matrix. This unit, which has been interpreted as having a glaciogenic origin (King, 1990), contains clasts of dark-purple rhyolite, granite and other presumably intrabasinal sedimentary material. The Bauline Line Member is interpreted to pass vertically and laterally into sediments of the Torbay Member (King, 1990). Recent construction work in the Topsail area has uncovered new outcrop that significantly increased the southern extent of this unit, which can now be traced as far south as Topsail Head.

Conformably overlying the Torbay Member are thick siliceous sandstone beds of the Mannings Hill Member. This unit contains interbedded dark-green chert, and minor discontinuous lenses of dark-green siltstone. It represents the highest stratigraphic unit exposed within the field area.

### Beaver Hat Intrusive Suite (Unit 10)

A suite of massive, fine-grained gabbroic plugs, dykes and plutons, assigned here to the newly defined and informally named Beaver Hat intrusive suite (Unit 10) occurs throughout the map area. This unit represents the youngest known intrusive event within the region, crosscutting sedimentary rocks as young as the Mannings Hill Member of the Conception Group, subsequent to their deformation. The intrusions typically form dykes and small isolated bodies, ranging in width from several metres up to ~1 km. Inland boundaries are typically unexposed, but where observed, the contact is sharp and irregular.

This unit is typically dark-green, fine- to medium-grained, chlorite-rich gabbro that contains minor disseminated pyrite. Locally, the unit displays well-developed magmatic layering, however such textures have only been observed on well-exposed coastal sections. Metre-scale, fine-grained gabbroic dykes included in the suite have sharp, relatively straight intrusive contacts with the surrounding units. Intrusions included within the unit are most abundant in the region immediately north of Portugal Cove, where they are emplaced into folded sedimentary rocks of the Wych Hazel Pond complex; these cannot be separated from the surrounding sediments at 1:25 000 scale mapping.

Mafic intrusive rocks similar to this suite have been previously identified in the Manuels area south to the Thousand Acre Marsh (Sparkes *et al*., 2005), and in the southern portion of the present map area where they have been assigned to the Dogberry Hill Gabbro (King, 1990). Broadly similar intrusions comprise the Whalesback gabbro (Williams and King, 1979), a series of small plutons emplaced into the Conception Group between the southernmost Avalon Peninsula and the Butlers Pond area (Sparkes *et al*., 2002). On the scale of the eastern Avalon Peninsula, these intrusions share a spatial association with not only zones of high strain, but also the regional trace of the Topsail Fault.

## NOTES ON REGIONAL DEFORMATION

In the area to the west of the Topsail Fault, the late Neoproterozoic volcanic and sedimentary rocks typically lack the development of a strong penetrative fabric, excluding areas where they are affected by advanced argillic alteration. The structural character of the same rocks in the region east of the Topsail Fault differs from that observed farther west, and reflects a more compressional environment with the development of regional-scale folding and eastward-directed thrusting (King, 1990). Regional-scale thrusts in this area have been inferred to be Late Proterozoic in age and are attributed to the same deformation that caused similar folding and thrusting in the nearby Flat Rock area (Calon, 2005).

### THRUST FAULTS AND FOLDS

Thrusting of sedimentary rocks here assigned to the Wych Hazel Pond complex over the Conception Group has been previous documented by King (1990) and Smith (1987). Smith stated that thrusting was either synchronous with, or postdated the development of broad open folds within siliceous sedimentary rocks here mapped as Wych Hazel Pond complex. Similar thrusts have been mapped in the region west of the Pouch Cove River Fault, where felsic volcanic rocks of the White Mountain volcanic suite are thrust eastward, over sedimentary rocks of the Wych Hazel Pond complex (Figure 2). Steeper faults with an inferred reverse sense of motion include the Shoe Cove Fault (King, 1990), which acts as the eastern boundary of closely spaced reverse faulting and strong north- to northeast-trending penetrative fabric.

Although most of the sedimentary sequence comprising the Wych Hazel Pond complex dips steeply to the northwest, several metre-scale synform and antiform structures were mapped. In the area of Cape St. Francis, metre-scale east-verging asymmetric folds attributed to eastward-directed thrusting, are developed within sedimentary rocks of the Conception Group, and are crosscut by the Beaver Hat intrusive suite. Tight, metre-scale chevron folds were also locally observed in the hanging wall of thrusts developed in the region west of Pouch Cove.

### ZONES OF HIGH-STRAIN DEFORMATION

A moderate to strong and penetrative northeast-trending regional foliation is developed subparallel to the Topsail Fault affecting rocks up to 3.5 km from the fault. This foliation locally develops into a regionally extensive, high-strain zone that is well developed along the eastern coastline of Conception Bay. The strain is attributed to deformation along the regional boundary that is mapped as the Topsail Fault (e.g., Rose, 1952; King, 1988). Some elements of the deformation associated with this structure have affected rocks as young as Early Middle Cambrian (Boyce and Hayes, 1991). Other elements may well be older. The relationship of high-strain deformation in the dyke swarm to cleavage associated with thrusting is at present uncertain.

Historically, the Topsail Fault has been characterized by oblique-slip motion with an important reverse slip component (Rose, 1952). The throw on this fault has been estimated between 7 to 10 km, with the down thrown side to the west (Miller, 1983). Recent mapping within and adjacent to the Topsail Fault identifies a complex history that includes dextral, sinistral and reverse senses of motion. Numerous shear sense indicators such as kink bands, structurally rotated xenoliths and pinch-and-swell structures provide evidence for both vertical and horizontal motion along the high-strain zone described above.

The major structural boundaries separating geological units along the east coast of Conception Bay have a predominant northeast trend and have been interpreted to represent splays of the main regional Topsail Fault (e.g., Pouch Cove River Fault, Shoe Cove Fault; King, 1990). The predominant trend of the major fault systems is also evident in the distribution of geological units, which are often elongated along a northeast–southwest trend.

## LATE BRITTLE STRUCTURES

Late east–west brittle faults are also developed within the map region. These faults often form prominent air photo lineaments, and commonly display a sinistral sense of motion. One such fault is the Portugal Cove–Windsor Lake Fault (King, 1990), which offsets the northeast-trending belt of basaltic rocks in the Portugal Cove area. The east–west faults postdate the development of the east-directed thrusting, however, it's uncertain whether these faults represent a late stage of the folding event or if, in fact, they are related to a completely separate period of deformation.

## LIMITS TO THE AGE OF DEFORMATION

Similar style folding and east-directed thrusting have been documented at Flat Rock, approximately 4 km east of the map area. In that region, east-verging asymmetric folds and associated east-directed thrusting appear to be similar to that observed along the eastern coast of Conception Bay. The deformation within the Flat Rock region has been attributed to the late Neoproterozoic Avalonian Orogeny, where it is interpreted to be associated with the formation of "syn-growth strata", represented by the upper Neoproterozoic sedimentary rocks of the Signal Hill Group (Calon, 2005).

Smith (1987) described fine-grained mafic intrusions, herein recognized as part of a regionally developed suite of hypabyssal intrusions (Beaver Hat intrusive suite), emplaced subparallel to fold hinges in the late Neoproterozoic sediments at Portugal Cove during deformation. The new regional mapping north of the Portugal Cove region, however, has demonstrated a number of instances where the hinges of folds affecting Neoproterozoic units are crosscut by similar fine-grained gabbroic dykes assigned to this suite. At Cape St. Francis, intrusions of the same suite cut obliquely across folds and thrusts in late Neoproterozoic sandstones of the Conception Group (Plate 8), indicating that magmatism postdates that deformation.

**Plate 8.** *East-verging folds developed within sedimentary rocks of the Conception Group. Folds are crosscut by a fine-grained mafic intrusive of the Beaver Hat intrusive suite.*

It is clear that the emplacement of the Beaver Hat intrusive suite provides the minimum limit for this deformation, which has a currently defined maximum limit of 582 Ma (age of the base of the Wych Hazel Pond complex, west of the Topsail Fault). Samples for U–Pb geochronology have been collected in order to establish a minimum limit for the deformation.

In the area immediately west of the Topsail Fault, where Cambrian strata unconformably overlie deformed 585 Ma and later Neoproterozoic rocks (O'Brien, 2002), narrow, discrete zones of pre-Cambrian deformation and post-Cambrian deformation have been documented (O'Brien, 2002; Sparkes *et al*., 2005; Sparkes, 2005). At Topsail Beach, along the trace of the Topsail Fault as defined by Rose (1952) and King (1988), Lower to Middle Cambrian shales (Rose, 1952; Boyce and Hayes, 1991) host a penetrative cleavage. It is unclear, however, which, if any, of the elements of the deformation adjoining the Topsail Fault (e.g., the aforementioned high-strain zone) is associated with the Paleozoic (or younger) movement that is recorded in the shales.

# MINERALIZATION

Some of the most prominent mineralization developed within the map area are pyritic gossan zones associated with the high-strain zone developed along the trace of the Topsail Fault. These zones, which consist of up to 10 percent disseminated pyrite, occur in several areas along the eastern coastline of Conception Bay (Figure 2) to the southern limit of the map area and beyond. The gossan zones are predominantly hosted within the Horse Cove complex. Based on considerations and correlations presented above (*see* Horse Cove complex), intrusions that host the pyritic gossan mineralization, postdate the development of the high-sulphidation epithermal system in the nearby Manuels area. Therefore, the pyrite in the gossans is unrelated to that in the silica-pyrite alteration associated with the latter epithermal system, and is likely to be structurally related.

The area does host a more subtle style of mineralization that bears strong similarities to the precious metal-bearing epithermal systems west of the Topsail Fault. Low-sulphidation-style epithermal veins at the Grog Pond prospect were first discovered by Basha (2001). These Au-bearing veins (up to 10 g/t, B. Sparkes, written communication, 2005) are hosted within crystal-rich ash-flow tuff of the White Mountain volcanic suite and represent the northern continuance of low-sulphidation-style veining in the eastern Avalon Peninsula. In this region, the epithermal veins have a broad stockwork-style distribution, and have average vein widths of less than 15 cm. The veins are identified by “waxy” pale-grey to brown chalcedonic silica that occurs with dark-red hematite and rare adularia (Plate 9). Locally, veins are associated with the development of a “chalky” kaolinite alteration along vein margins.

Like the Bergs and Steep Nap low-sulphidation gold prospects near Manuels, the low-sulphidation veins at the Grog Pond prospect occur in close proximity to the Holyrood Intrusive Suite. Although such intrusive rocks may play a mechanical role in siting vein development in the adjacent volcanic rocks (O’Brien, 2002; Sparkes *et al*., 2005), the granites themselves do not support vein development at Grog Pond.

Several areas of silica-hematite ± pyrite alteration have been identified within the felsic volcanic rocks (Unit 1) and associated granite intrusion (Unit 2) south of Grog Pond, but no other occurrences of low-sulphidation-style epithermal veins were noted.

Localized zones of anomalous gold (up to 1.4 g/t) have been identified in the Cape St. Francis area, in association with silica-pyrite alteration around the margin of the Unit 3 flow-banded rhyolite domes (Chislett, 1989; Rennie and de Carle, 1989). Rare, waxy chalcedonic silica veins are also developed within the same flow-banded rhyolite, but these are apparently barren. At this point it is unclear whether the silica-pyrite alteration and associated gold mineralization is associated with the regionally developed low-sulphidation system, or if it is related to a separate mineralizing event.

Other fault-related epigenetic mineral occurrences are associated with the fault contact between the Wych Hazel Pond complex and the Conception Group. Several small pyrite–chalcopyrite–galena occurrences have been identified in the sedimentary rocks of the Wych Hazel Pond complex and those of the adjacent Conception Group. Recent mineral exploration by Rubicon Minerals Corporation has also identified quartz veins with chalcopyrite, galena and greenockite in float near Funnel Pond, west of the Bauline Line Extension. These quartz veins are hosted within the hematite-rich basalt (Unit 5) of the Wych Hazel Pond complex. Weak epidote and K-feldspar wall-rock alteration is developed adjacent to the veins. These veins locally contain up to 2.8 g/t Au (B. Sparkes, written communication, 2005). Similar style quartz veins in the same area are cored by pale-grey chalcedonic silica, which may suggest that this occurrence may be related to the regional epithermal system.

**Plate 9.** *Low-sulphidation veins of the Grog Pond prospect contained within crystal-rich ash-flow tuff of the White Mountain volcanic suite.*

## SUMMARY AND CONCLUSIONS

1) Several well-defined, regionally extensive geological units mapped west of the Topsail Fault, and fundamental components of the Holyrood Horst, can be traced across the fault from the area of Topsail Head, north to Cape St. Francis. These include subaerial felsic volcanic rocks of the pre-620 Ma White Mountain volcanic suite, granite of the 625 to 620 Ma Holyrood Intrusive Suite, and volcano-sedimentary rocks of the 580 Ma and younger Wych Hazel Pond complex.

2) The lithology of the Holyrood Intrusive Suite and adjacent White Mountain volcanic suite rocks closely match that seen in the Holyrood Horst. Facies in the younger Wych Hazel Pond complex, however, are more diverse east of the Topsail Fault. The presence of White Mountain volcanic suite clasts in sedimentary breccias near the base of the younger Wych Hazel Pond complex implies their contact – now tectonic – was originally depositional (and an unconformity).

3) The Wych Hazel Pond complex contains two distinct basaltic successions, a lower epidote-rich unit associated with the regional development of a hyaloclastite unit and a stratigraphically higher hematite-rich basalt. Further work is required to determine if the two successions are geochemically separable.

4) The map area records multiple post-620 Ma intrusive events, many or most of which are not exposed west of the Topsail Fault. Mafic and intermediate to felsic magmatism was sited along the trace of the Topsail Fault, first as focused dyke swarms at about 580 Ma, along the precursor to (or active site of) a major high-strain zone. Subsequent activity is recorded by mafic magmas emplaced into a broader belt paralleling the fault, and intruded into rocks as young as the Conception Group, subsequent to their deformation.

5) Folding and associated thrusting is well developed in the Wych Hazel Pond complex in the area of Portugal Cove and in the region west of Pouch Cove. Based on correlation with tectonic history in the Flat Rock area to the east (Calon, 2005), this deformation is tentatively attributed to the late Neoproterozoic tectonism. The maximum age of these structures is provided by the 582 Ma age from tuffs at the base of the Wych Hazel Pond complex.

6) The presence of low-sulphidation-style, gold-bearing chalcedonic silica veins in subaerial volcanic rocks of the White Mountain volcanic suite east of the Topsail Fault provides further evidence for the wide-spread development of the late Neoproterozoic epithermal system. The close proximity of mineralized veins to Holyrood Intrusive Suite, matches the setting seen elsewhere in the eastern Avalon Peninsula, and highlights the rocks adjacent to the margin of older intrusions as regional prospecting targets.

7) The intrusion of the Herring Cove diorite may represent a heat source to drive the late Neoproterozoic (580 Ma or younger; Sparkes *et al.*, 2005), low-sulphidation epithermal system, seen at Grog Pond and other areas along the east margin of the Holyrood Horst. Other known magmatism in the region is either too old or, apparently, too young.

8) Emplacement of the Beaver Hat intrusive suite is the youngest regional intrusive event within the map area, postdating the development of folding and east-directed thrusting. Samples of this unit have been collected for U–Pb dating in order to establish a new minimum time limit to the regional post-582 Ma deformation, and test the hypothesis that deformation is Neoproterozoic in age and related to the development of the Flat Rock Thrust and related structures in the eastern Avalon Peninsula.

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