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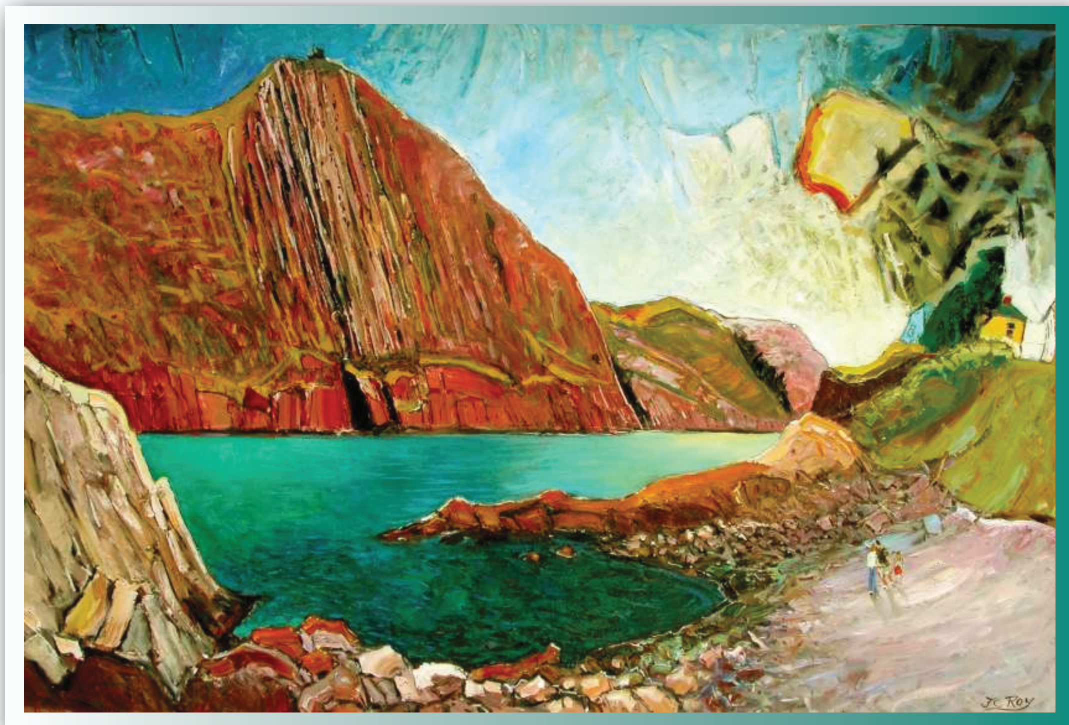

Jean Claude Roy, *Signal Hill from Fort Amherst*, oil on canvas / huile sur toile, 48" x 72", 2006

FIELD TRIP GUIDEBOOK - A5

NEOPROTEROZOIC EPITHERMAL GOLD MINERALIZATION OF THE NORTHEASTERN AVALON PENINSULA, NEWFOUNDLAND

Leaders: Sean J. O'Brien, Gregory W. Sparkes, Greg Dunning, Benoît Dubé and Barry Sparkes

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FIELD TRIP GUIDEBOOK – A5

NEOPROTEROZOIC EPITHERMAL GOLD MINERALIZATION OF THE NORTHEASTERN AVALON PENINSULA, NEWFOUNDLAND

FIELD TRIP LEADERS

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SAFETY INFORMATION

General Information

The Geological Association of Canada (GAC) recognizes that its field trips may involve hazards to the leaders and participants. It is the policy of the Geological Association of Canada to provide for the safety of participants during field trips, and to take every precaution, reasonable in the circumstances, to ensure that field trips are run with due regard for the safety of leaders and participants. GAC recommends steel-toed safety boots when working around road cuts, cliffs, or other locations where there is a potential hazard from falling objects. GAC will not supply safety boots to participants. Some field trip stops require sturdy hiking boots for safety. Field trip leaders are responsible for identifying any such stops, making participants aware well in advance that such footwear is required for the stop, and ensuring that participants do not go into areas for which their footwear is inadequate for safety. Field trip leaders should notify participants if some stops will require waterproof footwear.

The weather in Newfoundland in May is unpredictable, and participants should be prepared for a wide range of temperatures and conditions. Always take suitable clothing. A rain suit, sweater, and sturdy footwear are essential at almost any time of the year. Gloves and a warm hat could prove invaluable if it is cold and wet, and a sunhat and sunscreen might be just as essential. It is not impossible for all such clothing items to be needed on the same day.

Above all, field trip participants are responsible for acting in a manner that is safe for themselves and their co-participants. This responsibility includes using personal protective equipment (PPE) when necessary (when recommended by the field trip leader or upon personal identification of a hazard requiring PPE use). It also includes informing the field trip leaders of any matters of which they have knowledge that may affect their health and safety or that of co-participants. Field Trip participants should pay close attention to instructions from the trip leaders and GAC representatives at all field trip stops. Specific dangers and precautions will be reiterated at individual localities.

Specific Hazards

Some of the stops on this field trip are in coastal localities. Access to the coastal sections may require short hikes, in some cases over rough, stony or wet terrain. Participants should be in good physical condition and accustomed to exercise. The coastal sections contain saltwater pools, seaweed, mud and other wet areas; in some cases it may be necessary to cross brooks or rivers. There is a strong possibility that participants will get their feet wet, and we recommend waterproof footwear. We also recommend footwear that provides sturdy ankle support, as localities may also involve traversing across beach boulders or uneven rock surfaces. On some of the coastal sections that have boulders or weed-covered sections, participants may find a hiking stick a useful aid in walking safely.

Coastal localities present some specific hazards, and participants MUST behave appropriately for the safety of all. High sea cliffs are extremely dangerous, and falls at such localities would almost certainly be fatal. Participants must stay clear of the cliff edges at all times, stay with the field trip group, and follow instructions from leaders. Coastal sections elsewhere may lie below cliff faces, and participants must be aware of the constant danger from falling debris. Please stay away from any overhanging cliffs or steep faces, and do not hammer any locations immediately beneath the cliffs. In all coastal localities, participants must keep a safe distance from the ocean, and be aware of the magnitude and reach of ocean waves. Participants should be aware that unusually large "freak" waves present a very real hazard in some areas. If you are swept off the rocks into the ocean, your chances of survival are negligible. If possible, stay on dry sections of outcrops that lack any seaweed or algal deposits, and stay well back from the open water. Remember that wave-washed surfaces may be slippery and treacherous, and avoid any area where there is even a slight possibility of falling into the water. If it is necessary to ascend from the shoreline, avoid unconsolidated material, and be aware that other participants may be below you. Take care descending to the shoreline from above.

Other field trip stops are located on or adjacent to roads. At these stops, participants should make sure that they stay off the roads, and pay careful attention to traffic, which may be distracted by the field trip group. Participants should be extremely cautious in crossing roads, and ensure that they are visible to any drivers. Roadcut outcrops present hazards from loose material, and they should be treated with the same caution as coastal cliffs; be extremely careful and avoid hammering beneath any overhanging surfaces.

The hammering of rock outcrops, which is in most cases completely unnecessary, represents a significant "flying debris" hazard to the perpetrator and other participants. For this reason, we ask that outcrops not be assaulted in this way; if you have a genuine reason to collect a sample, inform the leaders, and then make sure that you do so safely and with concern for others. Many locations on trips contain outcrops that have unusual features, and these should be preserved for future visitors. Frankly, our preference is that you leave hammers at home or in the field trip vans.

Subsequent sections of this guidebook contain the stop descriptions and outcrop information for the field trip. In addition to the general precautions and hazards noted above, the introductions for specific localities make note of specific safety concerns such as traffic, water, cliffs or loose ground. Field trip participants must read these cautions carefully and take appropriate precautions for their own safety and the safety of others.

INTRODUCTION

Welcome to Newfoundland!

Welcome to GAC-MAC St. John's 2012. This field trip will explore part of the Neoproterozoic Avalonian Belt, which represents a portion of the Newfoundland Appalachians. The Avalonian volcano-plutonic terrane hosts numerous examples of well-preserved, late Neoproterozoic, high- and low-sulphidation-style epithermal systems, representing some of the largest metamorphosed, precious-metal-bearing epithermal systems in Canada.

These hydrothermal systems formed within an extensive late Neoproterozoic orogenic system, vestiges of which are preserved within the younger Appalachian–Caledonian and Variscan orogens throughout the North Atlantic borderlands. Magmatism, sedimentation and tectonism related to this Avalonian cycle pre-date much of the Appalachian Wilson cycle of opening and closing of the Paleozoic Proto-Atlantic (Iapetus) Ocean. The older tectonic events are in part linked to the development of the extensive Pan African orogenic system.

The Avalonian Belt chronicles the development of magmatic arcs and intervening marine to terrestrial basins that evolved at an active plate margin peripheral to the ancient continent of Gondwana between *ca.* 800 and 540 Ma. The rocks of the Avalonian Belt record the complex, episodic and protracted development and dispersal of segments of a Neoproterozoic orogenic system that, in part, was analogous in scale and tectonic setting to present-day Pacific Rim magmatic arcs, including the Andean Belt. Importantly, large-scale precious-metal bearing hydrothermal systems developed at several times during the formation of the Avalonian Belt.

Neoproterozoic Hydrothermal Systems in the North American Avalonian Belt

The defining Proterozoic characteristic of the Avalonian Belt, both within and outside the confines of the Appalachian Orogenic Belt, is widespread magmatic activity, most notably between 640 and 560 Ma. In this period, extensive magmatic arcs developed in a variety of arc and back-arc or analogous continental extensional settings. Construction of these volcano-plutonic arcs coincided with, and was succeeded by, the accumulation of marine through terrestrial siliciclastic sediments in basins of variable dimensions, setting, complexity and age.

Many of the magmas generated at this time rose to high crustal levels and vented onto the surface as subaerial, caldera-facies, volcanic complexes. In some cases, cooling and degassing of these magmas resulted in establishment of large-scale hydrothermal convective systems active at high levels in the crust. The resultant hydrothermal alteration was locally accompanied by the deposition of gold, with or without silver and copper, in a variety of volcanic, sedimentary, hypabyssal and plutonic settings.

The North American Avalonian Belt hosts many examples of Neoproterozoic gold-bearing systems belonging to the epithermal and associated intrusion-related clans of lode-gold deposits (*see* Dubé *et al.*, 2001). The best-documented Neoproterozoic Avalonian gold deposits are the Hope Brook Mine (Au–Cu) in Newfoundland, and the Brewer (Au–Cu), Hail, Ridgeway and Barite Hill gold mines in northern South Carolina (Figure 1; *see* O'Brien *et al.*, 1998 and references therein). Together, they contain a total gold resource in excess of 5,000,000 ounces.

The Hope Brook and Brewer mines represent well-documented examples of metamorphosed, high-sulphidation-type epithermal systems (*see* Dubé *et al.*, 1998; Scheetz *et al.*, 1991). Similar alteration systems occur in other parts of the Avalonian Belt, most notably in the northern Burin Peninsula, southeastern Newfoundland. Barite Hill represents a possible example of a high-sulphidation-style, gold-rich VMS deposit. The style of mineralization at Ridgeway and Hail mines is more equivocal, and both syn-metamorphic and metamorphosed epithermal origins have been argued for these deposits. Both share a number of features with non-carbonate stockwork-disseminated mineralization, and they may correspond to relatively deeper, intrusion-related systems (*see* O'Brien *et al.*, 1998). Some local remobilization and enrichment of Neoproterozoic mineralization may have occurred during Paleozoic tectonism of the Avalonian Belt, particularly in the Carolinas. To date, classic low-sulphidation-style epithermal systems have only been identified within Avalonian rocks of Newfoundland. The Steep Nap prospect, in southeastern Newfoundland, is an excellent example of a late Neoproterozoic low-sulphidation colloform quartz–adularia Au–Ag vein system (Mills *et al.*, 1999).

Examples of porphyry-style mineralization in the Avalonian Belt are rare, and occur mainly in eastern Canada. Although no major Avalonian porphyry deposits are known, the presence of porphyry-style or porphyry-related mineralization in several prospects (*e.g.*, Butler's Pond, Lodestar, Conns Pond in Newfoundland; Coxheath, in Nova Scotia) and the widespread development of high-sulphidation systems in spatially associated volcanic rocks,

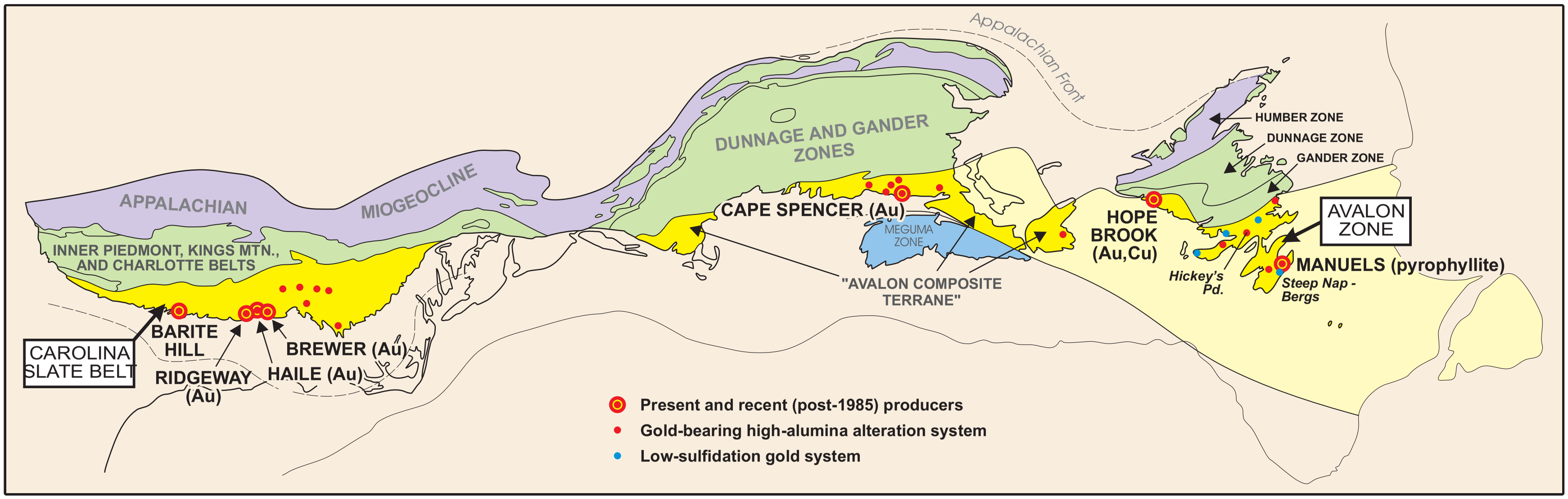

Figure 1. *Distribution of Avalonian rocks within the Appalachian Orogen (modified from O'Brien* et al., *1999a; base map modified from William and Hatcher, 1983).*

argue that porphyry-style mineralization is a potential exploration target in the Avalonian Belt (O'Brien *et al.*, 1999b, 2000).

Hydrothermal alteration and precious-metal mineralization within the North Atlantic Avalonian Belt typically occur in the upper parts of thick volcanic piles, close to the boundary with overlying Neoproterozoic siliciclastic rocks, and near the intrusive contacts with high-level comagmatic plutonic suites. Their position, relative to overlying sedimentary packages, may reflect their formation during waning volcanic activity, at which time the fossil hydrothermal systems could reach maturity without disruption by subsequent magmatic pulses.

Finally, the presence within the Avalonian Belt of large-scale advanced argillic alteration at the interface between subaerial felsic volcanic rocks and shallow marine to terrestrial volcanogenic sedimentary rocks suggests that environments conducive to the formation of Au-rich, high-sulphidation-style VMS deposits may also be preserved. Polymetallic base-metal mineralization in shallow marine successions adjacent to high-sulphidation epithermal belts in Newfoundland (*e.g.*, Peter Snout, Pastureland Road) may illustrate such potential for Au-rich VMS systems (Dubé *et al.*, 2001).

GEOLOGY AND MINERALIZATION

Avalonian-cycle Neoproterozoic Epithermal and Intrusion-related Gold Systems

The formation and preservation of precious-metal bearing epithermal and intrusion-related systems are integral aspects of the late Neoproterozoic tectonic history of the volcano-plutonic arc complexes that characterize the Avalonian and related accreted peri-Gondwanan terranes of the eastern Appalachians (*see* review papers *in* Nance and Thompson, 1996). These Neoproterozoic high-sulphidation-, low-sulphidation- and intrusion-related gold systems are linked to Avalonian-cycle magmatic pulses that pre-date much of the Appalachian Wilson cycle of opening and closure of the Paleozoic Proto-Atlantic (Iapetus) Ocean (*see* O'Brien *et al.*, 1983). These gold systems formed in a once-contiguous, Pan-African-cycle orogenic belt, composed of complex assemblages of 760 to 540 Ma calc-alkaline to alkaline arcs and intervening marine and terrestrial siliciclastic sedimentary basins. Accretion of the mineralized arcs to the inboard elements of the Appalachian Orogenic Belt occurred primarily in the Silurian and Devonian, at which time the Cambro-Ordovician Iapetus Ocean and its marginal basins were closed (*see* Williams, 1979 and reviews *in* Williams *et al.*, 1995).

Gold in the Neoproterozoic high-sulphidation systems occurs with copper in vuggy silica and in breccias and/or network fracture systems, within zones of polyphase silicic replacement, enveloped by regionally developed (metamorphosed) zones of quartz–pyrophyllite–andalusite–alunite-bearing advanced argillic alteration (Dube *et al.*, 1998; O'Brien *et al.*, 1999a). In other instances, regionally developed (and apparently barren) pyrophyllite–diaspore-bearing advanced argillic alteration zones, related to either weakly developed or deeply eroded high-sulphidation systems, are juxtaposed with younger Neoproterozoic low-sulphidation colloform–crustiform banded, silica–adularia vein and breccia systems that contain significant gold grades. Several of the epithermal belts are spatially associated with breccia-hosted Cu–Au (*e.g.*, Butlers Pond) and Au–Cu–Zn mineralization; however, most of this intrusion-related gold mineralization formed during demonstrably earlier magmatic events (Sparkes *et al.*, 2002; O'Brien *et al.*, 2000, 2005).

Large tracts of the mineralized Avalonian belt became submerged by the end of the Proterozoic and remained so through the early Paleozoic, until its accretion to North America in Late Silurian–Devonian times. Where the Avalonian rocks are far removed from the Appalachian Central Mobile Belt, Neoproterozoic low-sulphidation mineralization is exceptionally well preserved. Deeper and more extensively tectonized high-sulphidation systems are preserved in areas that were more strongly affected by Paleozoic deformation on the Burin Peninsula, and also within the Appalachian Central Mobile Belt in the Hermitage Flexure region of southern Newfoundland, respectively (*e.g.*, Dubé *et al.*, 1998, O'Brien *et al.*, 1999a). Early tilting of the mineralized successions and subsequent rifting, collapse and marine incursions, during late Neoproterozoic through Early Paleozoic break-up and dispersal of the Avalonian belt, reduced the scale and rate of erosion of mineralized successions, favouring their preservation through time (*e.g.*, Dubé *et al.*, 1998, O'Brien *et al.*, 2005). The recognition of the geochemical, mineralogical and textural signatures of modern high- and low-sulphidation epithermal systems in these deformed rocks allows the distinction from mainly younger, shear-zone related (*e.g.*, orogenic) gold systems formed at deeper crustal levels, within the Paleozoic orogenic hinterland.

(Note: General reviews of the geology of the Avalonian rocks can be found in O'Brien et al.*, 1990, 1996 and Williams* et al.*, 1995; further details of their precious metal systems are given in O'Brien, 2002; O'Brien and Sparkes 2004; O'Brien* et al.*, 1998, 1999a, b, 2001; Dubé* et al.*, 1998, 2001; Mills* et al.*, 1999; Sparkes* et al.*, 2002, 2005; Hinchey* et al.*, 2000; O'Driscoll* et al.*, 2001).*

The Eastern Avalon Holyrood Horst

The distribution of geological units within the central portion of the eastern Avalon Peninsula is largely controlled by an area of regional uplift (Figure 2) known as the Holyrood Horst (McCartney, 1969; O'Brien *et al.*, 2001). This north-south trending structure plunges toward the south and is dominated by the regionally extensive, *ca.* 620 Ma Holyrood Intrusive Suite at its core (King, 1988). Plutonic rocks related to the Holyrood Intrusive Suite were historically interpreted to be broadly coeval and comagmatic with the surrounding volcanic rocks, known as the Harbour Main Group, which dominate the remainder of the horst structure (O'Brien *et al.*, 1997 and references therein). However, further geochronological studies within the area have identified the existence of several sequences of volcanic and associated volcaniclastic sedimentary rocks ranging in age from 730 to 580 Ma (Figure 2; O'Brien *et al.*, 2001). O'Brien *et al.* (2001) further subdivided the Harbour Main Group into six main subdivisions; in decreasing age they are: Hawke Hill Tuff (*ca.* 730 Ma), Triangle Andesite, Peak Tuff, Blue Hill Basalt, Manuels Volcanic Suite (*ca.* 580 Ma) and the Wych Hazel Pond Complex. The plutonic and volcanic rocks within the core of the horst structure are flanked by a sequence of Neoproterozoic marine, deltaic and fluviatile siliciclastic sedimentary rocks, disposed symmetrically around the older core, and shoaling upwards (*e.g.*, Wych Hazel Pond, Conception, and St. John's groups; Rose, 1952; King, 1988; O'Brien *et al.*, 2001). The Neoproterozoic volcanic, plutonic and sedimentary rocks are unconformably overlain by a fossiliferous, shale-rich, Cambrian to earliest Ordovician cover sequence, exposed around Conception Bay (Figure 3). Prior to the deposition of the Cambrian platformal sedimentary cover sequence, the underlying rock units were subjected to inhomogeneous deformation, low-grade metamorphism, uplift and erosion.

The Horst structure is somewhat asymmetric based on current knowledge and geochronological data, with the majority of the older volcanic rocks exposed along its western margin. Along the eastern margin of the horst, plutonic rocks correlated with the Holyrood Intrusive Suite are juxtaposed with and locally intrude a bimodal volcanic suite consisting of predominantly subaerial felsic volcanic rocks (Figure 3). These volcanic rocks contain an extensive zone of advanced argillic alteration, approximately 15 km in length and up to 1 km in width (Figure 4), referred to as the eastern Avalon high-alumina belt (Hayes and O'Driscoll, 1990). This belt of alteration is host to the local development of pyrophyllite–diaspore high-sulphidation-style epithermal alteration (Papezik and Keats, 1976; Papezik *et al.*, 1978; Hayes and O'Driscoll, 1990; O'Brien *et al.*, 1998). The pyrophyllite deposits have produced commercially on an intermittent basis. In the mid 1990's the iden-

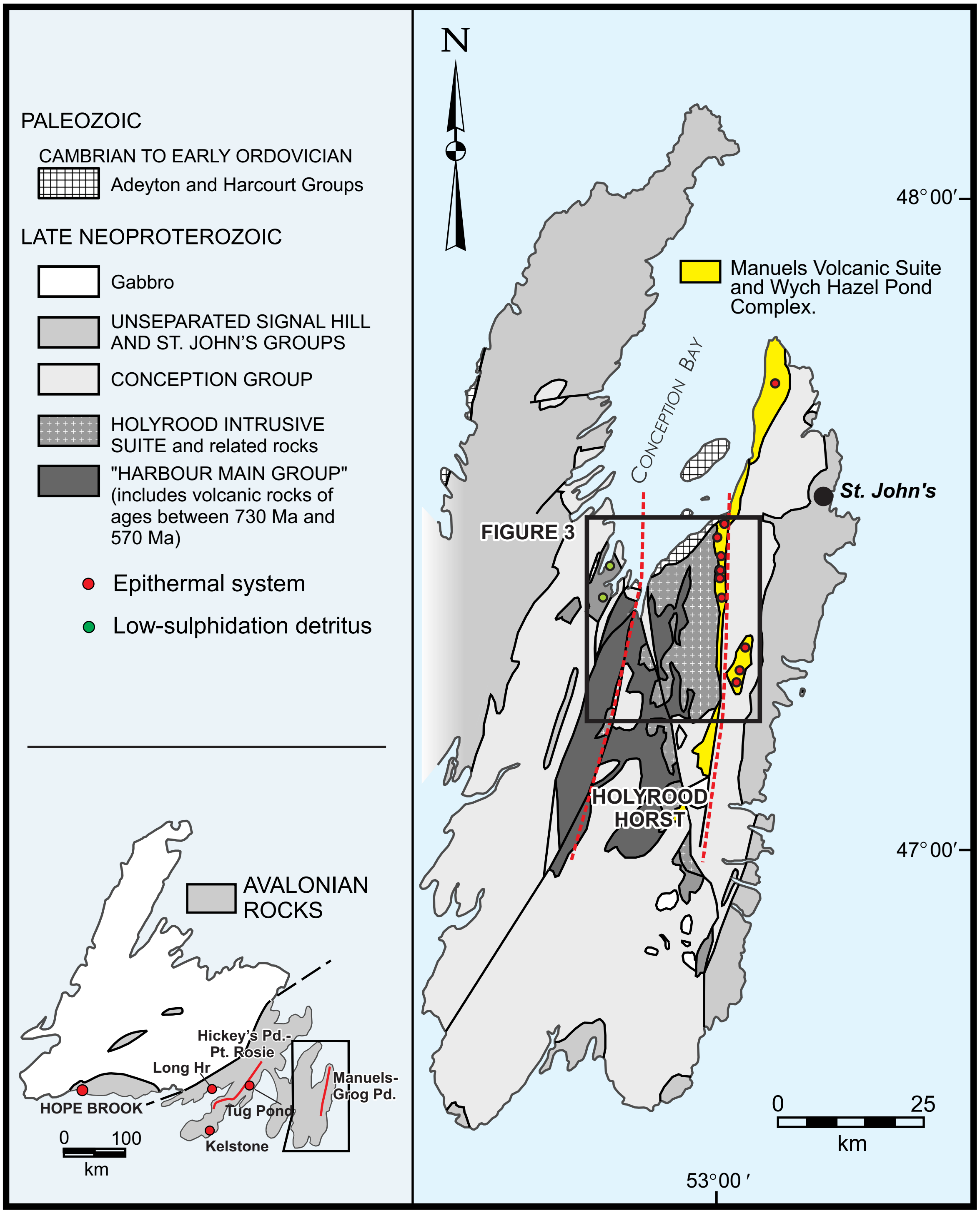

Figure 2. *Simplified geological map of the Avalon Peninsula (modified from King, 1988). Shaded area on inset map shows approximate distribution of "Avalonian" rocks, red dots and lines delineate epithermal prospects and/or deposits (modified from O'Brien* et al.*, 1998).*

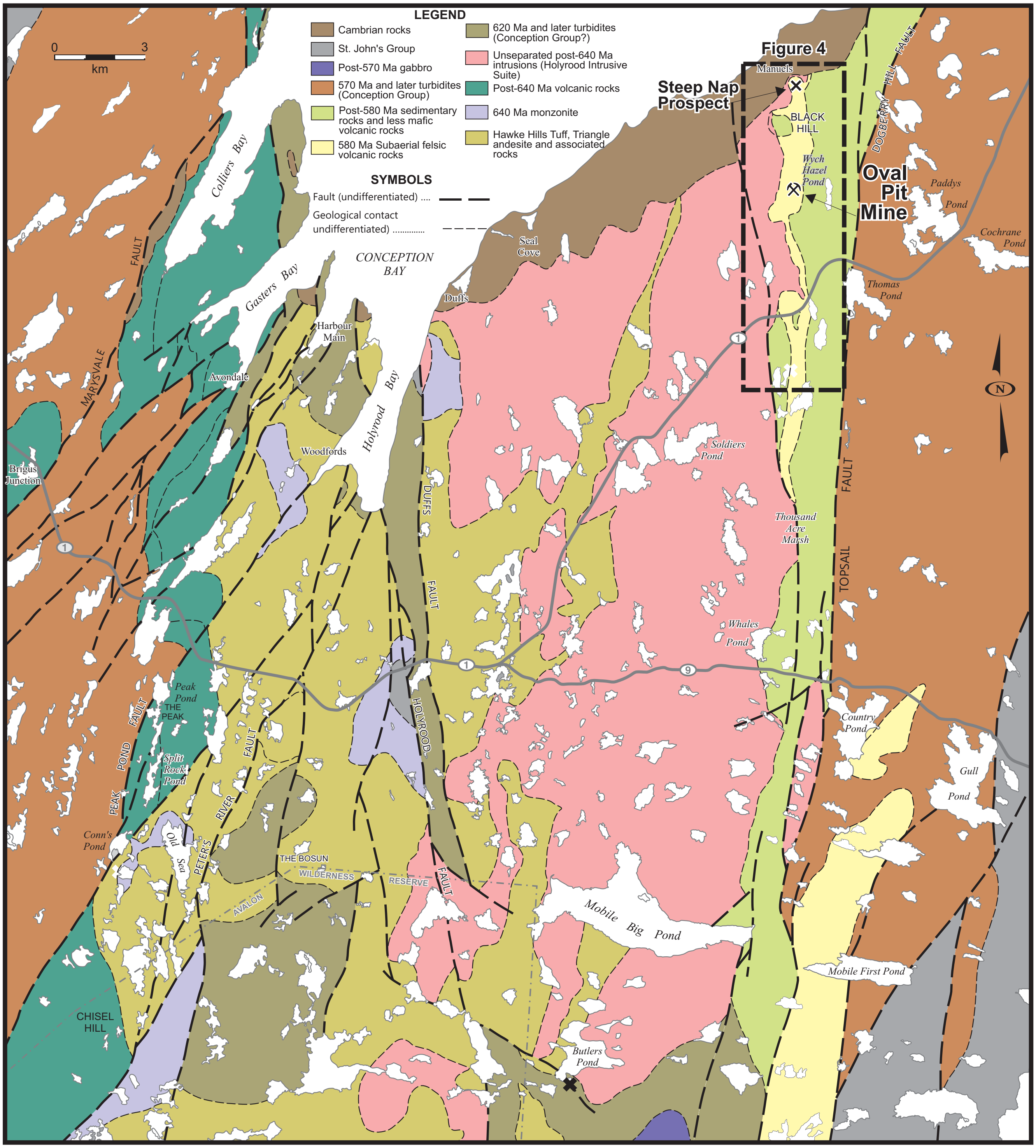

Figure 3. *Simplified geological map of the eastern Avalon Holyrood Horst, and surrounding units (modified from O'Brien* et al.*, 2001).*

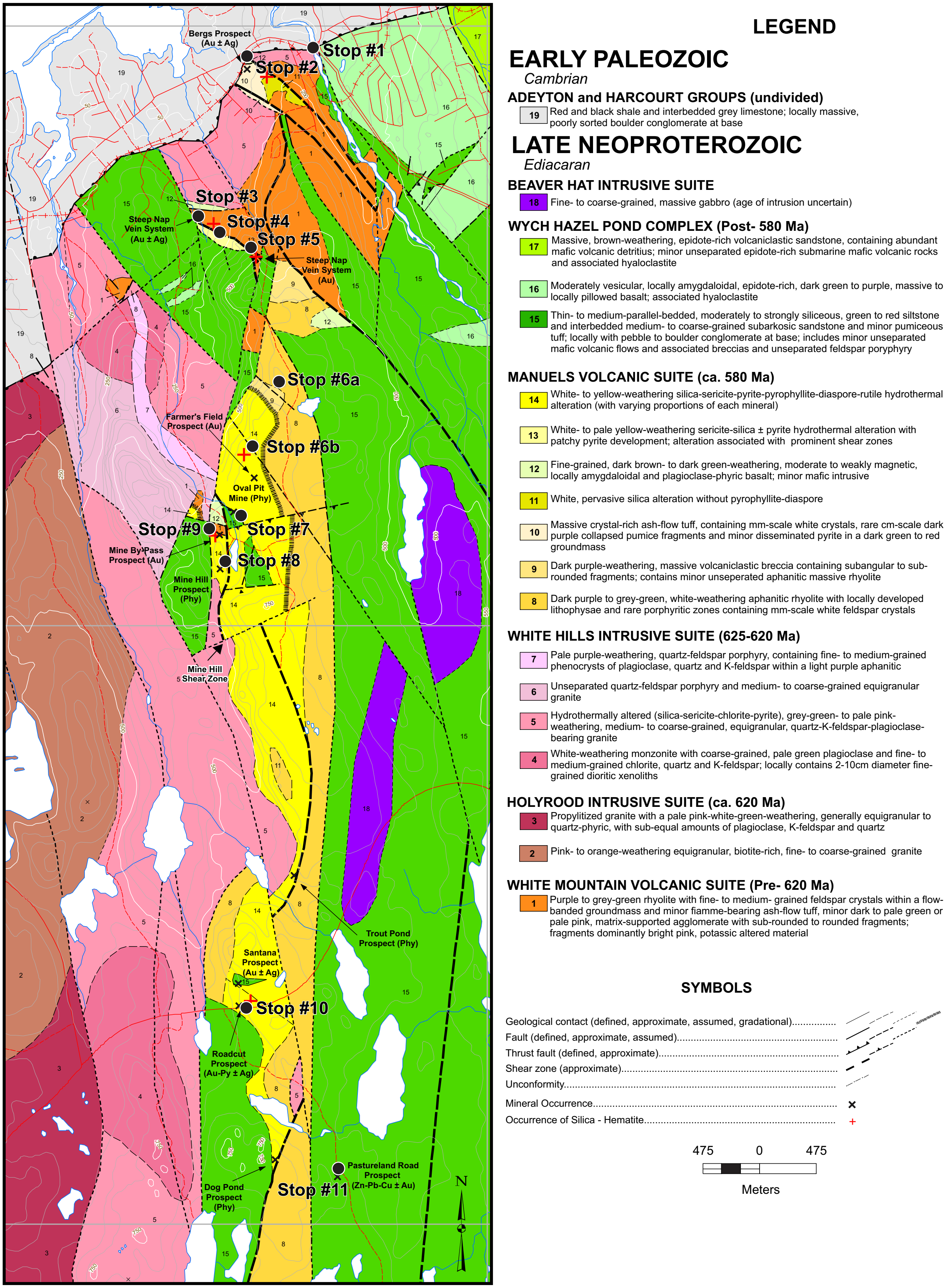

Figure 4. *Regional geological map of the eastern side of the Holyrood Horst.*

tification of auriferous low-sulphidation related veins was first noted by O'Brien *et al.* (1997, 1998), and since that time several occurrences of crustiform–colloform, adularia-bearing low-sulphidation related veins have been identified (Mills *et al.*, 1999; O'Brien, 2002; O'Brien and Sparkes, 2004; B.A. Sparkes, 2003a, b, 2005a, b).

Neoproterozoic Epithermal Systems of the Eastern Margin of the Holyrood Horst–Eastern Avalon High-Alumina Belt

The high-sulphidation, pyrophyllite–diaspore-bearing, advanced argillic alteration within the eastern Avalon Zone is primarily confined to the eastern margin of the Holyrood Horst, where it is hosted within predominantly felsic rocks of the composite Manuels Volcanic Suite (O'Brien *et al.*, 2001). The precious-metal-bearing, low-sulphidation veining is developed proximal to the high-sulphidation alteration, and is hosted by the pre-620 Ma White Mountain Volcanic Suite as well as the *ca.* 580 Ma Manuels Volcanic Suite (Sparkes *et al.*, 2005). The main occurrence of pyrophyllite–diaspore alteration is developed within the Oval Pit Mine (Figure 4). From here the alteration can be traced southward, along the zone known as the Mine Hill Shear Zone (Figure 4). This major structural feature defines the regional boundary between the older White Mountain Volcanic Suite to the west and the younger Manuels Volcanic Suite to the east (Sparkes *et al.*, 2005). In the vicinity of the Oval Pit Mine the Manuels Volcanic Suite is unconformably overlain by siliciclastic sedimentary and associated mafic volcanic rocks of the *ca.* 580 Ma (and younger) Wych Hazel Pond Complex. The onset of marine sedimentation generally corresponds with the cessation of volcanism and marks the onset of an extensive period of basin infilling, the termination of the high-sulphidation-related alteration, and the transition into a submarine mineralizing environment.

The age of the rhyolite and ash-flow tuff hosting the pyrophyllite–diaspore alteration (and maximum age of the high-sulphidation system) is precisely defined at 584 ± 1 Ma (Sparkes *et al.*, 2005). The sedimentary rocks of the overlying Wych Hazel Pond Complex contain detritus eroded from the high-sulphidation alteration. The base of the complex is drawn at a silica–pyrite-altered conglomerate, which is overlain by a pumiceous tuff bed that has been dated at 582 ± 1.5 Ma (Sparkes *et al.*, 2005). Together, these data constrain the formation, uplift and erosion of the high-sulphidation-style advanced argillic alteration to a period from 585 to 580.5 Ma.

The most extensive zone of low-sulphidation veining identified to date occurs in the region of the Steep Nap prospect (Figure 4), located approximately 3 km to the north of the Oval Pit Mine, where crustiform–colloform banded veins can be traced intermittently for up to 550 m along strike (B.A. Sparkes, 2005a). At the Steep Nap prospect the low-sulphidation related veins are hosted within a polylithic lapilli tuff of the pre-620 Ma White Mountain Volcanic Suite. These veins locally display well preserved boiling textures and similar veins in the region have produced up to 54 g/t Au (O'Brien and Sparkes, 2004). The maximum age limit for gold-bearing colloform–crustiform chalcedonic silica–adularia ± calcite veins is provided by a vein-bearing crystal-rich ash-flow tuff, dated at 582 ± 4 Ma. The low-sulphidation system, which is unconformably overlain by sedimentary rocks containing lower Cambrian fossils, is thus bracketed between 586 Ma and the age for the Lower Cambrian (between *ca.* 540 and 513 Ma). Feldspar-porphyry intrusions into the Wych Hazel Pond Complex sedimentary sequence yield a preliminary age of 585 ± 5 Ma. The porphyries, which are geochemically distinct from the older plutons, are the youngest felsic intrusions within the region and may play an important role in the development of the regional epithermal systems (Sparkes *et al.*, 2005, 2007). Available data are consistent with a model whereby the high sulphidation system has been focused along (and above) a pre-existing structure coincident with the contact between the 625-620 Ma plutonic rocks and the younger, *ca.*580 Ma volcanic suite. This boundary is now marked by the post-alteration Mine Hill Shear Zone (Figure 4).

The relationship between the high- and low-sulphidation epithermal systems remains equivocal. Current modelling for such systems (*e.g.*, Hedenquist *et al.*, 2000) would imply that Oval Pit Mine (pyrophyllite–diaspore) and the Bergs–Steep Nap system (chalcedonic silica–adularia ± calcite) formed in contrasting environments at distinctly different crustal levels. Thus the proximity of these two types of systems in the eastern Holyrood Horst would require their original separation in either space or time. Existing field and U–Pb geochronological data do not provide enough precision to separate the two systems with respect to the timing of their formation to adequately explain the observed proximity of such contrasting epithermal systems. The possibility remains that the low-sulphidation colloform–crustiform veins and breccias represent a slightly younger (>1 Ma) telescoped, near-surface epithermal system overprinting a relatively deeper high-sulphidation system.

TRIP ITINERARY

Overview

The field trip departs the Delta Hotel and proceeds west to Manuels via Route 2, turning northwest (right) onto Route 60 (Manuels Access Road), and continuing onto the Manuels River Historic Site (on the immediate right, after crossing the Manuels River Bridge). Geologically, the route we follow to the first stop takes us downward through much of the late Neoproterozoic stratigraphic section of the eastern Avalon Peninsula: from the deltaic sandstones and shales of the St. John's Group (which underlies much of the city of St. John's), down through the Mistaken Point Formation and other marine siliciclastic sedimentary rocks of the Conception Group, across the Topsail Fault system, and onto the eastern edge of the Holyrood Horst. The itinerary includes field stops that will focus primarily on various styles of hydrothermal alteration and related gold, copper and silver mineralization within late Neoproterozoic volcanic and plutonic rocks of the Avalonian Belt of the eastern Appalachians.

The trip will begin at the northern end of the eastern Avalon high-alumina belt, at the unconformable contact between hydrothermally altered volcanic and plutonic rocks (historically included within the Harbour Main Group and Holyrood Intrusive Suite, respectively) and unaltered, shale-rich Cambrian platformal cover (**Stop 1; Figure 4**). We then proceed to the west to view the altered granite exposed immediately under the unconformity near the low-sulphidation-style Berg's prospect (**Stop 2; Figure 4**). From here we proceed southward along the alteration belt, to examine exposures of low-sulphidation style gold-bearing quartz–adularia–hematite veins and related breccias and host rocks at the Steep Nap prospect (**Stops 3 to 5; Figure 4**). The trip will proceed farther south, stopping at low-sulphidation style breccias on the margin of the advanced argillic alteration (**Stop 6; Figure 4**), then proceeding on to the main zone of advanced argillic alteration exposed within the Oval Pit Mine (**Stop 7; Figure 4**). We will also examine the post-alteration high strain zone developed within the advanced argillic alteration at Mine Hill (**Stop 8; Figure 4**), and nearby silica-altered auriferous breccias of the Mine By-Pass prospect (**Stop 9; Figure 4**). From here we will leave and travel south along Route 61 (Foxtrap Access Road) to the intersection with Route 1, to further examine some occurrences of silica-altered auriferous hydrothermal breccias at the Roadcut prospect (**Stop 10; Figure 4**). For our final stop we will follow Route 61 under the overpass then onto a secondary gravel road for about 2 km, stopping at a roadside exposure of Zn–Pb–Cu–Ag–Au mineralization, known as the Pastureland Road prospect.

STOP 1: Manuels River Historic Site

Location: *North side of Route 60 at the Manuels River Bridge; park in Manuels River kiosk parking lot. Walk down the steps to the river to examine the basal boulder conglomerate.*

We stop here to review the day's itinerary, look at maps, and briefly visit the basal conglomerate of the Early Cambrian to Early Ordovician platformal cover to the Avalonian Neoproterozoic volcanic and plutonic rocks. The latter were altered, mineralized and subsequently deformed in the latest Neoproterozoic, prior to the deposition of the conglomerate. The conglomerate in this region contains deformed clasts of high- and low-sulphidation epithermal systems; some silica-altered clasts occur in outcrops in Manuels River.

Geologically, the route here took us down section through late Neoproterozoic deltaic sandstones and shales of the St. John's Group, downwards through the Ediacaran-fossil bearing Mistaken Point Formation and other marine siliciclastic sedimentary rocks of the Conception Group, across the Topsail Fault system, onto the eastern edge of the Holyrood Horst and the volcano-plutonic core of the Avalon Peninsula. We are now at the northern end of what is informally called the eastern Avalon high-alumina belt, at the contact between hydrothermally altered volcanic and plutonic rocks and unaltered, shale-rich Cambrian platformal cover.

STOP 2: Unconformity of Early Cambrian Shale and Limestone on Late Neoproterozoic, Hydrothermally Altered Granitic and Volcanic Rocks, Eastern Avalon High-Alumina Belt

Location: *South side of Conception Bay Highway, just west of Berg's Store (opposite Cherry Lane); park in lot adjacent to Berg's Ice Cream store. Walk southwest along Route 60 (away from Manuels River Bridge), keeping on shoulder of the road. Cross Route 60 at the crosswalk beyond Bergs store.*

EXERCISE EXTREME CAUTION!

Fast-moving traffic! Cross on the light. Stay close to the outcrop; the shoulder is narrow in this area.

The outcrop on the south side of the road exposes the disconformity between fossiliferous Lower Cambrian Brigus Formation (Adeyton Group; *see* paleontological review in

Boyce (1988)) and the underlying hydrothermally altered succession of the eastern Avalon high-alumina belt. Sub-Cambrian basement here includes volcanic and granitic rocks that host the Bergs low-sulphidation-style vein system (which once was visible in now-covered outcrops in the adjacent Cherry Hill subdivision). These outcrops provide stratigraphic evidence for the Precambrian age of the host rocks and of the alteration system. The little-disturbed Cambrian strata demonstrate the lack of Paleozoic orogenesis in the immediate area. This is one of the northernmost exposures of this hydrothermal system, which continues (initially, at least) at very shallow depth, northward under the gently dipping to flat-lying Cambrian cover.

The roadside outcrop shows a well-developed regolith zone below the basal Cambrian contact. There has been carbonate infilling along the regolith and within fractures extending a metre or more into the basement rocks. Minor early Paleozoic copper mineralization is associated with the carbonate. Both the volcanic and plutonic rocks below the unconformity are altered (sericite–silica, with minor hematite and pyrite). These Neoproterozoic rocks are cut by structurally controlled (extensional) sub-horizontal and less obvious steeply-dipping quartz and carbonate veins. An earlier set of thin, banded quartz–hematite veins are hydrothermal in origin. Hydrothermal quartz–hematite ± adularia veins and breccias having variably elevated gold values occur locally, both in outcrop, and as large angular blocks immediately south and north of here; similar veins are exposed in nearby outcrops.

Superb exposures of the unconformity between the fossiliferous Cambrian and an underlying regolith of epithermal-style veins, breccias and hydrothermally altered volcanic and plutonic rocks were uncovered during construction of the housing subdivision, and provided key chronological relationships. The boulder conglomerate contains large, typically rounded clasts (1 cm to >1 m) of silica-rich breccia, chalcedonic silica, crustiform- and colliform-banded silica veins, and hematite–silica–adularia veins, as well as silica, argillic and advanced argillic alteration that was deformed prior to incorporation into the conglomerate. The conglomerate also samples fresh flow-banded rhyolite, altered granite and foliated mafic rocks. Construction work in the same area exposed an angular unconformity separating cleaved Neoproterozoic volcanic rocks from overlying, gently dipping to flat-lying, non-cleaved Cambrian rocks. The northeast to east-northeast-trending steep cleavage in the Neoproterozoic basement is truncated at the unconformity surface (further details of the nature and significance of the unconformity, as well as references to earlier work are given in O'Brien (2002).

Bergs Prospect: Gold-bearing crustiform banded, low-sulphidation-style epithermal quartz veins and breccias of the Bergs prospect were discovered in 2001 (O'Brien, 2002). At that time, gold assays up to 7.2 g/t in grab samples were obtained from outcrop, subcrop, and large angular boulders of silica–hematite-altered and hydrothermally veined subaerial volcanic rocks. Excavations at the site of a new housing development at the north end of the prospect exposed an extensive area in which mineralized and/or altered float, subcrop and outcrop occurred; most of the mineralized area is now covered by private residences. Chip sampling of silica altered breccia (including vein breccia) exposed in 2001 returned results averaging about 250 ppb Au over 20 m. Subsequently, grab samples taken by Rubicon Minerals Corporation assaying up to 9.6 g/t were obtained from banded veins in the same area. A short distance farther south, crustiform-banded silica–hematite veins intrude rhyolite and rhyolite breccia with weak yet pervasive silica alteration, and have yielded gold assays up to 54.3 g/t (O'Brien and Sparkes, 2004).

The veins display well-developed and distinct millimetre-scale crustiform banding and local colloform banding; veins are hematite-bearing and brecciated internally. Common alteration minerals occurring within the mineralized veins and related breccias include chlorite and illite. The higher grade veins contain two phases of red hematite, with the earlier hematite intergrown with chalcedonic silica; specularite is developed locally. Typically, veins at Bergs are narrower than at nearby Steep Nap prospect (*see* Stop 3) and exhibit a multi-directional, stockwork-like pattern. Adularia at Bergs, unlike that at Steep Nap, is white-weathering. Well preserved bladed and crustiform–colloform textures are also locally developed, and are similar to those seen at Steep Nap.

At Bergs, gold also occurs in a distinctive volcano-sedimentary/hydrothermal breccia with a deep red, earthy hematite-rich, non-siliceous matrix, which weathers recessively, and in which are set numerous variably broken, variably sized, equant to platy fragments of silica and crustiform-banded silica–hematite vein material. Fragments of hydrothermal veins and vein breccia occur throughout the host breccia. The rock unit is neither an *in situ* hydrothermal breccia nor an internally brecciated vein complex, and bears similarity to modern hydrothermal eruption breccias (J. Hedenquist, pers. comm., 2003). Grab samples taken from banded vein fragments in the breccia contain between 2.1 and 7.75 g/t Au. The presence of these surface breccias indicate that shallow crustal levels are preserved in these Neoproterozoic systems.

The Berg's prospect was tested with a single reconnaissance drillhole in 2003. This drilling intersected several zones of network-style banded low-sulphidation-related veins and associated breccias hosting anomalous gold mineralization, locally assaying up to 507 ppb Au over 2.2 m, as well as narrower higher grade assays of up to 2.3 g/t Au over 0.20 m (B.A. Sparkes, 2003a); an enrichment of selenium and mercury is also locally noted with some mineralized samples, and silver values are generally low in comparison with those obtained from the Steep Nap prospect (*op. cit.*).

At Bergs, banded low-sulphidation veins occur in proximity to a hybrid suite of variably silica-altered and pyritic granites. The granites are significantly older (up to 30 Ma) than the established lower time limit of the low-sulphidation veins (the 582 ± 4 Ma age of host volcanic rocks). Their presence as a basement feature along the margin of the Holyrood Horst may have influenced the siting of not only the high-sulphidation system and later Neoproterozoic strain, but also the low-sulphidation veins. Similar granites have been mapped up to and beyond (east of) the Topsail Fault, where they can be readily separated from a regionally extensive composite suite of younger mafic to intermediate intrusions. Some of these younger *ca.* 580 Ma intrusions have been emplaced as syn-sedimentary hypabyssal bodies into the Wych Hazel Pond Complex.

STOP 3: Steep Nap Road Prospect: Au–Ag-bearing, Low-sulphidation-style Veins and Breccias

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

The blasted outcrop on the south side of the road forms part of the Steep Nap prospect. Discovered in 1995, the prospect consists of gold-bearing hydrothermal quartz–hematite–adularia veins in pyroclastic and hydrothermal breccias (O'Brien *et al.*, 1998; Mills *et al.*, 1999). The veins in this exposure have many of the characteristics of low-sulphidation (adularia–sericite) epithermal gold mineralization: *e.g.*, adularia- and chalcedony-bearing; crustiform and colloform textures; low silver/gold ratio (generally <10/1), chalcedonic recrystallization and carbonate replacement textures.

We are located about 3 km to the north of the Oval Pit pyrophyllite mine (*see* Stop 7), and about 1.25 km south-southwest of the Berg's prospect. The largest veins in this outcrop have returned assays of 3.3 g/t Au and 20 g/t Ag (Mills *et al.*, 1999). This 60 m long outcrop of felsic pyroclastic rocks contains at least 100 veins, ranging in size from 1 mm up to 1.7 m; most are less than 2 cm wide. Several types of breccia are also exposed. The main auriferous material forms a 1.7 m wide composite vein composed of crustiform bands of adularia–quartz–chalcedony and minor hematite. Very little sulphide mineralization is present in any of the veins. The largest auriferous veins have been traced along strike for more than 550 m. Samples collected from trenches excavated by Rubicon Minerals Corporation have locally assayed up to 9.23 g/t Au (B.A. Sparkes, 2003b).

The earliest veins are crustiform-banded, and consist of grey recrystallized chalcedony and white quartz, with or without minor chlorite and hematite. A second group of veins consist of crustiform and locally colloform bands of adularia, grey recrystallized chalcedony, white quartz and hematite. These display chalcedonic recrystallization textures (mosaic texture) and carbonate replacement textures (parallel bladed texture) in thin section, and are anomalous in gold.

The latest veins are characterized by weakly banded quartz along the margin, bounded by crystalline comb quartz nearer the centre, surrounding a hematite core. Veins such as these, which contain a coarse-grained crystalline texture are in many cases barren or only weakly anomalous in gold.

In many instances, especially in the larger veins, internal brecciation of the vein material by hematite has occurred; hematite fracturing of the surrounding outcrop also occurs locally. The earliest hydrothermal breccias are gold-bearing and have a matrix of grey recrystallized chalcedony and minor adularia that forms cockade textures cored by sericite–chlorite-altered clasts. This breccia is crosscut by the main quartz–hematite–adularia vein, and by smaller veins cored by comb quartz and hematite. Other, later breccias have either a black, chlorite-rich and/or brown, hematite-rich matrix. These breccias contain fragments of banded vein material, and are thus either late syn-, and/or post-veining. The two matrix types are typically mixed. The late breccias with vein material fragments return anomalous gold values.

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

The presence of crustiform textures with chalcedonic silica and K-feldspar in the form of adularia indicate the mineralized veins formed during boiling of near-neutral pH fluids associated with episodic pressure release. Neutral fluids rose into a zone of increased permeability, in this case created by faults. Confining pressure was reduced as fluids neared the paleosurface; the fluid boiled, CO_2 was given off; the resultant drop in pH and temperature led to low-T, K-feldspar formation (adularia), and metal precipitation from silica gels. The system gradually sealed, pressure built up and boiling stopped; renewed fracturing broke the sealed cap in the system, and the process repeated.

The early cockade-textured hydrothermal breccia reflects hydrofracturing and tectonic brecciation synchronous with boiling; this is evident from crustiform-banded adularia and chalcedonic silica in the matrix. Breccias also formed during later stage hydrothermal activity in the same system. These are Au–Ag-bearing only where they contain mineralized adularia-bearing vein fragments.

The entire mineralizing system is cut by mafic dykes; these are located distal to the footwall on the road exposure, at the footwall in trenches 3 and 4 and also at the ridge exposure. These dykes were likely feeders to mafic flows in the overlying Wych Hazel Pond Complex, a shallow marine basin-fill environment formed during an extensional tectonic setting. Elsewhere within the eastern Avalon Peninsula, the formation of mafic dykes as part of a dyke swarm along the eastern coastline of Conception Bay, have been bracketed between 582-576 Ma (Skipton, 2011).

Vein features preserved here demonstrate that these rocks formed within the boiling level of a low-sulphidation epithermal system at an approximate depth suitable for precious metal deposition. An exploration diamond drilling program, completed by Rubicon Minerals Corporation in 2005, intersected broad mineralized intervals (up to 45 m in core length) of veins, vein-stockworks and hydrothermal breccias. Mineralized intersections were obtained in 5 of the 7 holes drilled, with the best result assaying 1.9 g/t Au over 0.7 m (B.A. Sparkes, 2005a).

The Steep Nap Prospect and related Au–Ag mineralization was the first late Neoproterozoic, Au–Ag-bearing, low-sulphidation-type epithermal system documented in Avalonian rocks, and is amongst the oldest confirmed examples of that style of mineralization known anywhere. Low-sulphidation-type alteration systems, which may host either bulk tonnage or bonanza-style mineralization, represent an important, yet challenging, target for precious-metal exploration within the Avalon Zone. Prospective geological environments include subaerial rhyolitic to rhyodacitic volcanic piles and associated rhyolitic dome complexes. The nature of the linkage between the low-sulphidation-type Steep Nap system and nearby pyrophyllite–diaspore-bearing advanced argillic alteration has important regional implications in terms of Au–Ag exploration, both locally and regionally in the larger Avalonian belt, and is the focus of ongoing investigations.

STOP 4: Steep Nap Trench #3

Location: *Follow the trail up hill (south) to an open exploration trench that exposes the Steep Nap vein, approximately 300 m southeast of Stop 3. Please respect the fact that we are walking on private land and refrain from littering.*

This stop offers an excellent view of the multiple phases present in the Steep Nap mineralizing system. Here we are approximately 30 m above the roadside vein exposure base on present day topography. At this locality we see that the system is developed along the contact zone between rhyolitic volcaniclastic rocks and a flow-banded to massive rhyolite unit. Typical wallrock alteration within this region consists of silicification combined with chlorite and illite alteration developed proximal to the vein. At approximately 5 m from the vein, the alteration is gradational into a more hematite-rich assemblage, again with minor amounts of illite. A post-mineralization dyke is again intruded along the vein and breccia margin in the vein footwall.

The earliest vein phase observed here is a cockade-textured vein breccia containing clasts of altered lapilli tuff, this vein breccia is typically weakly anomalous in gold. The breccia matrix consists of quartz (chalcedony) and adularia and is similar to that observed in the road exposure. A second vein event contains crustiform–colloform banded quartz–adularia veins with spectacular coarse colloform textures, this vein typically contains from 50 to 300 ppb Au. A third vein event consists of centimetre-scale bands of crustiform banded quartz–adularia with illite–chlorite–hematite. This vein phase typically contains 500 ppb to >1 g/t Au.

The earlier of the two hydrothermal breccias post-dating the formation of the main vein contains a matrix of silica–specularite–chlorite and rare pyrite. Clasts in the breccia consist of crustiform–colloform banded quartz–adularia vein fragments in addition to fragments of strongly altered volcanic rocks. This breccia phase contains an average of approximately 1 g/t Au; it is not clear if gold is present only in the vein fragments or in the breccia matrix as well. The second hydrothermal breccia evident in the trench contains a matrix of dominantly hematite and chlorite along with several percent sulphides. The sulphides include, in decreasing order of abundance, pyrite, chalcopyrite and galena. Clasts in the breccia consists of vein material with various textures (including spectacular examples of lattice-bladed carbonate overgrown by silica and adularia, along with 'moss' and 'mould' textures), silica-altered clasts and flow-banded rhyolite clasts. These breccias have returned grades of 4.5 g/t Au in grab samples and 1.8 g/t Au from channel samples.

The latest veins are observed in the vein hanging-wall and are characterized by weakly banded quartz along the margin, bounded by crystalline comb quartz nearer the centre, surrounding a hematite core. These are similar to those observed on the road exposure and return only weakly anomalous gold values.

STOP 5: Steep Nap Trench #5

Location: *Head south from the trench to the power line; follow the power line to the east, branching off on the trail to the right which proceeds up hill to the stripped outcrops on the ridge. If weather permits, this stop offers an excellent view of the relatively flat lying Cambrian cover exposed on the islands within Conception Bay.*

This stop is located approximately 70 m above the roadside vein, based on present day topography. Here the exposures of the main Steep Nap vein system are hosted within a complex rhyolite unit. The rhyolite is mainly massive and flow banded, although local areas exhibit a sub-porphyritic texture. The veins at this location measure up to 1.4 m wide (true width) within an alteration/brecciation envelope measuring over 6 m wide. The veins exhibit classic crustiform banded quartz–adularia textures with channel samples returning up to 103 ppb Au over 1.0 m; locally elevated As, Sb and Te are also noted in some of the samples (B.A. Sparkes, 2005b). Enveloping the vein system is a variably developed zone of brecciation/alteration within the host rhyolite. Stockwork fracturing is accompanied by chlorite–hematite–silica alteration and minor pyrite. This alteration zone is weakly elevated in gold. However, note that as we move up to areas of higher elevation there is a marked decrease in the overall development of well-developed banded veins and an increased abundance of hematitic hydrothermal brecciation.

Return to the powerline and back down the hill along the path which branches to the right from the powerline, stop at the flat exposure of hydrothermal breccia.

This stop in the path is referred to as the 'Jigsaw Breccia'. The zone consists of hydrobrecciated rhyolite cut by a mosaic stockwork of quartz–hematite–chlorite veinlets. The veinlets contain weakly banded crystalline quartz core by hematite and chlorite. Assay samples taken from the outcrop have returned anomalous gold values (*ca.* 100–150 ppb). The location of the zone relative to the known main vein/breccia occurrences suggests that a broader overall alteration system is present at Steep Nap.

Follow path back to Steep Nap Road.

STOP 6: Farmers Fields: Banded Rhyolites and Silica–Hematite Veins and Breccias – A Steep Nap Extension?

Location: *Head southwest along Anchorage Road until reaching the intersection with Minerals Road, then turn left onto Minerals Road. Precede along the road, past the Oval Pit Mine, to the area of the Farmer's fields. The first stop will be at the third field on the left. Proceed across the field to the area that has been channel sampled.*

<u>Part 1</u>

In this area we see well developed flow-banded rhyolite of the Manuels Volcanic Suite displaying a distinct maroon coloration. Here we are approximately 170 m above the roadside vein at Steep Nap, based on present day topography, and we are approximately 2 km south of the Steep Nap prospect. In this area we no longer see the characteristic colloform–crustiform banded chalcedonic silica veins as at Steep Nap; however, narrow quartz–hematite–chlorite ± pyrite veins and broader breccia zones are still locally developed. These features are interpreted as high-level features of the deeper epithermal system. Channel sampling of these veins have returned anomalous gold values of up to 136 ppb Au over 1.40 m (B.A. Sparkes, 2005b).

Return to road and proceed back along the road to the large field on the right at the end of the wire fence.

Part 2

Here we are about 500 m northeast of the Oval Pit Mine, which is a pyrophyllite–diaspore deposit within the more regionally extensive zone of advanced argillic alteration; this area represents the transition point from a low-sulphidation to a high-sulphidation environment within the area of the Oval Pit Mine. At this location we will examine outcrops of veins and breccias similar to those seen peripheral to the Steep Nap system. Veins and breccias here are weakly anomalous in gold, and typically contain between 50 ppb and 1 g/t Au. The most widespread veins here are cockade style breccia veins with hematite and silica; boiling features are absent. The most anomalous values are from the hydrothermal breccias containing chalcedonic silica. These features are interpreted as representing higher level features of the low-sulphidation system. This locality represents the closest occurrence of low-sulphidation related features to the high-sulphidation style alteration.

STOP 7: Oval Pit Pyrophyllite Mine

Location: *Trinity Resources and Energy (Newfoundland Pyrophyllite Division) Oval Pit Mine property: Head back along Minerals Road to the mine entrance. Stop at the Mine office. Time and weather permitting, we will first walk along the mine road to a look-out point on the edge of the Oval Pit, for an overview of the mine.*

WHILE ON THE MINE SITE, PLEASE WEAR THE HARD HAT THAT HAS BEEN PROVIDED! Also, be sure to follow all safety instructions and stay well clear of the edges of the open pit at all times.

The view from the top of the pit shows a number of features including the outline of the pyrophyllite–diaspore ore zone, the unconformably overlying sediments, which are rich in detrital altered clasts, and some of the larger scale structures affecting the alteration system. The most notable of these is a steep reverse fault that juxtaposes the alteration zone (in the south pit extension) with the sedimentary succession. The structure has about 60 m of vertical throw. The same structure has a significant component of subhorizontal displacement. Vertical and horizontal displacement of the ore zone along this fault is mimicked in the overall shape of the open pit, particularly the southwest extension.

The pyrophyllite deposits of this area were discovered in 1898 and were first mined in the period from 1903 to 1905, with approximately 7750 tons of hand-picked ore shipped from a quarry near Johnnies Pond (presumably at or near the site of the Mine Hill deposit;

Vhay, 1937; Spence, 1940). Pyrophyllite ore was produced intermittently in the mid-1930s and 1940s by the Industrial Minerals Company of Newfoundland, mainly from the area around Mine Hill, but also from the Trout Pond and Dog Pond prospects, located farther south (Figure 4). Mining of the Oval Pit pyrophyllite deposit was carried out from 1956 to 1996 (*e.g.*, Lee, 1958), first by Newfoundland Minerals Ltd. and eventually, by Armstrong World Industries Canada Ltd. Exploration drilling of all deposits was carried out over this interval. Until now, pyrophyllite from this deposit has been traditionally used exclusively for ceramic applications, and was shipped in bulk to the US ceramics plants. The deposit is now owned by Trinity Resources and Energy Limited and is operated by its Newfoundland Pyrophyllite Division. The owners produce a variety of high-end pyrophyllite products, including fillers and whiteners for paper, plastic and paint, plus a number of specialty ceramic uses; this product is milled and packaged on-site.

The earliest geological study of the pyrophyllite deposits was carried out by Buddington (1916). A detailed study of the Mine Hill, Trout Pond and Dog Pond prospects was carried out by Vhay (1937). A number of investigations followed the development of the Oval Pit Mine (*e.g.*, Keats, 1970; Papezik and Keats, 1976; Papezik and Hume, 1984). The most recent geological mapping of this region is that of Hayes and O'Driscoll (1989, 1990), and Hayes (1997) and by the authors (O'Brien *et al.*, 1997, 1998, 2001; Sparkes *et al.*, 2005; G.W. Sparkes, 2005).

A well-exposed section through an extensive advanced argillic hydrothermal system is preserved in the Oval Pit Mine and in the immediate surrounding area. Alteration can be subdivided from east to west into subzones of argillic, advanced argillic and massive silicic alteration. The argillic zone is characterized by the presence of silica and sericite, with or without pyrophyllite, and the common occurrence of hydrothermal hematite. The advanced argillic zone contains subzones of massive pyrophyllite, sericite and diaspore, with minor barite and rutile (*e.g.*, Oval Pit), and of silica, pyrophyllite and sericite, locally with 5 to 10% pyrite. Smaller zones of massive silicic alteration are mainly in the form of metre-scale pods of high-grade silica, containing less than 5% sericite and/or pyrophyllite. Locally, pyrite forms the matrix of associated silica breccias. No large or continuous zone of silicic alteration has been identified at surface. The zones of silicic alteration are irregularly distributed in detail, but appear to be located mainly to the northeast of the advanced argillic zone. The original distribution of silica and pyrophyllite within the advanced argillic alteration zone indicate that they are essentially contemporaneous. Pyritic rocks intimately associated with the pyrophyllite are not typically anomalous in gold, although values up to 0.8 g/t have been noted locally. The highest gold values noted to date are associated with hydrothermal breccias at the edge of the advanced argillic zone (*e.g.*, *see* Stop 9).

The presence of pyrophyllite [$Al_2Si_4O_{10}(OH)_2$] and diaspore [AlO(OH)], together with barite and metre-scale silicic (>95 percent SiO_2) zones, coupled with the almost total absence of kaolinite, is compatible with an advanced argillic alteration system associated with a magmatic-derived high-sulphidation system. The apparent absence of widespread silica alteration, vuggy silica, and alunite within the alteration zone may indicate that the pH was not acid enough to produce this assemblage. A pH in the range 3 to 5 is implied by the observed presence of pyrophyllite and diaspore with quartz, and is consistent with this suggestion. However, in the apparent absence of the topaz, lazulite, andalusite and zunyite (diagnostic minerals of ascending hypogene acid fluids with probable magmatic components), it remains to be confirmed whether this alteration system is entirely magmatically derived, or alternatively, in part steam-heated (*cf.* Reyes, 1990).

The advanced argillic alteration zone passes outward into red subaerial rhyolites showing mild silicic alteration associated with the formation of quartz–hematite veins and breccias. These host rocks have been dated at 584 ±1 Ma, and are in turn overlain by immature siliciclastic sedimentary rocks of the basal Wych Hazel Pond Complex (Sparkes *et al.*, 2005). The latter are well exposed in the upper benches on the west side of the open pit. There, the lower 60 m part of the succession consists mainly of red to purple, fine to coarse-grained fluvial/alluvial siliciclastic rocks, containing rare pumice-rich tuff layers. One such tuff bed occurs near the base of the succession, and is dated at 582 ± 1.5 Ma. This brackets the age of the advanced argillic system between 585 and 580.5 Ma. The yellow-weathering boulder conglomerate, *ca.* 3 m thick, is pyrite-bearing, and contains large well-rounded clasts of pyrophyllite, sericite and silica clasts derived from the underlying volcanic-hosted advanced argillic alteration zone. The conglomerates in the lower part of the succession contain altered and unaltered detritus, none of which record any pre-incorporation deformation. The lower red conglomerate unit gives way upwards to extensively slumped beds of green siltstone and thin and medium beds of grey, coarse-grained feldspathic grit. The latter occur as planar beds, as internally slumped beds interlayered with siltstone and bounded by planar beds, or as totally disrupted and discontinuous layers affected by soft-sediment folding and faulting. Northwest of here, these rocks are interlayered with pillow breccia and mafic hyaloclastite.

This sedimentary succession is deformed by an open southeast-plunging syncline. The base of the succession does not appear to have a significantly irregular morphology, although the nature of the epithermal alteration beneath the sediments would imply some uplift to bring these rocks to the (syn-sediment) paleosurface.

STOP 8: Mine Hill Quarry: High-strain Zone in Advanced Argillic Alteration; Pyrophyllite Ore

Location: *Turn left after leaving the mine and proceed along Minerals Road. Follow the narrow road immediately west of Johnnies Pond to the large quarry near the end of the pond.*

WATCH OUT FOR FALLING ROCK. THE LARGE BLOCKS ON FLOOR MAY NOT BE STABLE

The Mine Hill Quarry represents one of the early attempts at commercial production from the pyrophyllite deposits of this region. Prior to the development of the Oval Pit deposit in the mid-1950s, most production from this area had come from the immediate Mine Hill–Johnnies Pond area. Reverse-sense ductile shear zones have accompanying, intense, steeply dipping foliation and down-dip stretching lineations. These are well exposed in the quarry wall (recent bulk sampling by the mine operators may have resulted in the loss of some of the best exposures).

The protolith of the alteration is likely a welded tuff. Discontinuous pyritic zones are developed within the advanced argillic zones in this area. Most of the eastern and central portions of the quarry expose highly strained pyrophyllite–sericite–quartz alteration, in which the silica forms discrete knobs. The western end of the quarry exposes highly strained pyrophyllite–sericite ore. Elsewhere on Mine Hill, the alteration zone is overlain by basal conglomerate of the Wych Hazel Pond Complex and is intruded by an unaltered, pre-tectonic (albeit weakly foliated) diabase dyke.

The high strain evident at this locality is in contrast to the situation around much of the Oval Pit Mine, where, except for narrow high strain zones, the overall ductile strain is much lower. This strain is in part due to the Mine Hill Shear Zone (*cf.* Sparkes *et al.*, 2005), which is regionally coincident with both the main area of advanced argillic alteration and the boundary between 620-625 Ma magmatic rocks and the younger *ca*. 584 ± 1 Ma Manuels

Volcanic Suite. Locally, pyritic granite intrudes the volcanic sequence on the back of Mine Hill; this phase has been dated at 619 ± 1 Ma (Sparkes, 2005), indicating that the host to the alteration at this locality is part of the older White Mountain Volcanic Suite. Ar–Ar dating of sericite from the Mine Hill Shear Zone has dated the deformation along the structure at 537 Ma (Sparkes, 2005); however, this is interpreted to represent younger reactivation of a long lived structure, the history of which played a significant role in siting the development of the advanced argillic alteration throughout the high-alumina belt.

STOP 9: Mine By-pass Gold Prospect

Location: *Proceed back along the road adjacent to Johnnies Pond, and turn left just before reaching Minerals Road. Continue on to the large rock cut, which is host to the Mine By-pass prospect, located on back of the mine office.*

WATCH OUT FOR FALLING ROCK ... NOTE THE RECENT ROCK FALLS!

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

Within the breccias, pyrite occurs as individual mm-scale euhedral crystals, and as irregular zones, in which the pyrite is fine grained and heavily disseminated. Multiple generations of silica alteration are recorded by fragments hosted within the breccia, with some dark grey silica fragments displaying evidence of pre-breccia hematite alteration.

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

STOP 10: Roadcut Au–Ag Prospect:

Location: *North side of Route 1, immediately east of Foxtrap Access ramp. Leave pyrophyllite mine property via Minerals Rd. and turn west onto the new CBS by-pass. Exit onto Route 61 (Foxtrap Access road) and proceed south (left) to the intersection with Route 1. Park immediately north of westbound ramp onto Route 1 and cross Route 61. Walk up the access ramp, stopping at the long outcrop on the north side of Route 1; the rusty-weathering exposures are part of the Roadcut prospect.*

EXERCISE EXTREME CAUTION WALKING ON THE BUSY HIGHWAY RAMP HERE AND WATCH FOR ONCOMING TRAFFIC. STAY ON THE GRAVEL SHOULDER AT ALL TIMES!

The outcrop on the north side of the west-bound lane on Route 1 exposes a 100-m-wide section through a locally auriferous (up to 11.2 g/t Au) zone of advanced argillic alteration developed in the same late Neoproterozoic volcanic succession seen in earlier stops. The prospect is sited near the western edge of the eastern Avalon high-alumina Belt, approximately 4 km along strike to the south from the Oval Pit pyrophyllite mine and the Mine By-pass prospect. Hydrothermal alteration (silica–sericite ± chlorite ± pyrite ± magnetite) is developed in a succession of flow-banded rhyolite, pumice-rich lapilli tuff or tuff-breccia, and lithophysae-bearing ash-flow material, near the contact with overlying tuffaceous sedimentary rocks, and within several hundred metres of the boundary between the host volcanic rocks and the monzonite–diorite–granite complex of the White Hills Intrusive Suite.

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

The larger silicic alteration zone contains areas of ‘pebbly’ breccia, composed of dark grey sericite–pyrophyllite–pyrite fragments in a silica matrix, as well as zones of more angular to subrounded breccia with silicic-altered rhyolitic material in a chlorite-rich matrix. Both are present within a significant, *ca.* 10-m-wide zone of gold mineralization in the central part of the outcrop. A chip sample taken across this zone averaged 3 g/t over 10 m. Anomalous gold values occur in the pebbly breccias, but highest gold values (up to 11.2 g/t) are obtained from silica-rich breccia with chlorite–pyrite (plus minor K-feldspar and muscovite) matrix and from felsic hydrothermal breccia with banded rhyolite clasts (O’Brien and O’Driscoll, 1996, 1997a, b; O’Brien *et al.*, 1997, 1998). Pyrite occurs as disseminations, clots and thin veinlets within the matrix of the breccias. The auriferous breccias yield assays up to 210 g/t Ag and 2 g/t As. The gold-bearing breccias at this locality are comparable in many respects to those seen in the previous stop (4 km along strike to the north). Channel sampling of the pyritic chlorite breccia conducted by Rubicon Minerals returned assays of 16.1 g/t Au and 63 g/t Ag. Grab samples from the pyritic–silica–sericite zone west of the breccia return assays up to 11.6 g/t Au and 725 g/t Ag.

Immediately to the north of this area is the Santana prospect, discovered in late 1998 by Fort Knox Gold Resources Inc. This prospect occurs in a succession of late Neoproterozoic subaerial volcanic rocks, near the top of a 585-580 Ma rhyolitic to rhyodacitic volcanic sequence, several metres below the stratigraphic contact with overlying, unaltered Wych Hazel Pond Complex sedimentary rocks. The initial discovery of precious metal mineralization was in fly-rock from blasting associated with construction of a fibre optic cable system. Blasted blocks of sericite–silica altered material with veinlets and fracture coatings of pyrite and galena returned assays up to 31.6 g/t Au in angular float. Subsequent trenching in the area of the fibre optic cable uncovered the same alteration and localized examples of similar mineralization in outcrop, which assayed up to 6.2 g/t Au and 612 g/t Ag.

The best Au–Ag mineralization is in light grey–green, silicic rocks with up to 5% sericite, and locally disseminated pyrite. The absence of hematite dusting and very low sulphide content are apparent characteristics of the mineralized zone. The silicic alteration is locally cut by quartz–hematite ± pyrite veinlets that are themselves locally cut by narrow (*ca.* 5 mm) grey veinlets of galena, sphalerite and anglesite ($PbSO_4$). The Au and Ag mineralization appears to be restricted to the most silicic material, associated with fracture controlled, grey sulphide veinlets, containing pyrite, sphalerite, galena and anglesite. Pyrite occurs as subrounded aggregates or clots in the larger veinlets, and as fine disseminations along fractures. Opal is locally developed.

The mineralization at the Santana prospect has some characteristics that are analogous with low-sulphidation epithermal systems – *e.g.*, association with rhyolite domes, high Ag/Au ratio and an association with lead. However, neither adularia nor colloform–crustiform quartz veins diagnostic of such system have yet been found. The Santana prospect also exhibits some characteristics of alteration zones related to or peripheral to a colloform–crustiform quartz–adularia low sulphidation Au–Ag vein system elsewhere in this belt.

STOP 11: Pastureland Road (Zn–Pb–Cu–Au–Ag) Prospect

Location: *Proceed through underpass on Route 61 and take the second right onto a secondary gravel road. Travel along the road for approximately 2 km to a large cleared area located on the right hand side of the road.*

Sulphide mineralization at this locality was originally noted by Hayes and O'Driscoll (1990). More extensive Zn-rich mineralization was discovered here in 1999 by Fort Knox Gold Inc.; trenching and shallow diamond-drilling was carried out by subsequent licence holders. The Zn–Pb–Cu–Au–Ag mineralization is hosted by the *ca.* 580-565 Ma Wych Hazel Pond Complex. This shallow marine mafic volcanic and sedimentary succession is here intruded by hypabyssal feldspar porphyry.

Mineralization occurs in deformed, fine- to coarse-grained volcanic breccias (hyaloclastites) of mafic and mixed mafic–felsic composition, containing chilled fragments of purple-grey, vesicular mafic to intermediate material in a green, chloritized matrix. Zn–Pb–Cu mineralization is developed in fine-grained silicified fragmental rocks of presumed mafic protolith within a zone, several tens of metres wide, adjacent to a folded body of fine-grained grey plagioclase porphyry. Sphalerite, galena and chalcopyrite occur together with pyrite as disseminations, as network fractures, and in early-mineralized fragments within the fine-grained, grey, fragmental rocks. The entire zone is weakly anomalous in gold (*ca.* 20-100 ppb), and in some silicified areas has yielded values up to 2.1 g/t Au; Ba (>2000 ppm) and Ag (up to 1.5 oz/t) are anomalous throughout. Higher grade sulphide-rich zones at surface (up to 8.9% Zn and 5.2% Pb in grab samples; A. Turpin, pers. comm., 2000) have a semi-massive appearance, and form discontinuous pods or strain augen. The largest of several pods has approximate surface dimensions of about 1 by 0.5 m. A short vertical drill hole collared in one such pod shows these are more extensive in the immediate subsurface; this hole intersected mineralized rocks that include a zone of 3.1% Zn and 1.35% Cu over 6 m.

The mineralized rocks are affected by part of a major regional high-strain zone, but mineralization is pretectonic. This prospect is near the site of the Thousand Acre Shear Zone, a major vertical or near-vertical zone of high-strain developed on a regional scale, immediately west of and parallel to the Topsail Fault.

Together, the Manuels Volcanic Suite and the overlying Wych Hazel Pond Complex record the transition from mineralized (Au–Ag) subaerial epithermal conditions to mineralized (Zn–Pb–Cu) submarine conditions. These successions record the collapse and submergence of the metallogenically important *ca.* 580 Ma volcanic arc, characterized by widespread hydrothermal activity. The upper marine volcano-sedimentary succession may have significant, largely untested potential for both conventional and Au rich VMS-style mineralization. This unit has significant aerial extent, most notably to the north-northeast, where it can be traced onto the St. John's Peninsula. Any indication of quartz–sericite–pyrite and, more importantly, of aluminous alteration (andalusite–kyanite–pyrophyllite with pyrite) will strongly emphasize the potential for Au-rich VMS mineralization in the area.

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Paul Myrow and Guy Narbonne

FT-A4 **Mistaken Point: A Potential World Heritage Site for the Ediacaran Biota**
Richard Thomas

FT-A5 **Neoproterozoic Epithermal Gold Mineralization of the Northeastern Avalon Peninsula, Newfoundland**
Sean J. O'Brien, Gregory W. Sparkes, Greg Dunning, Benoît Dubé and Barry Sparkes

FT-A9 **Cores from the Ben Nevis and Jeanne d'Arc Reservoirs: A Study in Contrasts**
Duncan McIlroy, Iain Sinclair, Jordan Stead and Alison Turpin

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Guy M. Narbonne, Marc Laflamme, Richard Thomas, Catherine Ward and Alex G. Liu

FT-B2 **Peri-Gondwanan Arc-Back Arc Complex and Badger Retroarc Foreland Basin: Development of the Exploits Orocline of Central Newfoundland**
Brian O'Brien

FT-B3 **Stratigraphy, Tectonics and Petroleum Potential of the Deformed Laurentian Margin and Foreland Basins in western Newfoundland**
John W.F. Waldron, Larry Hicks and Shawna E. White

FT-B4 **Volcanic Massive Sulphide Deposits of the Appalachian Central Mobile Belt**
Steve Piercey and John Hinchey

FT-B5 **Meguma Terrane Revisited: Stratigraphy, Metamorphism, Paleontology and Provenance**
Chris E. White and Sandra M. Barr

FT-B6 **The Grenville Province of Southeastern Labrador and Adjacent Quebec**
Charles F. Gower

FT-B7 **Geotourism and the Coastal Geologic Heritage of the Bonavista Peninsula: Current Challenges and Future Opportunities**
Amanda McCallum and Sean O'Brien