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A NOTE ON NEOPROTEROZOIC GOLD, EARLY PALEOZOIC COPPER AND BASEMENT–COVER RELATIONSHIPS ON THE MARGINS OF THE HOLYROOD HORST, SOUTHEASTERN NEWFOUNDLAND

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ABSTRACT

A new occurrence of gold-bearing, epithermal-style quartz veins and silica-rich breccias has been discovered in late Neoproterozoic Avalonian rocks at the north end of the eastern Avalon high-alumina belt, in Manuels (Conception Bay South), southeastern Newfoundland. Preliminary sampling indicates that gold mineralization is associated with massive and crustiform-banded chalcedonic silica, occurring together with hematite, crystalline quartz and locally, adularia. Several aspects of the nature and setting of the new discovery lend support to existing models that highlight the low-sulphidation-style precious-metal potential of the large-scale fossil epithermal system along the eastern margin of the Holyrood Horst.

Newly documented relationships exposed along recently excavated outcrops of the (Avalonian) sub-Cambrian unconformity in the same area provide independent stratigraphic control for the pre-Cambrian age of the hydrothermal alteration and gold mineralization. The truncation of a penetrative cleavage in the Neoproterozoic basement at the Cambrian unconformity demonstrates the Neoproterozoic age of tectonism along structures related to a fundamental geological boundary at the eastern edge of the Holyrood Horst. A single, penetrative cleavage of Paleozoic age is regionally developed in rocks above and below the same Cambrian unconformity along the western margin of the Holyrood Horst. In that area, the cleaved Cambrian cover unconformably overlies Neoproterozoic tectonic boundaries between rocks of diverse age and facies within the Neoproterozoic succession. In a number of places, the Paleozoic cleavage is more pervasively and penetratively developed in the Cambrian cover than in the basement.

Small-scale examples of copper mineralization in the Cambrian cover around the Holyrood Horst contrast with that in underlying basement rocks and exhibit characteristics of sediment-hosted stratiform copper-style (SSC) mineralization. The Cambrian copper occurs mainly as chalcocite, patchily distributed in reduced grey zones in variegated shale and algal limestone, at and near the basement contact.

INTRODUCTION

Regional and detailed bedrock mapping and integrated studies of mineral occurrences were carried out in several parts of the central Avalon Peninsula (NTS 1N map area) during the 2001 field season. This work was undertaken as part of the Geological Survey's continuing program of geological investigations in the Appalachian Avalon Zone (e.g., O'Brien *et al*., 1997, 1998, 1999, 2001a, b). Field investigations and related geochemical and geochronologic studies have focused on refining the newly proposed magmatic and volcano-stratigraphic framework for this region (*cf.* O'Brien *et al.*, 2001a) and establishing the nature, age and settings of precious- and base-metal mineralization within that framework. This work has produced a number of interesting results, including the discovery of epithermal gold and sediment-hosted copper mineralization in Neoproterozoic and Paleozoic rocks, respectively. These findings and several other new results which are demonstrative of this region's diverse and protracted history of mineralization and tectonism, are summarized briefly below.

THE BERGS PROSPECT: A NEW GOLD-BEARING EPITHERMAL VEIN SYSTEM IN THE EASTERN AVALON HIGH-ALUMINA BELT

A new zone of banded, epithermal-style, gold-bearing quartz veins and silica-rich breccias, herein named the Bergs Prospect, was discovered within late Neoproterozoic volcanic rocks near the eastern margin of the Holyrood Horst of the Avalon Peninsula (Figure 1). Gold mineralization (up to 7.2 g/t in grab sample; Table 1) and associated silica–

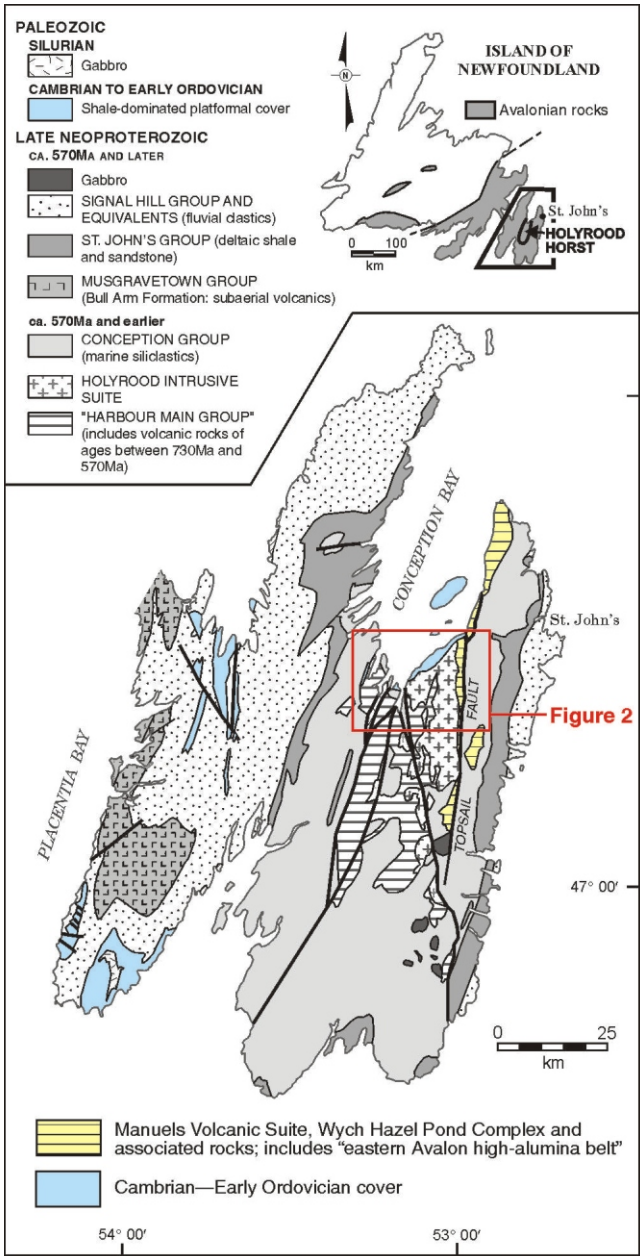

Figure 1. *Major geological units of the Avalon Zone on the Avalon Peninsula, eastern Newfoundland, showing the distribution of early Paleozoic cover and the late Neoproterozoic rocks that host the mineralized hydrothermal alteration zones along the eastern side of the Holyrood Horst (modified from O'Brien* et al., *2001a).*

hematite-altered and hydrothermally veined subaerial volcanic rocks occur in outcrop, subcrop, and large (≤3m) angular boulders immediately south of Route 60[1], in the community of Manuels, Conception Bay South (Figure 2). The newly discovered mineralization is sited at the north end of the eastern Avalon high-alumina belt (*cf.* Hayes and O'Driscoll, 1990), an extensive zone (>15 km strike-length) of volcanic-hosted, epithermal-style alteration known for its commercial pyrophyllite deposits (Vhay, 1937; Papezik and Keats, 1976; Oval Pit Mine), which are interpreted as part of the advanced argillic facies of a high-sulphidation-type hydrothermal system (*see* O'Brien *et al.*, 1998; Dubé *et al.*,

Table 1. Gold values from the Bergs Prospect, eastern Avalon Zone, Manuels (Conception Bay South), Newfoundland

Sample Number	Au ppb	Rock Type
01-1	34	grey chalcedonic silica
01-2	97	banded silica vein breccia
01-3	127	hematite–silica vein breccia
01-4	349	hematite–silica vein breccia; trace adularia
01-5	68	massive silica
01-6	256	hematite–silica breccia
01-7	583	hematite–silica breccia
01-8	37	hematite–silica breccia
01-9	158	hematite–silica breccia; trace pyrite
01-10	305	dark grey banded chalcedonic silica
01-11	534	massive chalcedonic silica
01-47	597	crustiform-banded chalcedonic silica
01-48	306	hematite–silica vein breccia
01-49	7220	banded chalcedonic silica–adularia vein
01-50	919	chalcedonic silica–adularia vein breccia
01-52	59	vein breccia
01-53	1335	crustiform-banded silica–hematite vein
Berg 1	5	crystalline silica–adularia(?) vein
Berg 2	4950	crustiform adularia–silica vein
02-01	1746	grey to black chalcedonic silica breccia
02-02	5	grey silica breccia with chlorite
02-03	74	grey-banded silica with hematite
02-04	5668	grey-banded chalcedonic silica vein with hematite and chlorite
02-05	240	grey crystalline and banded chalcedonic silica
02-06	992	crustiform-banded chalcedonic silica vein
02-07	126	crystalline silica with hematite
02-08	715	grey-banded chalcedonic silica from regolith block

[1] The Bergs Prospect exposed immediately south of Route 60 (Conception Bay Highway), near the Cherry Lane intersection, adjacent to the right-of-way of the abandoned CN rail line.

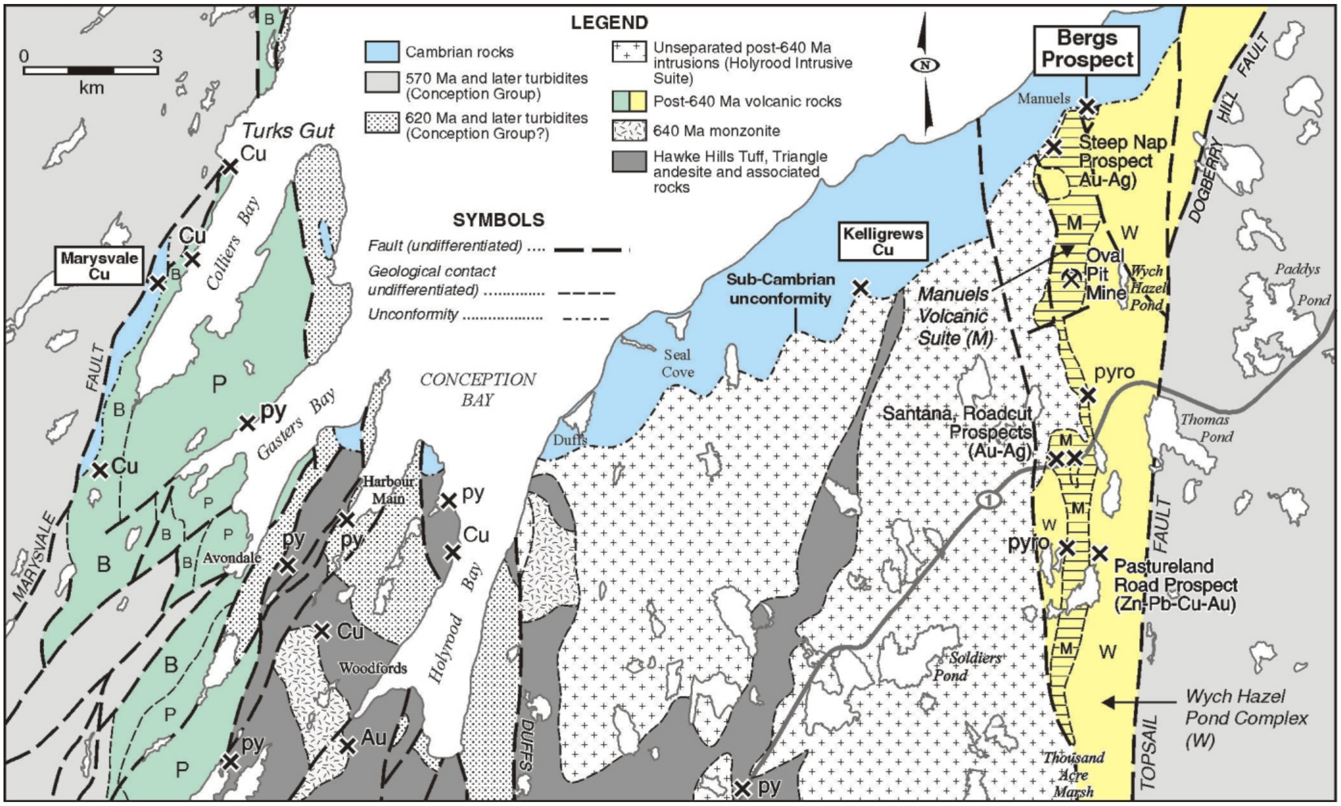

Figure 2. *Simplified geological map of the southern part Conception Bay, showing the location of Neoproterozoic and early Paleozoic mineral occurrences discussed in the text (B= Blue Hills Basalt; P = Peak Tuff). Modified from O'Brien* et al., *2001a.*

2001). Precious-metals prospects in the belt are typically vein- or breccia-hosted (e.g., Steep Nap, Roadcut, Mine By-Pass and Santana prospects; O'Brien *et al.,* 2001b). Some exhibit classic characteristics of low-sulphidation gold-vein systems (e.g., Steep Nap Prospect; Mills *et al.,* 1999), and some, if not all, may have formed late in the evolution of the larger hydrothermal system.

Several outcrops and large angular boulders of silica-veined and/or hydrothermally altered volcanic rocks and silica-altered plutonic rocks were exposed and, in some instances, subsequently removed for fill or re-covered during ongoing excavations at the site of a new housing development. The mineralized veins and breccias occur in late Neoproterozoic subaerial, red to maroon rhyolitic flows, fine-grained tuff-breccias and spherulitic rhyolite of the Manuels volcanic suite, part of the larger, previously undivided Harbour Main Group (*see* O'Brien *et al.,* 2001a). The Bergs Prospect is located approximately 1 km northeast of the Steep Nap low-sulphidation gold prospect (Mills *et al.,* 1999), and approximately 4 km north–northeast of the Manuels pyrophyllite–diaspore deposit (Oval Pit Mine; Figure 2; *see* O'Brien *et al.,* 1998, 2001b).

Gold mineralization occurs in crustiform-banded veins composed primarily of chalcedonic silica and crystalline quartz, and in silica-rich, hematite- and/or chlorite-bearing vein-breccia. The best gold grades at surface occur in banded veins and broken and internally brecciated vein material immediately east of an adjoining zone (ca. 20 m exposed width) rich in white to light-grey hydrothermal silica. The latter includes both brecciated veins and polyphase, network-style silica flooding, associated with hematite, in hydrothermally brecciated, oxidized felsic pyroclastic material.

Banded and massive, white to pale-grey silica occurs in both crystalline and amorphous chalcedonic forms, within massive and cockade-textured breccias, and in both intact and weakly to intensely brecciated, mm- to cm-scale veins exhibiting well-preserved crustiform texture (Plates 1 to 4). The chalcedonic and crystalline silica material is intergrown with earthy, dark red to pale red, hydrothermal hematite (plus minor specularite) and to a lesser degree, dark green chlorite and apple-green sericite. Adularia is apparently rare at surface, although is locally present in some of the mineralized boulders. Blasted outcrop and large, angular boulders

Plate 1. *Gold-bearing crustiform- and colliform-banded chalcedonic silica vein, containing hematite and crystalline quartz, Bergs Prospect (sample is approximately 13 cm wide).*

(0.5 m to 3 m in diameter) of red, maroon and grey, variably silicified rhyolite and fine-grained felsic breccia, containing 2- to 20-cm-wide chalcedonic-silica-bearing veins, sampled immediately adjacent to the main silica-rich zone, have returned assays between 1.2 and 7.2 g/t Au. The highest gold value was obtained from a chalcedonic silica vein that contains crustiform-banded, pale orange adularia. The main zone of silica is itself anomalous in gold over the width that was exposed at the time of sampling, averaging approximately 250 ppb Au over 20 m (*see* Table 1).

The mineralized zone is bounded to the east by well-cleaved mafic rocks of presumed volcanic protolith and to the west and southwest by grey, strongly altered, massive grey silica-rock with weakly to moderately disseminated pyrite. The protolith of the latter rock is unclear but the intense alteration resembles that seen in granite elsewhere in this belt (O'Brien *et al.,* 2001b). The silica-altered rocks are spatially associated with small areas of pyrite–sericite-bearing hydrothermally altered, felsic volcanic rocks. The silica-rich rocks pass to the west and southwest into an openly folded belt of altered granites and porphyries that lie east of (and locally underneath) parts of the eastern Avalon high-alumina belt. Granites adjacent to the Bergs Prospect also contain locally developed coarse-grained galena and chalcopyrite along fractures.

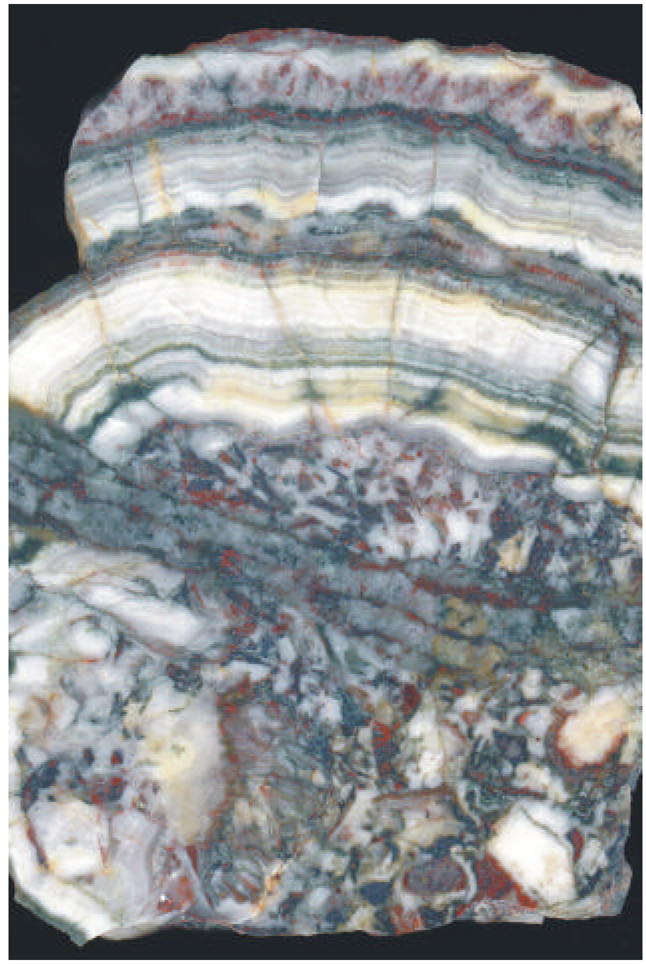

Plate 2. *Brecciated and crustiform-banded rock, Bergs Prospect (sample is approximately 8 cm wide).*

Outcrop exposed during the course of construction (some of which has since been covered) demonstrated the zone of veins and breccia to be more-or-less continuous along strike for several tens of metres. The southern extent of the system is unknown, although smaller discontinuous zones of silica-altered material and silica–hematite veins are exposed sporadically along strike for approximately 250 m. The zone passes northward under the unconformably overlying shale-rich fossiliferous Cambrian cover sequence, the base of which is defined by a boulder conglomerate unique to this immediate area (*see below*). Regionally, the thickness of the Cambrian cover increases northward to about 300 m (*see* Hutchinson, 1962), although in the immediate area of the Bergs Prospect, and northward for several tens of metres, the Cambrian rocks form a relatively thin veneer above an irregular paleosurface of mineralized rocks. Hydrothermally altered and brecciated rocks locally occur north of Route 60, in small areas of outcrop and subcrop that form metre-scale basement outliers in the Cambrian, apparently representing areas of high relief in the sub-Cambrian basement.

Plate 3. *Silica-brecciated oxidized volcanic breccia, crosscut by crustiform-banded vein with crystalline hematite core; breccia and vein cut by thin hematite fractures (sample is approximately 12 cm wide).*

The vein and breccia system at the Bergs Prospect is analogous to that seen at the nearby Steep Nap Prospect (Mills *et al.*, 1999) in several respects. Both systems contain well-preserved crustiform banded chalcedonic silica veins hosted by variably oxidized felsic flows and tuff-breccia of the Manuels volcanic suite. These occur near the boundary with mafic volcanic and/or sedimentary facies of the Wych Hazel Pond complex. Both systems are hematite-rich and contain hydrothermal sericite and chlorite. Both are depleted in copper and zinc, and in both cases, the highest gold grades occur where the banded chalcedonic silica veins contain adularia and are brecciated by hematite. Adularia is rare in outcrop at the Bergs Prospect, however, as are continuous, rectilinear veins, typical of the Steep Nap prospect. Preliminary geochemical data also indicate that gold/silver ratios are significantly lower in the mineralized material at the Bergs Prospect than in the Steep Nap veins. The data also indicate that gold mineralization at the Bergs Prospect is associated with an enrichment in mercury.

Plate 4. *Silica vein-breccia with anomalous gold (from zone with average grade of approximately 250 ppb over 20 m).*

The nature of this newly discovered mineralization at the Bergs Prospect lends support to exisiting models for the epithermal, low-sulphidation origin of gold mineralization in the eastern Avalon high-alumina belt and clearly demonstrates the further potential for discovery of precious-metal mineralization, specifically low-sulphidation-style gold (e.g., O'Brien *et al.,* 1998, 2001b; Mills *et al.,*1999; Dubé *et al.,* 2001).

CAMBRIAN COVER–NEOPROTEROZOIC BASEMENT RELATIONSHIPS ON THE MARGINS OF THE HOLYROOD HORST

A well-known, regionally developed unconformity (e.g., Howell, 1925; Rose, 1952; McCartney, 1967) separates the fossiliferous Cambrian to earliest Ordovician strata exposed around the south shore of Conception Bay from several contrasting elements of the underlying 730 to 580 Ma Neoproterozoic succession of the Avalon Peninsula (Figure 2). The recent excavations at Manuels that led to the discovery of the Bergs Prospect also uncovered new exposures of this sub-Cambrian unconformity. These provide new stratigraphic constraints on the age of gold mineralization and subsequent cleavage development within the Neoproterozoic successions along the east margin of the Holyrood Horst, away from the zone of Paleozoic deformation along the Topsail Fault. Mapping of Cambrian and Neoproterozoic rocks on the west side of the Holyrood Horst illustrates contrasting styles of deformation prior to and following the deposition of the same Cambrian cover.

EASTERN HOLYROOD HORST

At the Bergs Prospect, coarse-grained boulder conglomerate and associated gritty sandstone, which is overlain by fossiliferous grey shale of Early Cambrian age, lie unconformably on a regolith of epithermal-style veins, breccias and hydrothermally altered volcanic and plutonic rocks. The conglomerate is composed of large, typically rounded clasts that vary from a few centimetres to greater than 1 m in diameter; these include silica-rich breccia, chalcedonic silica, crustiform- and colliform-banded silica veins, and hematite–silica–K-feldspar veins, as well as silica-altered and fresh, red to buff (unaltered and altered) flow-banded rhyolite, altered granite and foliated mafic rocks. The boulder conglomerate and associated gritty and locally calcareous sandstone has clearly eroded the gold-bearing veins and adjacent altered material (Plate 5).

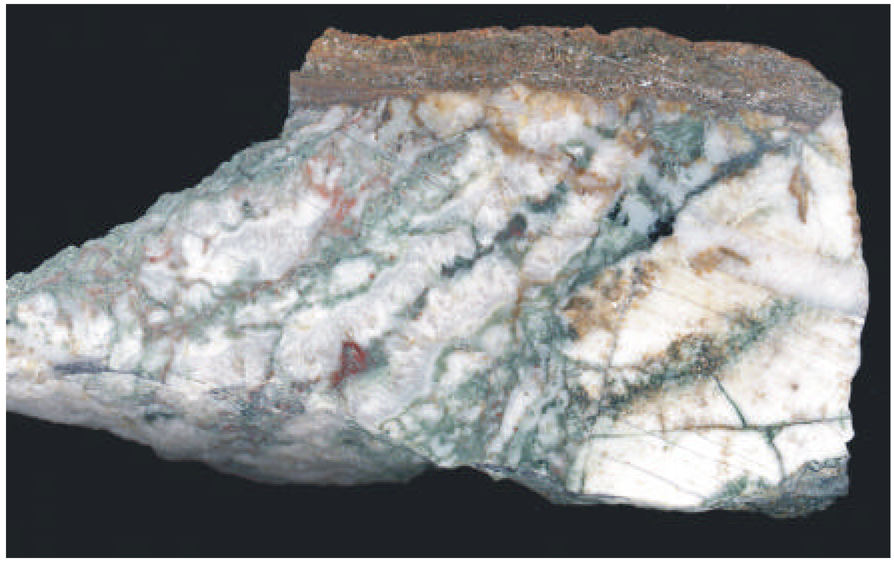

Plate 5. *Sample from regolith zone at sub-Cambrian unconformity, with layered gritty material from cover on brecciated gold-bearing (4.9 g/t Au) vein material from basement, Bergs Prospect (sample is approximately 12 cm wide).*

Strongly cleaved to schistose, chloritic and sericitic volcanic rocks of the Manuels volcanic suite and deformed mafic rocks, possibly belonging to the Wych Hazel Pond complex (O'Brien *et al.*, 2001a), lie adjacent to (and east of) silica-altered and veined material at the Bergs Prospect. The recent construction work has exposed an angular unconformity separating penetratively cleaved Neoproterozoic volcanic rocks from overlying boulder conglomerate at the base of the gently dipping to flat-lying, uncleaved Cambrian shales and limestone (Plate 6). The steep cleavage in the Neoproterozoic basement is truncated at the unconformity surface. The Cambrian succession immediately above the unconformity consists of a basal coarse-grained boulder conglomerate overlain by fossiliferous (hyalithid-bearing) pink to buff (and locally pyrite–chalcopyrite-bearing) limestone and limey grit, and fossiliferous dark-grey to red and grey shale, all of which are part of the Early Cambrian Brigus Formation of the Adeyton Group (*see* Boyce, 1988).

Plate 6. *Unconformity surface; basal boulder conglomerate unit of fossiliferous Cambrian sedimentary cover on penetratively cleaved Late Neoproterozoic basement. The conglomerate is overlain by flat-lying Cambrian limestone in adjacent outcrops.*

This new exposure demonstrates the Neoproterozoic age of this penetratively developed cleavage. The strain appears to have been focused along the east contact of the Manuels volcanic suite, at (or near) the contact with Wych Hazel Pond complex, and thus indicates a period of late Neoproterozoic remobilization along this metallogenically important, regional boundary (*see* O'Brien *et al.*, 2001 a, b). These new data lend support to the view that high-strain-style tectonism of hydrothermally altered pyrophyllite–silica rocks along strike to the south (e.g., at the Mine Hill pyrophyllite deposit; O'Brien *et al.*, 1997, 2001b) occurred in the late Neoproterozoic, subsequent to deposition of the Wych Hazel Pond complex. The deformation predates the post-Cambrian tectonism along the nearby Topsail Fault and some of the related northwest- and northeast-trending splays from that structure.

These basement–cover relationships not only provide unequivocal stratigraphic evidence for the Proterozoic age of vein- and breccia-hosted mineralization in this part of the eastern Avalon high-alumina belt but also, when integrated with available geochronology, demonstrate clearly that the mineralized epithermal system has been affected by post-580 Ma late Neoproterozoic tectonism. Understanding the nature and extent of these late Neoproterozoic structures (and investigating possible links - if any - to syn-mineralization tectonism) are key aspects of precious-metal exploration in this belt.

The sub-Cambrian unconformity exposed at the Bergs Prospect has been mapped in a number of areas around southern Conception Bay (e.g., McCartney, 1967), where a regolith developed on Neoproterozoic granitic, volcanic and sedimentary rocks is overlain by lower Cambrian beds of shale or fine-grained nodular limestone. The thick, coarse-grained, basal boulder conglomerate facies appears to be unique to the north end of the eastern Avalon high-alumina belt. The basal conglomerate in nearby Manuels River, which is thicker (≤6 m), better sorted and (with the exception of the lowermost bed) finer grained than that exposed at the Bergs Prospect, has been interpreted as a beach deposit that accumulated close to a rocky coastal cliff (Howell, 1925; Anderson and King, 1982). The location, nature and limited distribution of this facies is also consistent with a scenario where the boulder deposit was sited on early Paleozoic topographic feature(s) coincident with Neoproterozoic splays from the paleo-Topsail Fault; these secondary structures may also have played a role in siting the mineralized zones in the eastern Avalon hydrothermal systems.

WESTERN HOLYROOD HORST

The relationships of structures in the Neoproterozic basement and Cambrian cover was also studied during regional mapping in the Marysvale region of southwestern Conception Bay. Preliminary results show that the same, principal (and single) northeast-trending regional cleavage is developed in both the Cambrian cover succession (Adeyton Group) and in the underlying marine sedimentary rocks of the late Neoproterozoic Conception Group. The regional cleavage has a pronounced parallellism in both Proterozoic and Paleozoic rocks in this part of western Conception Bay, and in many instances, is more penetratively developed in the Cambrian shale-rich cover.

What may be cleavageless folds in the late Proterozoic Conception Group, near the faulted boundary with the Peak Tuff of the Harbour Main Group (O'Brien *et al.,* 2001a), are clearly truncated by a sub-Cambrian unconformity (e.g., Bacon Cove; McCartney, 1967; Riveros, 1998). These folds are overprinted by the same penetrative, coplanar cleavage that is well developed in overlying Lower Cambrian strata, which have also been openly folded. Farther west near Marysvale, the boundary between Harbour Main and Conception groups is coincident with a 2- to 3-m-wide fault zone defined in part by syntectonic crystalline quartz-veins and tectonically brecciated volcanic and sedimentary rocks. Cambrian limestone and shale unconformably overlie this tectonically brecciated Neoproterozoic fault boundary. The boundary contrasts with that found along strike to the north at Turks Gut, where boulder conglomerate of presumed (albeit not proven) Conception Group affinity overlies vesicular basalt of the Harbour Main Group (McCartney, 1967).

The data from this area are consistent with that from the Bergs Prospect area on the opposing side of the Holyrood Horst, and from areas farther east in the Avalon Peninsula (e.g., Anderson *et al.,* 1975; King, 1990; Calon, 2001), and demonstrate that late Neoproterozoic sedimentary and volcanic rocks were initially folded and faulted in the Neoproterozoic, and subsequently tectonized and regionally cleaved during post-Cambrian events.

CAMBRIAN SEDIMENT-HOSTED COPPER MINERALIZATION

Contrasting styles and ages of copper mineralization occur above and below the sub-Cambrian unconformity around Conception Bay South. Examples of early Paleozoic sediment-hosted copper mineralization were discovered within Cambrian limestone near the community of Marysvale, at the western edge of the Holyrood Horst, near the aforementioned boundary between the underlying Neoproterozoic basalt and marine sedimentary rocks (Figure 2). Weakly to moderately disseminated chalcocite (1.4% Cu over 0.8 m) is distributed in a patchy fashion, parallel to bedding and overprinted by cleavage, within a laterally discontinuous, 1- to 1.5-m-thick zone of bleached grey-green algal limestone (Plate 7). The grey-green redox-style mineralized zone occurs in a primarily pink to dark red, manganese-rich nodular algal limestone, belonging to the Early Cambrian Smith Point Formation of the Adeyton Group. In the area of mineralization, the limestone unit is approximately 3.5 m thick, and is overlain by well-cleaved red shale and slate of the Early Cambrian Brigus Formation.

The style of earlier copper mineralization in the Neoproterozoic basement rocks, best seen several kilometres farther north at Turks Gut (McCartney, 1967), is more consistent with volcanic-redbed copper (e.g., Kirkham, 1995). At Turks Gut, chalcocite, chalcopyrite, bornite, pyrite and traces of native copper occur as disseminations and vesicle-fills in basalt, and also as Cu–Ag-bearing quartz-carbonate veins and veinlets (O'Brien *et al.,* 1997).

Small-scale copper showings in the Cambrian cover occur in calcareous rocks at, and immediately above, the sub-Cambrian unconformity in several other areas around Conception Bay South. At the Berg's Prospect (*see earlier*), traces of chalcopyrite occur with coarse-grained pyrite in siliceous to calcareous gritty sandstone that overlies Neoproterozoic gold-bearing chalcedonic silica veins. Calcareous sandstone and limestone that were deposited into cracks in the underlying regolith in the same area also contain traces of chalcopyrite. Copper mineralization locally occurs along the same contact several kilometres to the west at the Kelligrews Property, at Kelligrews, Conception Bay South.

Plate 7. *Disseminated chalcocite and malachite from grey-reduced zone in pink and red algal limestone of the Smith Point Formation, Adeyton Group, at Marysvale.*

In this property, thin beds of nodular limestone and interbedded green shale of Early Cambrian age rest unconformably on Neoproterozoic granite and granodiorite of the Holyrood Intrusive Suite. Locally developed, grey-reduced zones in pink limestone and adjacent green shale are stained with malachite. Chalcocite occurs in rubble and subcrop of the pink limestone, where it is weakly disseminated in narrow grey-reduced zones, and locally concentrated into small irregular patches of higher grade material; grab samples of the limestone have returned assays as high as 3% copper, 0.3 oz/ton Ag. and greater than 220 ppm Mo (P. Dwyer, written communication, 2001). Fracture surfaces in underlying intrusive rocks contain traces of copper mineralization that may be related to fluids percolating downward from the overlying Cambrian strata. Similar copper staining occurs in both the Neoproterozoic granite and granodiorite and in overlying flat-lying Cambrian at the exposures of the sub-Cambrian unconformity along the new Conception Bay by-pass road, immediately east of the intersection with Dunns Road.

Known copper mineralization in the Cambrian rocks is typically associated with redox zones within calcareous sandstones, green and grey shales and algal limestones that were deposited in a once continuous and regionally extensive shale-rich basin. Examples are not restricted to the Conception Bay area, and similar malachite-stained Cambrian rocks containing minor chalcocite mineralization (0.1 to 1.0% Cu) are known in the Trinity Bay and southern Burin Peninsula areas (*see* O'Brien and King, 2001; and unpublished data). Although known occurrences are small and typically low-grade, their presence points to the existence of cupriferous fluids within the Cambrian basins, and suggests that these rocks could represent a possible exploration target for sediment-hosted stratiform copper mineralization.

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