A PROSPECTOR'S CUIDE TO ALTERATION AND EPITHIERMAL COLD MINERALIZATION -EXAMPLES FROM EASTERN NEWFOUNDLAND

A Pre-Conference Field Trip

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Newfoundland Branch

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Date: October 31, 2012

Sponsors: CIM Newfoundland Branch Department of Natural Resources Matty Mitchell Prospectors Resource Room

Introduction

General Characteristics of Epithermal Related Mineralization

Epithermal systems are predominantly "near surface" (<2 km depth) features that can be associated with the development of gold, silver and base metal mineralization. These systems are broadly subdivided into two main categories, namely *high*- and *low-sulphidation* systems, but in more deeply eroded areas, *porphyry copper* related mineralization may also be present (Figure 1). High-sulphidation and low-sulphidation systems display some similar styles of mineralization and *alteration*, but the two systems can be separated based on the presence of several key ore minerals along with the alteration related to the formation of the mineralization (Table 1). Understanding the distribution and zonation of these alteration minerals is vital in targeting the most prospective portions of epithermal systems. (*Note: Words in italics are explained in Glossary*).

High-sulphidation systems, also known as quartz-alunite-pyrophyllite-dickite-kaolinite systems, are generally dominated by *disseminated* or *replacement style* ore, which often contain copper minerals such as *covellite* or *enargite*, along with gold. This mineralization is commonly developed within zones of "*vuggy*" silica and *alunite* alteration which is surrounded by a broader zone of *pyrophyllite-illite* dominated alteration (Figure 2). High-sulphidation systems are characterized by development of broad alteration haloes, resulting from high temperature, *acidic*, oxidized, *hydrothermal* fluids, which result in pervasive alteration of the original host rock.

Low-sulphidation systems, also referred to as quartz-*adularia-sericite*-calcite systems, are mostly vein or *stockwork* style mineralization which is predominantly associated with *chalcedonic* silica with or without *adularia*. These systems are generally sulphide-poor and are dominated by gold and silver mineralization, but may also be anomalous in copper, lead and zinc. Low-sulphidation systems are predominantly associated with very narrow, restricted alteration haloes dominated by *illite* or *illite-smectite* alteration assemblages (Figure 2), which result from low temperature, near neutral, reduced, hydrothermal fluids. Surficial *sinter* deposits related to the development of these systems are often barren with respect to precious metals, but can be enriched in other elements such as mercury, selenium, antimony, arsenic and locally molybdenum.

Mineralogy of gangue -		
frequency of occurrence (abundance)		
	Low-sulphidation	High-sulphidation
Quartz	ubiquitous (abundant)	ubiquitous (abundant)
Chalcedony	common (variable)	common (minor)
Calcite	common (variable)	absent (except as overprint)
Adularia	common (variable)	absent
Illite	common (abundant)	uncommon (minor)
Kaolinite	rare (except as overprint)	common (minor)
Pyrophyllite-diaspore	absent (except as overprint)	common (variable)
Alunite	absent (except as overprint)	common (minor)
Barite	common (very minor)	common (minor)

Table 1: Comparison of common alteration minerals associated with the development of high- and low-sulphidation systems, from White and Hedenquist, 1995.

Neoproterozoic Hydrothermal Systems in the North American Avalonian Belt

(modified from O'Brien et al., 2012)

The North American Avalonian Belt (Figure 3) hosts many examples of Neoproterozoic (1000 – 542 Ma) 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), Haile, Ridgeway and Barite Hill gold mines in northern South Carolina (Figure 3; *see* O'Brien *et al.*, 1998 and references therein).

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 Haile mines is more unclear, and both *syn-metamorphic* and metamorphosed epithermal origins have been argued for these deposits. 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). Less well exposed, but hosting high-grade mineralization, is the adjacent Berg's prospect, which has locally produced grab samples of up to 54 g/t Au (O'Brien and Sparkes, 2004).

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, 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.

Finally, the presence within the Avalonian Belt of large-scale *advanced argillic* alteration at the boundary 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).

Regional Geological Setting

(modified from O'Brien et al., 2012)

Avalonian-cycle Neoproterozoic epithermal and intrusion-related gold systems:

Gold in the Neoproterozoic high-sulphidation systems occurs with copper in vuggy silica (Plate 1) 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 (Dubé *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 (Plate 2) containing significant gold grades. Several of the epithermal belts are spatially associated with breccia-hosted Cu–Au (e.g. Butlers Pond prospect) and Au–Cu–Zn mineralization; however, most of this intrusion-related gold mineralization formed during earlier magmatic events.

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 known as the Holyrood *Horst* (Figure 4). The Horst structure is somewhat asymmetric based on current knowledge and geochronological data, with the majority of the older volcanic rocks exposed along the western margin of the horst structure. Along the eastern margin of the horst, plutonic rocks correlated with the Holyrood Intrusive Suite are juxtaposed and locally intrude a bimodal volcanic suite consisting of predominantly subaerial felsic volcanic rocks (Figure 4). These volcanic rocks contain an extensive zone of advanced argillic alteration, approximately 15km in length and up 1km in width (Figure 5) within an area referred to as the eastern Avalon high-alumina belt. This belt of alteration is host to the local development of pyrophyllite–diaspore high-sulphidation-style epithermal alteration. In the mid 1990's the identification 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.

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 the composite, predominantly felsic, Manuels Volcanic Suite. 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 Manuels Volcanic Suite. The main occurrence of pyrophyllite–diaspore alteration is developed within the Oval Pit Mine (Figure 5). From here the alteration can be traced southward along the Mine Hill Shear Zone (Figure 5). 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. 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 most extensive zone of low-sulphidation veining identified to date occurs in the region of the Steep Nap prospect (Figure 5), located approximately 3km to the north of the Oval Pit Mine; here crustiform–colloform banded veins can be traced intermittently for up to 550m along strike. 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 at the Bergs prospect (Plate 3).

Stop #1: Steep Nap Road Prospect: Au–Ag-bearing, Low-Sulphidation-Style Veins and Breccias

(modified from O'Brien et al., 2012)

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 #5), and about 1.25 km SSW of the Berg's prospect (Figure 5). 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 sulfide 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 (Sparkes, B.A., 2003).

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 fragments. 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 halos* and later patches and halos 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, CO₂ 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 hydraulic fracturing 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.

Vein features preserved here demonstrate that these rocks formed within the boiling level of a lowsulphidation 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-stockwork 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 (Sparkes, B.A., 2005a).

STOP 2: 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 1. 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* (Plate 4) 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-mineral 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 centimeter-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–galena. Clasts in the breccia consist of vein material with various textures (including spectacular examples of lattice-bladed carbonate overgrown by silica and adularia (Plate 5)), 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 3: 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 meters wide (true width) within an alteration/brecciation envelope measuring over 6 meters 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 (Sparkes, B.A., 2005b). Enveloping the vein system is a variably developed zone of brecciation/alteration within the host rhyolite. Network-style fracturing is accompanied by chlorite-hematite-silica alteration and minor pyrite. This alteration zone is weakly elevated in gold. Note

however, 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 power line and back down the hill along the path which branches to the right from the power line, 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 cored 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 4: 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. Proceed 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.

Stop 4a:

In this area we see well developed flow-banded rhyolite of the Manuels Volcanic Suite displaying a distinct maroon coloration. Here we are approximately 170m 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 \pm 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 (Sparkes, B.A., 2005b).

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

Stop 4b:

Here we are about 500m 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 what we have seen peripheral to the Steep Nap system. Veins and breccias here are weakly anomalous in gold, typically contain between 50 ppb and 1g/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 5: Oval Pit Pyrophyllite Mine

WHILE ON THE MINE SITE, PLEASE WEAR THE HARD HAT THAT HAS BEEN PROVIDED.

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.*

EXERCISE EXTREME CAUTION! PLEASE KEEP AWAY FROM EDGE OF THE OPEN PIT.

The view from the top of the pit shows a number of features including the outline of the pyrophyllitediaspore 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 5). 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; 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 silica* 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 meter-scale pods of high-grade silica, containing less than 5 percent sericite and/or pyrophyllite. Locally, pyrite forms the matrix of associated silica breccias. No large 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 7).

STOP 6: 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. Faulting is accompanied by 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 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.

STOP 7: 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 1.8g/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 8: 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.

Caution: oncoming traffic on ramp! Please walk on the gravel shoulder.

The outcrop on the north side of the west-bound lane on Route 1 exposes a 100-m-wide section through a locally auriferous (up to 11.2 g/t Au) zone of advanced argillic alteration developed in the same late Neoproterozoic volcanic succession as in today's earlier stops. The prospect is sited near the western edge of the eastern Avalon high-alumina Belt, approximately 4 km along strike to the south from the Oval Pit pyrophyllite mine and the Mine By-pass prospect. Hydrothermal alteration (silica–sericite–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 meters of the boundary of the host volcanic rocks with the intrusive rocks 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, 1997b; O'Brien *et al.*, 1997, 1998). Pyrite occurs as disseminations, clots and thin veinlets within the matrix of the breccias. The auriferous breccias yield assays up to 210 g/t Ag and 2 g/t As. The gold-bearing breccias at this locality are comparable in many respects to those seen in the previous stop (4 km on-strike to the north). 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 on the back 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 meters below the stratigraphic contact with overlying, unaltered Wych Hazel Pond sediments. 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 gold 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 gold and 612 g/t silver.

The best gold–silver 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 (PbSO₄). The gold and silver 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 lowsulphidation 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 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 9: 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 approx. 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 license 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, personal communication, 2000) have a semi-massive appearance, and form discontinuous pods. The largest of several pods has approximate surface dimensions of about 1 m 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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GLOSSARY

Acidic – Fluids having a pH of < 7, more commonly around 0-2 in acidic hydrothermal fluids related to high-sulphidation systems; similar to battery acid.

Adularia – (K, Na) AlSi₃O₈; low-temperature ($<200^{\circ}$ C) potassium feldspar, commonly light pink in color, but can also be white.

Advanced argillic – An alteration assemblage formed under low pH and high temperatures; common minerals include alunite, diaspore, pyrophyllite, dickite, tournaline, topaz, zunyite and white mica.

Alteration – The change in rocks and minerals due to the reaction with circulating hydrothermal fluids.

Alunite $- \text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$; sulfate mineral, related to acidic alteration within epithermal systems.

Andalusite $- Al_2SiO_5$; an aluminum silicate mineral which may develop during the metamorphism of advanced argillic alteration assemblages.

Argillic – An alteration assemblage characterized by the minerals illite, illite-smectite, smectite and carbonate.

Bimodal volcanic suite – A volcanic sequence containing a mixture of both mafic and felsic volcanic rocks.

Boiling textures – Pseudobladed calcite (calcite now replaced by silica) along with the development of colloform-crustiform banding in chalcedonic silica veins indicate boiling of the hydrothermal fluids.

Chalcedonic – A translucent to transparent milky or greyish quartz with distinctive microscopic crystals; similar appearance as candle wax.

Chalcedonic recrystallization – Silica minerals, except quartz, are unstable and convert to quartz after deposition.

Cockade – A subtype of crustiform banding, in which the fragments in a breccia become surrounded by crustiform bands.

Colloform – A texture developed in veins in which the external surface of a mineral or mineral aggregate (often silica) shows combined spherical, botryoidal, reniform, and mammillary forms.

Crustiform – A texture developed in veins in which the successive, narrow (up to a few centimeters) and sub-parallel bands are distinguished by differences in texture, mineral proportions and/or color.

Covellite – CuS; copper sulphide mineral, often displaying an indigo-blue coloration.

Dickite – $Al_2Si_2O_5(OH)_4$; a clay mineral, related to high temperature (~200-225°C) acidic alteration within epithermal systems.

Disseminated – Mineralization occurring throughout the host rock as individual crystals or as clusters of crystals.

Enargite – Cu₃AsS₄; generally has a black or iron-grey coloration and has a black streak.

Epithermal – Ore deposits formed at a shallow crustal depth (<2km depth) and temperatures ranging from <150 °C to ~300 °C.

Eutaxitic – The alignment of pumice fragments or glassy lenses within welded pyroclastic deposits defining a bedding-parallel foliation which is attributed to welding and compaction of pumice fragments.

Flow banding – Banding or layering developed in a volcanic flow as it is erupted on the surface.

High-sulphidation deposit – Epithermal systems formed from high temperature (200-300°C), oxidized, highly acidic (pH 0-2) hydrothermal fluids.

High strain zone – A structurally controlled zone with an intense penetrative fabric developed within the host rock indicating movement along a structure under high pressure.

Horst – Upthrown block lying between two steep-angled fault blocks.

Hydrothermal – Hot underground fluids capable of transporting metals in solution.

Hypabyssal – Intrusions that intrude to a shallow level within the crust and often forming dykes or sills; generally intrudes to depths of <1km.

Illite – $KAl_4Si_6Al_{1.5}O_{20}(OH)_4$; clay mineral indicative of temperatures >200 °C.

Illite-smectite – Clay mixture indicative of temperatures between 150-200°C, and a near-neutral pH.

Juxtaposed – Placed side by side due to fault movement.

Kaolinite - $Al_2Si_2O_5(OH)_4$; clay mineral, related to lower temperature (<200°C) acidic alteration within epithermal systems.

Lithophysae – These are spherulites that have a central vug, which may remain open or be lined or filled with a secondary mineral phase such as quartz or chlorite.

Low-sulphidation deposit – Epithermal system formed from near neutral, reduced, low temperature (generally <200°C) hydrothermal fluids.

Massive silica – Zones resulting from either the leaching of all other material by highly acidic hydrothermal fluid or by flooding by a silica-saturated fluid resulting in silica replacement.

Matrix – The material which supports the larger fragments within a breccia.

Polylithic lapilli tuff – A primary volcanic deposit consisting of a mixture of ash and rock fragments, with the fragments ranging from 2 - 64mm in diameter and consisting of several different rock types.

Polyphase silicic replacement – Replacement of the original host rock by silica as a result of hydrothermal alteration; this may be the result of several separate episodes of silica flooding.

Porphyry copper deposits - Copper ore bodies which are associated with porphyritic intrusive rocks and the fluids that accompany them during the transition and cooling from magma to rock. Successive envelopes of hydrothermal alteration typically enclose a core of ore minerals disseminated in often stockwork-forming hairline fractures and veins. Porphyry ore bodies typically contain between 0.4 and 1% copper with smaller amounts of other metals such as molybdenum, silver and gold.

Protolith – The original rock prior to being affected by alteration or deformation.

Pyroclastic – A volcanic deposit resulting from a volcanic eruption. These deposits can contain varying proportions of rock fragments and volcanic ash.

Pyrophyllite – $Al_2Si_4O_{10}(OH)_2$; hydrous aluminum silicate mineral, related to high temperature (200-250°C) acidic alteration within epithermal systems.

Remobilization halos – Halos resulting from the leaching of iron from the primary volcanic host rock.

Replacement-style - Mineralization that infills leached cavities or "vugs".

Sericite $-(K,Na)_2Si_6Al_2O_{20}(OH)_4$; fine-grained white mica.

Siliciclastic – Clastic, noncarbonated, sedimentary rocks that are almost exclusively silica-bearing, either in the form of quartz or other silica minerals.

Sinter – Layered silica forming in a hot spring environment, at or very near the earth's surface.

Specularite – Fe_2O_3 ; a variety of hematite.

Spherulitic – Spherulites consist of radiating arrays of crystal fibers and represent hightemperature devitrification of silica glass in volcanic rocks; typically they have diameters of between 0.1-2cm but can be much larger.

Stockwork - A complex system of structurally controlled, or randomly oriented, networkstyle veinlets.

Syn-metamorphic – Occurring at the same time as deformation.

Thrust fault – A type of fault in which lower or older rocks are pushed up over high or younger rocks.

Volcanogenic – Dominantly of volcanic origin.

Vuggy – Small cavities developed in a rock or vein resulting in a spongy appearance.

Wall rock alteration – Alteration that is developed marginal to a secondary feature such as a vein.

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Figure 1: Schematic cross section through an intrusive centered hydrothermal system outlining the environments of porphyry, high-sulfidation and low-sulfidation systems (Hedenquist and Lowenstern, 1994).



Figure 2: Schematic diagram of the fluid types and alteration zoning around high- and low-sulphidation epithermal systems (from White and Hedenquist, 1995).



Figure 3: Distribution of Avalonian rocks within the Appalachian Orogen (modified from O'Brien, Dubé and O'Driscoll, 1999; base map modified from William and Hatcher, 1983).



Figure 4: 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).



LEGEND

EARLY PALEOZOIC

Cambrian

ADEYTON and HARCOURT GROUPS (undivided) 19 Red and black shale and interbedded grey limestone; locally massive, poorly sorted boulder conglomerate at base

LATE NEOPROTEROZOIC

Ediacaran

BEAVER HAT INTRUSIVE SUITE

18 Fine- to coarse-grained, massive gabbro (age of intrusion uncertain)

WYCH HAZEL POND COMPLEX (Post- 580 Ma)

- 17 Massive, brown-weathering, epidote-rich volcaniclastic sandstone, containing abundant mafic volcanic detritius; minor unseparated epidote-rich submarine mafic volcanic rocks and associated hyaloclastite
- 16 Moderately vesicular, locally amygdaloidal, epidote-rich, dark green to purple, massive to locally pillowed basalt; associated hyaloclastite
- Thin- to medium-parallel-bedded, moderately to strongly siliceous, green to red siltstone and interbedded medium- to coarse-grained subarkosic sandstone and minor pumiceous tuff; locally with pebble to boulder conglomerate at base; includes minor unseparated mafic volcanic flows and associated breccias and unseparated feldspar poryphyry

MANUELS VOLCANIC SUITE (ca. 580 Ma)

- White- to yellow-weathering silica-sericite-pyrite-pyrophyllite-diaspore-rutile hydrothermal alteration (with varying proportions of each mineral)
- 13 White- to pale yellow-weathering sericite-silica ± pyrite hydrothermal alteration with patchy pyrite development; alteration associated with prominent shear zones
- 12 Fine-grained, dark brown- to dark green-weathering, moderate to weakly magnetic, locally amygdaloidal and plagioclase-phyric basalt; minor mafic intrusive
- 11 White, pervasive silica alteration without pyrophyllite-diaspore
- Massive crystal-rich ash-flow tuff, containing mm-scale white crystals, rare cm-scale dark purple collapsed pumice fragments and minor disseminated pyrite in a dark green to red groundmass
- 9 Dark purple-weathering, massive volcaniclastic breccia containing subangular to subrounded fragments; contains minor unseperated aphanitic massive rhyolite
- B Dark purple to grey-green, white-weathering aphanitic rhyolite with locally developed lithophysae and rare porphyritic zones containing mm-scale white feldspar crystals

WHITE HILLS INTRUSIVE SUITE (625-620 Ma)

- Pale purple-weathering, quartz-feldspar porphyry, containing fine- to medium-grained phenocrysts of plagioclase, quartz and K-feldspar within a light purple aphanitic
- 6 Unseparated quartz-feldspar porphyry and medium- to coarse-grained equigranular granite
- 5 Hydrothermally altered (silica-sericite-chlorite-pyrite), grey-green- to pale pinkweathering, medium- to coarse-grained, equigranular, quartz-K-feldspar-plagioclasebearing granite
- White-weathering monzonite with coarse-grained, pale green plagioclase and fine- to medium-grained chlorite, quartz and K-feldspar; locally contains 2-10cm diameter finegrained dioritic xenoliths

HOLYROOD INTRUSIVE SUITE (ca. 620 Ma)

- Propylitized granite with a pale pink-white-green-weathering, generally equigranular to quartz-phyric, with sub-equal amounts of plagioclase, K-feldspar and quartz
- 2 Pink- to orange-weathering equigranular, biotite-rich, fine- to coarse-grained granite

WHITE MOUNTAIN VOLCANIC SUITE (Pre- 620 Ma)

Purple to grey-green rhyolite with fine- to medium- grained feldspar crystals within a flowbanded groundmass and minor fiamme-bearing ash-flow tuff, minor dark to pale green or pale pink, matrix-supported agglomerate with sub-rounded to rounded fragments; fragments dominantly bright pink, potassic altered material

SYMBOLS



Figure 5: Regional geological map of the eastern side of the Holyrood Horst.



Plate 1: Well developed vuggy silica texture with abundant rusty weathering gossan and minor malachite staining; Hickey's Pond prospect, Burin Peninsula region.



Plate 2: Well developed cockade-style brecciation (right side of photo) followed by colloform-crustiform banded silica (grey and white) and adularia (pink) towards the center and lefthand portions of the photograph.



Plate 3: Visible gold in association with specularite in a chalcedonic silica vein from the Bergs prospect.



Plate 4: Well developed flow-banded rhyolite; Santana prospect.



Plate 5: Pseudobladed calcite with dark reddish brown hematite staining. Calcite is now replaced by silica.