Current Research (1998) Newfoundland Department of Mines and Energy
Geological Survey, Report 98-1, pages 93-124

GEOLOGICAL SETTING OF GOLD MINERALIZATION AND RELATED HYDROTHERMAL ALTERATION IN LATE NEOPROTEROZOIC (POST-640 Ma) AVALONIAN ROCKS OF NEWFOUNDLAND, WITH A REVIEW OF COEVAL GOLD DEPOSITS ELSEWHERE IN THE APPALACHIAN AVALONIAN BELT

S.J. O'Brien, B. Dubé[1], C.F. O'Driscoll[2] and J. Mills[3]
Regional Geology Section

ABSTRACT

Hydrothermal alteration and gold mineralization accompanied the formation of extensive volcano-plutonic arcs in at least two distinct episodes during the evolution of the Appalachian Avalonian belt. High-sulphidation (acid sulphate) gold and pyrophyllite, low-sulphidation (adularia–sericite) gold and porphyry-style gold–copper mineralization formed in the earlier magmatic event, mainly between 635 and 620 Ma. Younger Neoproterozoic mineralization, dated between 590 and 560 Ma, includes high-sulphidation gold–copper deposits, together with complex and equivocal, non-carbonate, stockwork-disseminated and/or remobilized metamorphogenic styles of gold deposits. In the latter instances, widespread hydrothermal alteration and obvious high-sulphidation mineralogical or chemical signatures are lacking.

Generally a marked spatial or genetic relationship exists between auriferous calc-alkaline subaerial volcanic rocks and overlying, or otherwise tectonically adjacent siliciclastic sedimentary basins. Strong spatial and genetic links exist between gold mineralization and calc-alkaline felsic to intermediate plutonic suites that are coeval with the host volcanic rocks. Many intrusions are composite, showing a wide lithological variation, and containing pre-, syn- and post-mineralizing phases. Important amongst the syn-mineralizing plutons are quartz- and quartz-feldspar porphyry intrusions. In the case of the volcanic-hosted, high-sulphidation mineralization, degassing of coeval magmas led to multistage acid alteration, responsible for ground preparation and formation of widespread advanced argillic alteration in the volcanic carapace. Subsequent silicic alteration and brecciation was accompanied by gold (± copper) mineralization. The magmatic roots of such systems are preserved and are locally mineralized. Low-sulphidation style gold mineralization is locally developed distal to high-sulphidation alteration zones in the same host rocks. Alteration in many instances is linked to the original magmatic plumbing system of the host volcanic field. Synvolcanic structural and lithological controls appear to be similarly linked to primary volcanic architecture. Syn-mineralizing structures are in many cases reactivated following alteration and mineralization, with or without remobilization and enrichment of gold.

The larger Avalonian system of the circum-North Atlantic area bears striking similarities in scale, facies development, plutonic character, overall tectonic setting and metallogenic style with magmatic arcs exposed around the present Pacific rim. An assessment of styles of Neoproterozoic Avalonian gold mineralization encountered along the 3000 km length of the Appalachians demonstrates significant potential for precious-metal mineralization and identifies the Avalonian as a large, under-explored gold–copper metallogenic belt.

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[1] Geological Survey of Canada, Quebec Geoscience Centre, Ste-Foy, Quebec G1V 4C7

[2] Mineral Deposits Section, Newfoundland Department of Mines and Energy

[3] Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X5

INTRODUCTION

Hydrothermally altered rocks are an integral component of the Appalachian Avalonian belt. Known auriferous hydrothermal systems occur in various magmatic and structural settings and, in many cases, display chemical and mineralogical signatures indicative of their generation in epithermal, transitional hypabyssal, and porphyry environments. The production of gold from these rocks dates back to earliest nineteenth century, subsequent to the 1799 discovery of placer gold in the southern Appalachian Avalonian belt, and the ensuing gold rush, which was the first in North America (*see* Carpenter, 1972). Early production was from placers or saprolite, and from Bonanza-style remobilized gold-bearing veins, almost exclusively in the southern Appalachians. Recent production has been primarily from bulk-tonnage, low-grade deposits.

The most well-known and best-documented Avalonian gold-bearing systems include the Hope Brook Mine (Au–Cu) in Newfoundland (McKenzie, 1986; Stewart, 1992; Dubé *et al.*, 1995; Dubé, 1996, Dubé and Dunning, 1998, *in press*), and the Brewer (Au–Cu), Haile, Ridgeway and Barite Hill gold mines in northern South Carolina (e.g., Worthington and Kiff, 1970; Feiss *et al.*, 1993; Gillon *et al.*, 1995; Zwaschka and Scheetz, 1995; Maddry and Kilbey, 1995). They represent the most significant gold deposits of the Appalachian orogen, having total gold resources (past production and reserves/resources) exceeding 5 000 000 oz Au. All five gold mines have as their principal host, late Neoproterozoic volcanic and/or sedimentary rocks; all have been brought into initial production or have seen renewed production within the past 15 years (Table 1).

Within the Appalachian Avalonian belt, hydrothermal alteration and gold mineralization is found mainly, but not exclusively, in volcanic, plutonic and volcanogenic sedimentary rocks of two broad age groupings, *viz.* 640 to 600 Ma and 600 to 560 Ma. Alteration and mineralization is sited near the margins of high-level composite intrusions and in the upper stratigraphic levels of thick volcanic successions, at or near the boundary with overlying sedimentary units. Alteration and mineralization, in many cases, are indicative of high-sulphidation (or acid-sulphate type) epithermal systems, as illustrated by the Hope Brook and Brewer gold deposits. Low-sulphidation gold-bearing quartz–adularia veins occur within parts of the eastern Avalon high-alumina belt in Newfoundland (O'Brien *et al.*, 1997a, b). Local evidence of gold-rich porphyry-copper-style mineralization is also present, such as at the Coxheath deposit in Cape Breton (Lynch and Ortega, 1997), and the Butlers Pond and Triangle Belt prospects in Newfoundland (O'Brien and O'Driscoll, 1996a, b; O'Brien *et al.*, 1997a). In addition, sediment-hosted "exhalative" or non-carbonate stockwork-disseminated mineralization (Haile and Ridgeway deposits), and gold-rich volcanogenic massive sulphide deposits (Barite Hill Mine), have been described mainly from South Carolina (e.g., Schmidt, 1985; Feiss *et al.*, 1993). Intensely deformed Avalonian gold deposits have been interpreted, in several instances, as being shear-zone-hosted and/or synmetamorphic (e.g., Hayward, 1992 for the Haile Mine; Stewart, 1992 for the Hope Brook Mine), although alternative pre-shearing exhalative or epithermal models for the same deposits have been argued (e.g., Feiss *et al.*, 1993; Dubé and Dunning, 1998). In several examples, the case has been also argued for the existence of Paleozoic syn-deformational remobilization and enrichment of a Neoproterozoic gold-rich epithermal-style system (e.g., Ridgeway deposits; Gillon *et al.*, 1995).

The following overview integrates the results of the authors' recent work from eastern and southern Newfoundland (including hitherto unpublished data) into a review of gold mineralization in late Neoproterozoic (post-640 Ma) Avalonian rocks[1]. Additional information has been drawn from non-confidential company assessment reports on file at the Newfoundland Department of Mines and Energy. This paper also includes a summary of gold deposits hosted by late Neoproterozoic Avalonian volcanic and sedimentary rocks in the Carolina Slate Belt of the southeastern U.S. Appalachians, which incorporates insights and correlations based on first-hand observations made by the first three authors in that area. A short summary of intrusion-hosted porphyry style alteration in late Neoproterozoic intrusive rocks in the Avalonian belt in Cape Breton Island is also presented, with a brief review of potential porphyry-style mineralization in the Avalonian of Newfoundland.

The paper is presented in four sections; the first introduces and defines the Avalonian system and places its precious-metal mineralization into a temporal and tectonic framework. The second describes the regional setting and style of hydrothermal alteration and gold mineralization in Avalonian rocks formed between 640 to 600 Ma; the third presents a similar treatment of post-600 Ma Neoproterozoic Avalonian rocks. The fourth presents a summary, followed by a conclusions section, and includes a discussion of implications for future precious-metal exploration in the Avalonian belt of Newfoundland.

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[1] Gold occurrences and exploration potential of pre-640 Ma Avalonian rocks are beyond the scope of this study, as is mineralization related to Paleozoic magmatism and remobilization that is hosted by Avalonian rocks within or marginal to the main zone of Appalachian orogenesis.

Table 1. Principal gold mines in Appalachian Avalonian rocks

MINE	TONNAGE	GRADE	STYLE	AGE OF MINERALIZATION
HOPE BROOK	11.2 mt[1]	4.54 g/t Au	high sulphidation	578–574 Ma (U–Pb zircon; Dubé and Dunning, *in press*)
BREWER	5.6 mt[2]	1.2 g/t Au	high sulphidation	synvolcanic (595–550 Ma on regional grounds)
HAILE	15.3 mt[3]	3.1 g/t Au	exhalative (?) or structurally controlled(?)	560–590 Ma (Re–Os on molybdenite: Maddry and Kilbey, 1995)
RIDGEWAY	56 mt[4]	1.1g/t Au	exhalative (?) with structural remobilization (?)	unconstrained
BARITE HILL	1.5 mt[5]	1.3 g/t Au	gold-rich VMS	unconstrained

Tonnages and grades from: 1 = MacKenzie (1986); 2 = Zwaschka and Scheetz (1995); 3 = Maddrey and Kilbey (1995); 4 = Gillon *et al.* (1995); 5 = LaPoint and Cherrywell (1995).

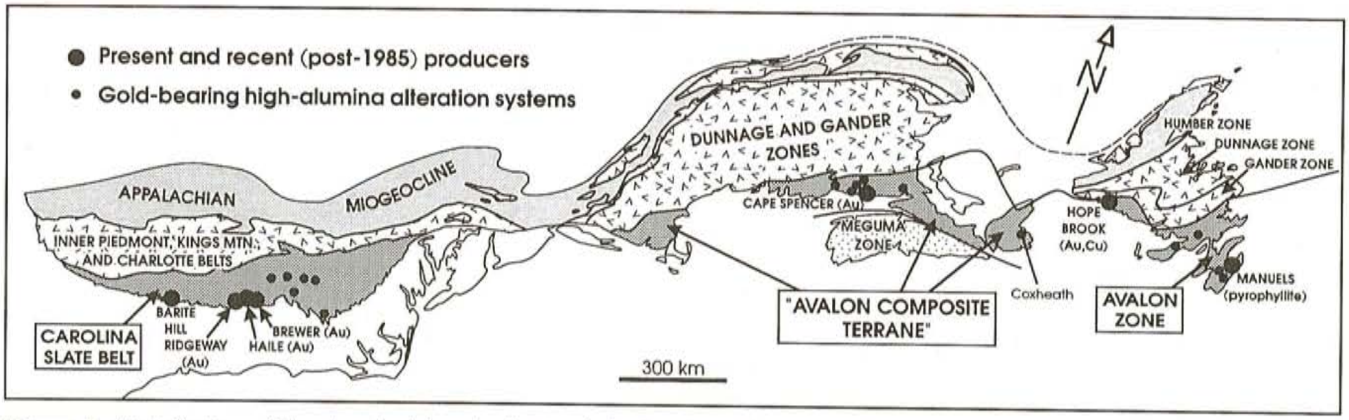

Figure 1. *Distribution of the Appalachian Avalonian belt showing gold mines and significant gold prospects (modified from Williams and Hatcher, 1983).*

THE AVALONIAN SYSTEM

The late Neoproterozoic Avalonian system of the North Atlantic region chronicles the development of segments of an extensive orogenic belt that evolved at an active plate margin peripheral to the ancient continent of Gondwana. Magmatism, sedimentation and tectonism related to this 760 to 550 Ma Avalonian cycle generally pre-dated the Appalachian Wilson cycle of opening and closure of the Paleozoic Proto-Atlantic (or Iapetus) Ocean (Wilson, 1966; Harland and Gayer, 1972). In North America, vestiges of this broader Avalonian orogenic system, include not only the Appalachian Avalon Zone (cf., Williams, 1979; Avalon *sensu stricto* of O'Brien *et al.*, 1996), but also the coeval and related Neoproterozoic peri-Gondwanan magmatic arc and basement successions that, in North America, lie immediately inboard of it along the length of the Appalachian orogen. All of these rocks were variously reworked within or incorporated into the southeastern margin of the Appalachian orogen, outboard of younger rocks of Iapetan origin, during episodic orogenesis throughout the Paleozoic.

This internally complex, tectonically disrupted chain, herein referred to as the Appalachian Avalonian belt, is traceable along strike for approximately 3000 km. It extends from the Avalonian type area in eastern Newfoundland (King, 1988; O'Brien *et al.*, 1996), along the south coast of Newfoundland (Dunning and O'Brien, 1989; O'Brien *et al.*, 1993), southwestward through Cape Breton and mainland Nova Scotia (Murphy *et al.*, 1990; Barr *et al.*, 1996), and thence to the southern New Brunswick coast (Rast *et al.*, 1976: Nance *et al.*, 1990), New England (Skeehan and Rast, 1991; Hepburn *et al.*, 1993), the Carolinas and northern Georgia (Secor *et al.*, 1986; Figure 1). Rocks of similar age and geological character occur in the subsurface in Florida (Suwanee Terrane; Heatherington *et al.*, 1996). The same Avalonian rocks extend northeastward into the Caledonide orogen in the United Kingdom where, as is the case in the

Appalachians, 680 to 560 Ma volcanic, plutonic and sedimentary sucessions lie outboard and southeast of early Paleozoic vestiges of the Iapetus Ocean. Avalonian rocks are not found in the Scandanavian Caledonides, but instead reappear south of the Tornquist suture as inliers in the European Variscides (e.g., Cadomian belt, D'Lemos *et al.*, 1990; Nance *et al.*, 1991). South of the Variscides, late Neoproterozoic rocks of an age, setting, lithology and stratigraphic framework similar to those of the Appalachian Avalonian belt occur within the Pan African orogenic system (O'Brien *et al.*, 1983, and LeBlanc and Lancelot, 1988 and references therein). The Avalonian belt in Newfoundland, coupled with its offshore extension across the Grand Banks, is at least 600 km wide, approximately twice the width of the remainder of the onland Appalachian orogen.

TIMING AND SETTING OF AVALONIAN MAGMATISM

The Late Proterozoic evolution of the Avalonian system, both in the Newfoundland type area, and elsewhere in the Appalachian–Caledonian orogen, and in its extension into the Variscan and the Pan-African orogenic belts, is characterized by four major tectonomagmatic events: ca. 760 Ma, ca. 680 to ca. 670 Ma, from ca. 640 to ca. 600 Ma, and from ca. 595 to ca. 560 Ma (O'Brien *et al.*, 1983, 1996; Tucker and Pharaoh, 1991; Barr *et al.*, 1996; Egal *et al.*, 1996). However, most workers agree that the defining geological moments of the Avalonian belt in the Proterozoic, are the major pulses of magmatic activity that occurred between ca. 640 Ma and the start of the Cambrian. During that interval, complex magmatic arcs developed in a variety of arc and back-arc or analogous continental-arc settings, in an overall (although not exclusively) extensional environment. In a number of instances, the development of these volcano-plutonic arc successions accompanied or preceded accumulation of siliciclastic sediments in marine and/or terrestrial basins of widely variable dimensions, that developed adjacent to or upon the volcanic carapaces.

Along the length of the Appalachian Avalonian belt, felsic magmas generated between 640 Ma and ca. 560 Ma, rose to high levels in the crust and, in many instances, were emplaced onto the surface as subaerial pyroclastic and flow facies volcanic rocks. Locally, these magma chambers were the driving force behind large-scale, high-level hydrothermal convective systems that resulted in hydrothermal alteration in surrounding volcanic and coeval intrusive rocks, and the deposition of precious metals. Such mineralization is encountered in several distinct volcanic and plutonic settings along the entire length of the Appalachians (*see* below).

A variety of plate tectonic models has been proposed for the Avalonian system, with an emerging consensus that it formed over a protracted period (between 200 and 150 million years) in an evolving continental margin magmatic arc and/or oceanic arc/back arc setting (*see* review *in* Nance and Thompson, 1996b). Differences in tectonic history recorded along the system reflect, in large part, the amalgamation and dispersal of distinct tectonic elements not only during the Neoproterozoic, but also during several pulses of Paleozoic tectonism (e.g., related to Appalachian, Caledonian or Variscan orogenic evolution). Strong similarities in scale, facies development, plutonic character, overall tectonic setting – and, importantly, metallogenic style – exist between the Avalonian system in the Neoproterozoic and the magmatic arcs exposed around the present-day Pacific rim.

640–600 Ma AVALONIAN ROCKS

On the scale of the Appalachians, magmatic rocks that formed between 640 and 600 Ma are traditionally considered the hallmark of the Avalonian belt in the Proterozoic (cf., Nance and Thompson, 1996a). In Newfoundland, such rocks occur in domal uplifts or faulted inliers within more extensive tracts of post-595 Ma Neoproterozoic siliciclastic rocks. The 640 to 600 Ma volcanic and related sedimentary rocks locally lie unconformably on ca. 680 to 670 Ma magmatic arc and arc-root volcano-plutonic complexes (e.g., O'Brien *et al.*, 1995), but in most instances, basal contacts are unexposed. They are overlain or intruded by volcanic, sedimentary and plutonic rocks of latest Neoproterozoic (post-595 Ma), Cambrian, Devonian and Carboniferous and Triassic ages.

Elsewhere within the Appalachian Avalonian belt, volcanic and plutonic rocks yielding ages between ca. 640 and 600 Ma have been described from Cape Breton Island (e.g., Keppie *et al.*, 1990; Barr *et al.*, 1996) and mainland Nova Scotia (Pé-Piper *et al.*, 1996), southern New Brunswick (e.g., Bevier and Barr, 1990; Bevier *et al.*, 1993); southeastern New England (e.g., Kaye and Zartman, 1980; Hermes and Zartman, 1985; Hepburn *et al.*, 1993) and in the Virgilina district of the Carolina Slate Belt (e.g., Harris and Glover, 1988). Coeval volcanic and plutonic rocks are found in the Avalonian belt outside the Appalachians in the Caledonides of Wales and southern England (Gibbons, 1990; Tucker and Pharoah, 1991; Gibbons and Horak, 1996), the Cadomian belt of France (Egal *et al.*, 1996) and its equivalents in the Iberian Massif (e.g., Quesada, 1990), and the Pan African belt of northwest Africa (e.g., Kroner, 1980, O'Brien *et al.*, 1983, and references therein).

DISTRIBUTION AND NATURE OF 640–600 Ma AVALONIAN ROCKS IN NEWFOUNDLAND

In Newfoundland, volcanic rocks that formed in the interval 640 to 600 Ma occur in three main areas: on the Avalon Peninsula within the Harbour Main Group (King, 1988, 1990; Krogh *et al.*, 1988; O'Brien and O'Driscoll, 1996a; O'Brien *et al.*, 1997a); on the western Connaigre

Peninsula within the Connaigre Bay Group (O'Driscoll and Strong, 1979; O'Brien *et al.*, 1995); and within the upper part of the Love Cove Group and the lower parts of the overlying Connecting Point Group in western Bonavista Bay (O'Brien and Knight, 1988; Knight and O'Brien, 1988; Dec *et al.*, 1992). Everywhere, the volcanic successions are characterized by complex facies architecture and the preponderance of mixed felsic to intermediate flows, pyroclastic and dome-facies hypabyssal rocks. In the Avalon and Connaigre peninsulas, in particular, the volcanic rocks are intruded by extensive coeval and compositionally similar plutons.

The geological record for this period includes plutonism, and coeval volcanism and related sedimentation within magmatic arc and arc-adjacent basin settings (King, 1990; Sears, 1990; Dec *et al.*, 1992; O'Brien *et al.*, 1990, 1995, 1996). Volcanic successions of this age have diverse chemical and lithological signatures, and represent a continuum from basalt, through andesite and rhyodacite, to rhyolite (Strong *et al.*, 1978a, b; Hussey, 1979; O'Driscoll and Strong, 1979; King, 1990; O'Brien, 1993, 1994; O'Brien and Knight, 1988; O'Brien *et al.*, 1990, 1995). They include calc-alkaline and transitional, calc-alkaline to tholeiitic rocks, and island-arc (arc-rift) tholeiites (Hussey, 1979; O'Brien *et al.*, 1990; Sears, 1990).

Calc-alkaline plutonic complexes have been emplaced into the volcanic successions shortly after their eruption. The largest of these are the 620 Ma Holyrood Intrusive Suite (Krogh *et al.*, 1988; King, 1990; O'Brien *et al.*, 1995) and the 621±3 Ma Simmons Brook Intrusive Suite (Williams, 1971; O'Brien *et al.*, 1995). The composition of these suites generally corresponds to that of the volcanic country rocks, and varies from gabbro, through tonalite and granodiorite to granite (O'Driscoll and Strong, 1979; Barr and Kerr, 1997). Felsic and intermediate phases are hornblende–biotite bearing, and have strong calc-alkaline affinities. The Holyrood Intrusive Suite, in particular, contains high-level phases characterized by extensive magmatic degassing.

Thick marine siliciclastic successions are spatially associated with 640 to 620 Ma volcanic rocks. The upper part of the Love Cove Group and the overlying Connecting Point Group in the Bonavista Bay area (O'Brien and Knight, 1988; Knight and O'Brien, 1988; Dec *et al.*, 1992) forms a 4- to 5-km-thick sequence of well-preserved, low-grade marine volcaniclastic sediments and interlayered tuffs formed by redeposition of epiclastic and pyroclastic sediments on submarine fans, proximal to active volcanic arcs. Sedimentation began at approximately 620 Ma and continued for at least 10 Ma (Dec *et al.*, 1992). The 626 ± 3 Ma Connaigre Bay Group of the Connaigre Peninsula also contains a thick sequence of marine siliciclastic rocks in its lower part (O'Driscoll and Strong, 1979; O'Brien *et al.*, 1995).

In the following section, the focus is drawn primarily on epithermal alteration and mineralization in volcanic rocks within this age range on the eastern Avalon Peninsula. A brief description of mineralization in similar intrusive rocks in the Avalonian of Cape Breton Island, Nova Scotia, is presented as an example of coeval Cu–Mo–Au mineralization in the porphyry environment.

HYDROTHERMAL ALTERATION AND GOLD MINERALIZATION IN 640–600 Ma AVALONIAN ROCKS

EASTERN AVALON HIGH-ALUMINA BELT

The largest continuous zone of hydrothermal alteration in rocks of this age in Newfoundland is the "eastern Avalon high-alumina belt " (Hayes and O'Driscoll, 1990). Alteration is sited along the eastern side of the Holyrood Horst, a periclinal dome of Late Proterozoic, primarily subaerial volcanic and coeval plutonic rocks that forms the core of the Avalon Peninsula (Figure 2). These are low-grade, well preserved rocks, which characteristically lack penetrative deformation. The oldest parts of the volcanic pile (ca. 640 to 620 Ma; Krogh *et al.*, 1988) found in the eastern and central parts of the Holyrood Horst, are intruded by 620-Ma granitic to monzonitic rocks, and in many instances, have been hydrothermally altered. This volcano-plutonic core of the Avalon Peninsula is flanked by an overlying, stratified succession of marine, deltaic and fluviatile siliciclastic sedimentary rocks, concentrically disposed around the older succession (King, 1980, 1988, 1990).

Alteration in the eastern Avalon high-alumina belt is developed primarily in subaerial pyroclastic volcanic rocks of the Harbour Main Group, and to a lesser degree in comagmatic plutons, part of the Holyrood Intrusive Suite. The eastern Avalon high-alumina belt has a strike length of at least 15 km, and varies in width from a few decametres up to 1 km. Its northern extension is covered by a gently dipping to flat-lying early Paleozoic platformal sedimentary succession. Historically, this zone is best known for its deposits of pyrophyllite (Buddington, 1916; Vhay, 1937; Keats, 1970; Papezik *et al.*, 1978), including the Armstrong World Industries Canada Limited *'Oval Pit Mine'* (Papezik and Hume, 1984). The more recent discovery of both high- and low-sulphidation-style gold occurrences in association with the high-alumina (or advanced argillic) alteration has established the eastern Avalon high-alumina belt as an important exploration target for epithermal and porphyry-style gold mineralization (*see* O'Brien and O'Driscoll, 1996a, b; O'Brien *et al.*, 1996, 1997a, b).

The host rocks of the eastern Avalon high-alumina belt are part of a thick subaerial succcession of welded and variously flattened, rhyolitic to dacitic, pumice-rich ash-flow

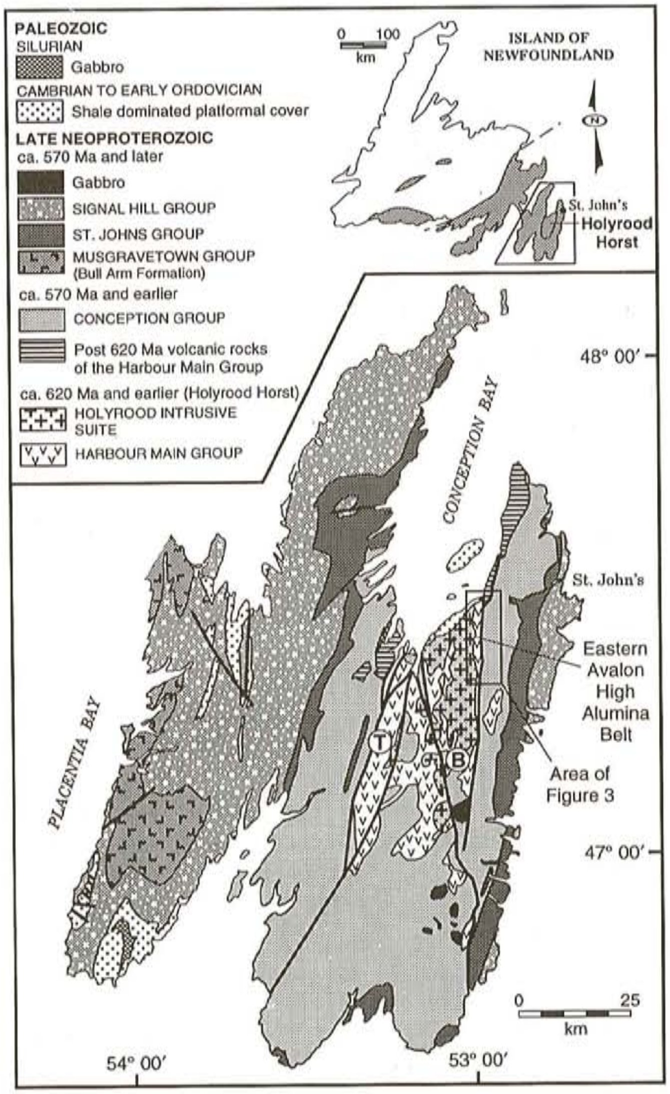

Figure 2. *Simplified geological map of the Avalon Peninsula (modified from King, 1988). Shaded area on inset map shows the approximate area of Avalonian rocks. T = Triangle belt, B = Butlers Pond.*

tuffs, stratigraphically associated with dome-facies flows, plugs and breccias of broadly similar composition. Hydrothermal alteration produced extensive zones of argillic, advanced argillic and massive silicic alteration, locally affected by hydrothermal brecciation. Hydrothermal alteration produced the assemblage silica–sercite–pyrite–pyrophyllite–diaspore–barite–hematite–gold in volcanic rocks along the eastern margin of the composite Holyrood Intrusive Suite. Alteration is spatially and genetically related to variously altered, felsic to intermediate intrusions and related porphyry phases that, too, occur primarily along the suite's eastern margin.

Hydrothermal alteration within the belt is primarily pretectonic with respect to the regional deformation. Ductility contrast between pyrophyllite-rich and silica-rich zones within the alteration zones has resulted in areas of high strain within the alteration zone, particularly on the long limbs of regional-scale folds.

Oval Pit Mine and Related Pyrophyllite Deposits

The pyrophyllite deposits of the eastern Avalon high-alumina belt were first mined between 1903 and 1905, with approximately 7750 tons of hand-picked ore shipped from a quarry at *Mine Hill* (Vhay 1937; Spence, 1940). Pyrophyllite ore was produced intermittently in the mid-1930s and 1940s by the Industrial Minerals Company of Newfoundland, mainly from area around Mine Hill, but also from the *Trout Pond* and *Dog Pond prospects*, located along strike several kilometres to the south (Figure 3). Mining of the Oval Pit pyrophyllite deposit has been carried out continuously from 1956 to 1996 (e.g., Lee, 1958; Batten and Hume, 1978), first by Newfoundland Minerals Limited, and subsequently, by Armstrong World Industries Canada Limited; exploration drilling of all deposits was carried out over this interval. Total production is estimated at 1 500 000 tonnes of ore at 17.5% Al_2O_3 and the reserves are estimated at 2.5 to 3 Mt at 14.5% Al_2O_3 (M. Dawe, personal communication, 1997). Early geological study of the pyrophyllite deposits by Buddington (1916) formed the basis for a more detailed study of the Mine Hill, Trout Pond and Dog Pond prospects by Vhay (1937). A number of investigations have been carried out since the development of the Oval Pit Mine; e.g., Keats (1970), Papezik and Keats (1976), Papezik and Hume (1984), Papezik *et al.* (1978) and Hayes (1996).

Oval Pit Mine

A well-exposed section through the eastern Avalon hydrothermal system is preserved in the Oval Pit Mine and in the immediate surrounding area. Alteration at the mine is subdivided from east to west into subzones of argillic, advanced argillic and massive silicic alteration. The hydrothermal alteration has developed within a thick tripartite succession of subaerial ash-flow tuffs, and dome-facies rhyolite flows and volcanic breccia. Adjacent to the main body of altered rocks, red subaerial rhyolites show the effects of mild silicic alteration associated with the formation of quartz–hematite veins and breccia. This hematite alteration is the younger of at least two such events, and results from leaching from hematite-rich volcanic rocks during advanced argillic alteration. An earlier regionally distributed stage of hematite alteration predates the advanced argillic alteration, and is caused by syn-volcanic thermal oxidation.

The argillic alteration 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 and minor barite and rutile (e.g., Oval Pit ore zone), and of silica, pyrophyllite and

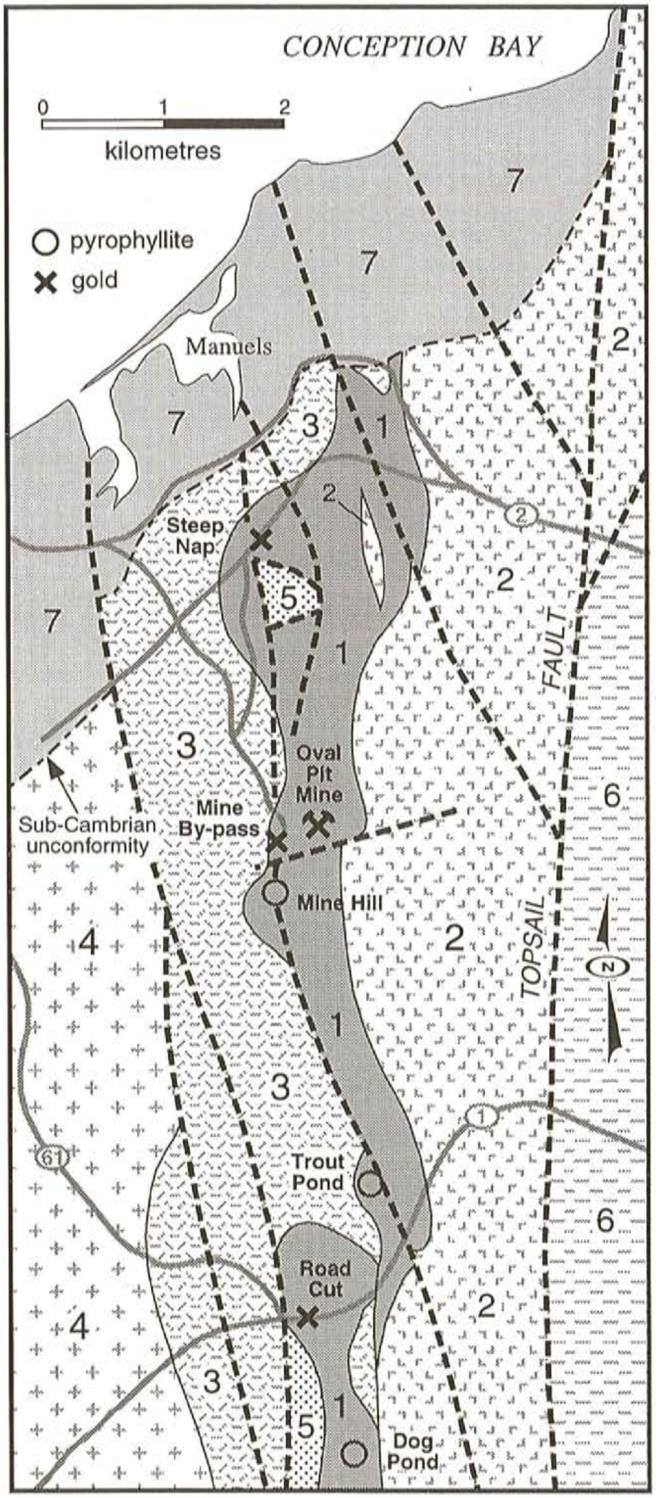

Figure 3. *Simplified geological map of the northern portion of the eastern Avalon high-alumina belt (modified in part from King, 1988 and Hayes and O'Driscoll, 1990), showing the approximate location of the prospects described in the text. 1 = eastern Avalon high-alumina belt and related rocks of the Harbour Main Group; 2 = unseparated mafic and felsic flows and sediments of the Harbour Main Group; 3 = unseparated monzonite, gabbro, granite and porphyry phases of the Holyrood Intrusive Suite; 4 = mainly weakly altered quartz-rich biotite granite (Holyrood Intrusive Suite); 5 = sediments of uncertain stratigraphic affiliation; 6 = Conception Group marine sediments; 7 = Cambrian cover sequence of mainly shaly rocks.*

sericite, locally containing 5 to 10 percent pyrite. Massive silicic alteration has produced metre- to decametre-scale pods of high-grade silica, containing less than 5 percent sericite and/or pyrophyllite. Locally, pyrite forms the matrix of spatially associated silicic-altered breccias. No single regionally continuous zone of silicic alteration has been identified at the surface. Zones of silicic alteration are irregularly distributed in detail, but appear to be located mainly in the northeast part of the advanced argillic zone. The original distribution of silica and pyrophyllite within the advanced argillic alteration zone is consistent with their contemporaneous origin. The commonly developed anastomosing pattern illustrated by the outcrop-scale distribution of silica and pyrophyllite in zones of low to medium strain is mainly the result of inhomogeneous post-alteration deformation.

Pyrophyllite ore locally displays exceptionally well-preserved relict textures, including flow bands (in hydrothermally altered rhyolites), and pumice lapilli (in similarly altered ash-flow tuffs) that demonstrate the nature of the protolith and reflect the pretectonic nature of the alteration (Plate 1). This pyrophyllite ore is texturally comparable to nearby unaltered pyroclastic rocks. In other cases, replacement of original textures by silica and pyrophyllite has occured in alternating bands, parallel to flow banding, crosscut by the regional cleavage. Diaspore nodules are well developed in the lower levels of the open pit, in association with massive pyrophyllite.

The volcanic-hosted advanced argillic alteration zone at the Oval Pit Mine is overlain by a succession of immature siliciclastic sedimentary rocks. A yellow-weathering, 3-m-thick boulder conglomerate passes upward into a tuff bed and into a 60-m-thick sequence of red to purple, fine- to coarse-grained fluvial-facies siliciclastic rocks, containing rare beds of reworked tuffaceous material. The redbeds give way upward to grey and green, extensively slumped siltstone, sandstone and conglomerate. The boulder conglomerate and tuff at the base of the sedimentary sequence contain many clasts derived from the advanced argillic alteration zone, together with intricately laminated and banded rhyolite clasts, and pyrite. The proportion of detrital, hydrothermally altered material decreases stratigraphically upward. No clasts (altered or otherwise) displaying pre-incorporation deformation were

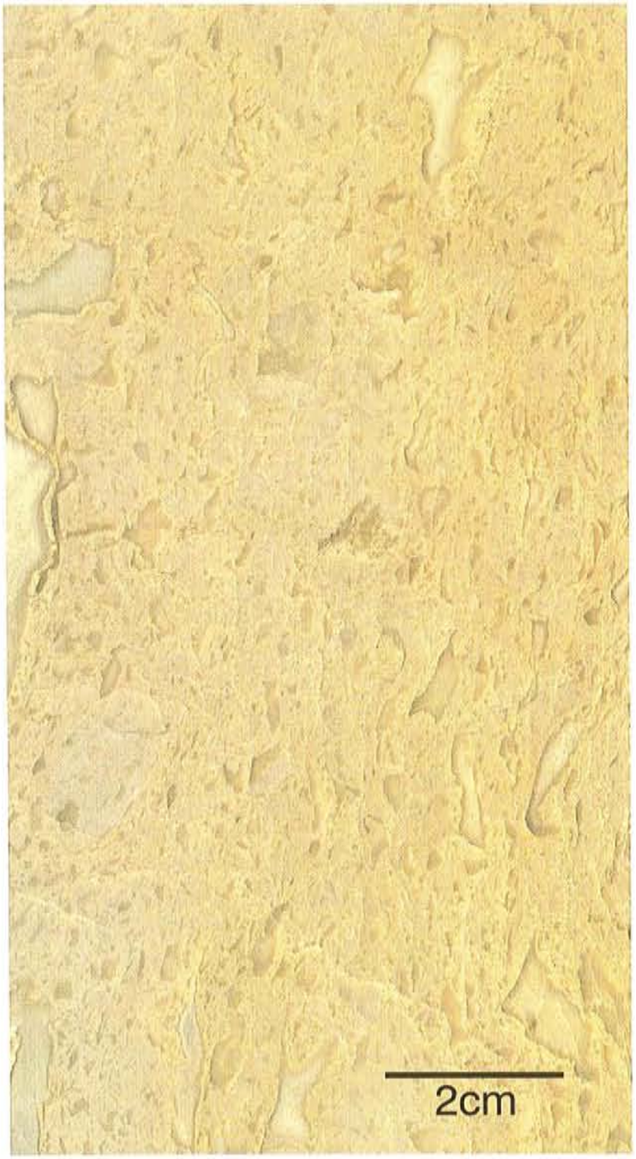

Plate 1. *Altered pumice lapilli in high-grade pyrophyllite ore, Oval Pit Mine.*

found. This sedimentary succession (and the underlying alteration zone) is deformed by an open southeast-plunging syncline at the Oval Pit Mine. The base of the succession does not appear to have a significantly irregular morphology.

Mine Hill Quarry

The Mine Hill quarry represents early (pre-1950s) attempts at commercial production from the pyrophyllite deposits of this belt. The quarry walls have exposed highly strained pyrophyllite–sericite–quartz rock of a tuffaceous protolith, in which silicic-altered material forms discrete knobs. Only the western end of the Mine Hill quarry exposes pyrophyllite (± sericite) ore. Discontinuous pyritic zones are common within the advanced argillic alteration in this area. Ductile shearing is particularly intense; well-developed, reverse-sense ductile shear zones with accompanying, intense, steeply dipping foliation are well preserved. Elsewhere on Mine Hill, this alteration zone is intruded by an unaltered, pretectonic (albeit weakly foliated) diabase dyke.

The high strain at the Mine Hill Quarry is in contrast to that in much of the Oval Pit Mine, where the overall ductile strain is much lower. This may reflect the location of the Oval Pit pyrophyllite ore zone in the core of a syncline (as indicated by the generally east–west trend of the bedding), relative to that of Mine Hill on the syncline's attenuated (north–south-trending) limb. In general, the zone of advanced argillic alteration has accommodated most of the strain in much of the eastern Avalon high-alumina belt. This is mainly due to competence contrast between the unaltered rhyolites and the adjacent pyrophyllite-rich rocks within the alteration zone.

Other Prospects

Pyrophyllite-bearing advanced argillic alteration at the Trout Pond prospect (Vhay, 1937) is associated with high-strain lithophysae-bearing rhyolitic rocks near the contact with altered (silica–sericite–hematite–pyrite) granite. Bedded siliciclastic rocks occur in fault contact with pyritic silicic-altered rock in the main Trout Pond adit. Pyrophyllite occurs as discontinous lenses up to 4 m in width. Adjacent rocks, which locally contain lithophysae up to 10 cm in diameter, include silica-rich rocks containing residual hematite, cut by quartz–hematite veinlets, as well as sericite-rich, silicic-altered rocks. In areas of low strain, the advanced argillic alteration front is sharp and is developed parallel to primary banding in rhyolitic rocks. Many of the aspects of the Trout Pond alteration are directly comparable to the Oval Pit Mine and the Mine Hill quarry.

At the Dog Pond prospect (Vhay, 1937), advanced argillic alteration is developed in flow-banded rhyolite and lithophysae-bearing rhyolitic rocks of probable ash-flow origin, immediately below a sequence of well-bedded, unaltered grey–green siliciclastic rocks. Pyrophyllite occurs as irregular, discontinuous zones up to 3.5 m wide, oblique to foliation, within larger areas of high-strain pyrophyllite–quartz schist, in a setting similar to Mine Hill. Silica–pyrophyllite-altered bands are tectonically disrupted by foliation developed at a high angle to banding. Tectonic breccias in the advanced argillic zone are locally rich in pyrite. The distribution of zones of primarily silica-altered material versus those of pyrophyllite is similar to that elsewhere in the belt, and is largely without symmetry. Away from the main advanced argillic zone, an area of weakly developed argillic alteration passes outward into lithophysae-bearing rhyolites cut by quartz–hematite veinlets.

Auriferous Hydrothermal Breccias

Mine By-pass Prospect

The zone of pyrophyllite-rich advanced argillic alteration at Mine Hill is in reverse fault contact with flow-banded rhyolites that have been affected by extensive polyphase hydrothermal brecciation and silica-flooding. The western boundary of the hydrothermal breccia zone is transitional over a few metres, from sericitic rhyolite, through weakly developed silica-rich stockwork defined by cm-scale veins of grey silica and silica breccia, into massive, hydrothermal breccia (Plate 2), flooded by maroon hematite. Pyrite occurs as individual mm-scale euhedra and as irregular cm-scale zones, in which fine-grained pyrite is heavily disseminated. The breccias contain fragments of at least two generations of silicic alteration. Some of the dark-grey silicic-altered fragments show evidence of earlier hematite alteration. The pyritic breccias have yielded assays up to 1.8 g/t Au and 6g/t Ag. The eastern boundary of the auriferous breccias is defined by a distinctive hydrothermal breccia having a buff to white silica-flooded matrix, which in turn is transitional, on a metre scale, into a larger zone of pyrophyllite–sericite alteration and sericite-bearing silicic alteration.

Roadcut Prospect

The Roadcut prospect is situated near the western edge of the the eastern Avalon high-alumina belt, approximately 4 km along strike to the south from the Oval Pit Mine and the Mine by-pass prospect. It lies within several hundred metres of the contact between felsic volcanic rocks and a composite, magma-mixed monzonite–diorite–granite complex at the eastern edge of the Holyrood Intrusive Suite. Gold mineralization (up to 11.2 g/t Au) occurs in hydrothermal breccias within a 100-m-wide section through a zone of advanced argillic and massive silicic alteration. The hydrothermal alteration (silica–sericite ± pyrophyllite ± chlorite ± pyrite ± K-feldspar) is developed in a succession of flow-banded rhyolite, pumice-rich lapilli tuff or tuff breccia, and lithophysae-bearing ash flows, near the contact with overlying tuffaceous sedimentary rocks. Mineralization was discovered in a roadcut following widening of the Trans-Canada Highway (Saunders, 1986).

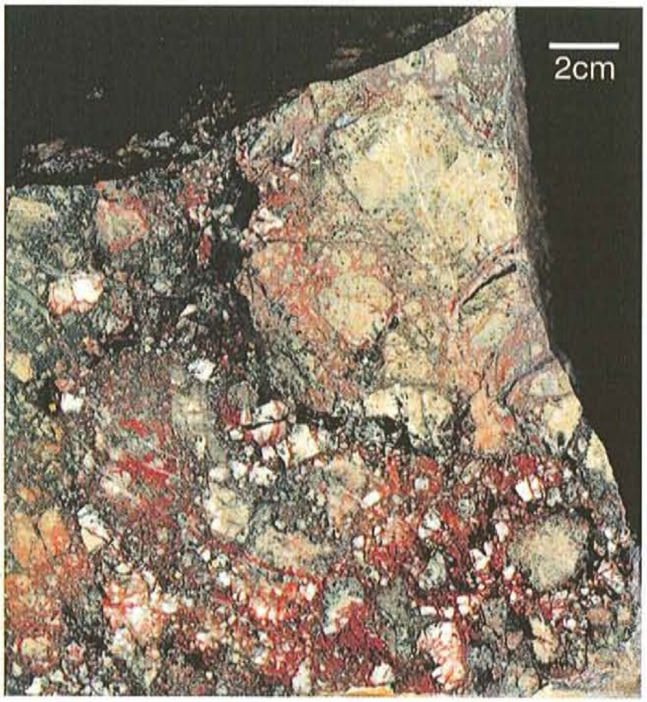

Plate 2. *Gold-bearing hydrothermal breccia from the Mine by-pass prospect.*

Large parts of the exposure consist of zones of massive silicic alteration, containing in excess of 90 percent (by volume) of silica-rich material. Silicic (silica-flooded) material contains blocks of sericite ± pyrophyllite ± silica-altered material of felsic volcanic protolith, in which alteration is developed parallel to fine eutaxitic- and flow-banding. The silica-flooded rock is locally spotted with small (ca. 1 cm) hematitized patches that are the remnants of otherwise completely replaced lithophysae-bearing ash flows. Subhorizontal quartz veins that crosscut sericite–silica altered rocks are post-alteration features related to movements on north-trending vertical faults at the western edge of the eastern Avalon high-alumina belt.

Rounded to subangular hydrothermal breccias occur within the silica zone; at least two breccia types are present. The first consists of fragments of dark-grey to buff, sericite–pyrophyllite–quartz±pyrite-bearing material in a silica-rich matrix. A second breccia type is characterized by variably silicic-altered material in a chlorite-rich matrix that contains minor pyrite and K-feldspar. Both breccias are associated with a zone of gold mineralization, approximately 10 m wide. A channel sample taken across the gold-bearing zone averaged 3 g/t Au over 10 m (P. Saunders, personal communication, 1997). Elevated gold values occur in the "pebbly" breccias, but highest gold values encountered in our studies (11.2 g/t) were obtained from silica-rich breccia having a chlorite–pyrite–K-feldspar matrix, and felsic hydrothermal breccia containing banded rhyolite clasts (O'Brien and O'Driscoll, 1996a, b; O'Brien *et al.*, 1997a, b and unpublished data). Pyrite occurs as disseminations, clots and thin veinlets within the matrix of the breccias. Consistently high gold values are found in fine- to coarse-grained angular breccia, in which 1 to 2 cm aggregates of euhedral to subhedral pyrite occur within irregular patches of maroon hematite (Plate 3). These auriferous breccias yield assays of up to 210 g/t Ag, have anomalous arsenic content (up to 2 g/t), and have slightly elevated concentrations of mercury and molybdenum.

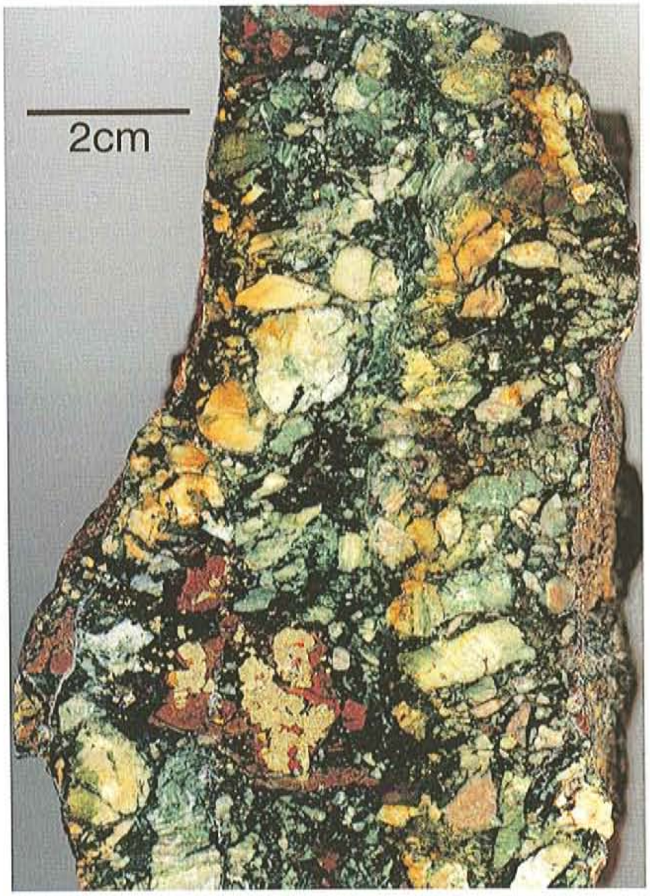

Plate 3. *Au-Ag-As-bearing chlorite-rich hydrothermal breccia (11.2 g/t Au, 210 g/t Ag), with pyrite and hematite in the matrix; Roadcut prospect.*

Low-Sulphidation Style, Au-bearing Veins (Steep Nap Prospect)

Gold-bearing, low-sulphidation epithermal-style mineralization (or adularia–sericite) occurs on the north end of the eastern Avalon high-alumina belt. The largest of these occurrences, the Steep Nap prospect, consists of gold-bearing hydrothermal quartz–hematite–adularia veins in pyroclastic and hydrothermal breccias of the Harbour Main Group. Grab samples from the largest vein bundle in the Steep Nap prospect contain up to 2.2 g/t Au (O'Brien and O'Driscoll, 1996b); a channel sample across the same veins averaged 3.3 g/t Au over approximately 1.7 m (C. Miles, personal communication, 1997). The main vein has been traced along strike to the southeast for approximately 300 m. The prospect is located approximately 3 km north of the main advanced argillic alteration zone at the Oval Pit Mine. Locally intense silica–sericite–pyrite alteration is exposed within a few hundred metres of the Steep Nap prospect. However, wall-rock alteration in the immediate host to the veins is typically weak, mainly in the form of chlorite and hematite, and locally sericite and silica.

At the Steep Nap prospect, a 60-m-wide exposure of low-strained felsic pyroclastic rocks is cut by more than 100 veinlets, veins and vein bundles. These trend northwest–southeast to north–south, dip steeply, and range in size from 1 mm up to approximately 2 m (most are less than 2 cm wide). The main auriferous material forms a steep, northwest-trending composite vein composed of colloform and crustiform bands of quartz (including recrystallized chalcedony), adularia, and minor hematite (Plate 4). The veins are typically devoid of sulphide mineralization. Within the mineralized vein bundle, hematite-rich vein cores or breccia are enriched in gold relative to banded quartz–chalcedony zones, which are in turn enriched in gold, relative to adularia-rich zones.

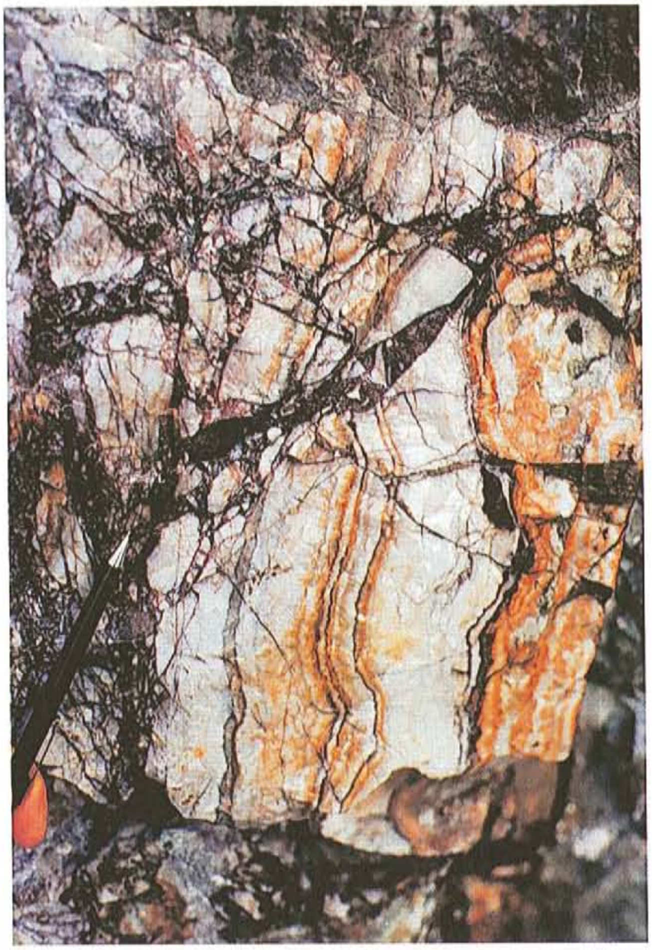

Plate 4. *Banded, gold-bearing quartz–adularia–hematite veins of the Steep Nap prospect.*

The earliest veins are crustiform-banded, and consist of grey recrystallized chalcedony and white quartz veins; these locally contain minor chlorite and hematite. A second group of veins contain crustiform and locally colloform bands of K-feldspar, grey recrystallized chalcedony, white quartz and hematite. The latest veins are characterized by weakly banded quartz along the margin, and crystalline comb quartz near the centre, surrounding a hematite-rich core. In many cases, especially in the larger veins, there is internal brecciation of the vein material by red hematite, intergrown with fine-grained chlorite, sericite and quartz. Hematite-filled fractures in the surrounding outcrop occur locally, especially in the hanging wall of the main mineralized vein.

The earliest hydrothermal breccias have a matrix of banded quartz, recrystallized chalcedony and minor K-feldspar, which forms cockade textures cored by angular sericite–chlorite-altered clasts. This breccia, which has developed in the pyroclastic host rocks of the veins, forms the immediate hanging wall of the main gold-bearing vein bundle.The later hydrothermal breccias have either a black chlorite-rich matrix or a brown iron oxide-rich matrix. They contain fragments of banded vein material, and are thus either late syn- and/or post-veining. Locally, the two matrix types mix. Post- and syn-veining hydrothermal brecciation are typically accompanied by the addition of hematite, chlorite and quartz.

Sericite, chlorite, and hematite are the main wall-rock alteration phases; there is also evidence of localized silicic alteration and hydrothermal albite and K-feldspar growth. 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. A 2-m-wide zone of pervasive chloritic alteration occurs mainly in the immediate hanging wall of the widest vein. However, in most instances, chlorite alteration is mainly confined to 1-cm-wide halos around pre-veining fractures and veinlets. Hematite alteration locally forms early remobilization halos and late patches and halos around late veinlets and fractures.

Hydrothermally Altered Intrusions

The volcanic rocks of the eastern Avalon high-alumina belt are intruded by polyphase, high-level plutons, displaying a wide range in composition from gabbro through monzonite to granite; these are part of the Holyrood Intrusive Suite. These plutons, which include I-type hornblende–biotite intrusions of calc-alkaline chemical affinity, display evidence of extensive magmatic degassing and are locally affected by hydrothermal alteration. Field and existing geochronological evidence (Krogh *et al.*, 1988) indicate that these are coeval with various parts of the intruded volcanic pile. The intrusive suite, as presently outlined, includes pre- or syn-alteration and post-alteration phases, and presents a window into the roots of the magmatic hydrothermal system related to the advanced argillic alteration in the eastern Avalon high-alumina belt.

Granitic rocks, adjacent to the Oval Pit Mine, have been affected by locally intense sericite–hematite alteration, and contain rare cm-scale, quartz–chalcocite–malachite veinlets. Similar granites exposed north of the Oval Pit Mine are affected by more intense hydrothermal alteration. Pyrite–sericite alteration occurs peripheral to a central zone of silicic alteration, in which bleached, albitized biotite granite is replaced by massive grey silica, containing traces of molybdenite and rare chalcopyrite along fractures (Plate 5). Weakly altered granite at the edge of the zone is cut by unaltered, foliated diabase dykes.

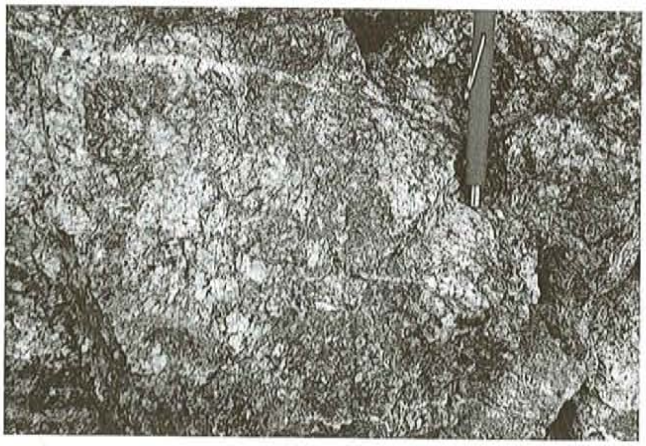

Plate 5. *Silicic alteration in granite of the eastern Avalon high-alumina belt.*

Granitic rocks in fault contact with altered rhyolites at the Trout Pond prospect are affected by locally intense silica–hematite–sericite alteration and typically contain disseminated pyrite. Similarly altered granite has a broad spatial association with hydrothermally altered rocks at the Mine Hill quarry and at the Dog Pond and Roadcut prospects. In the last case, granite exposures contain hydrothermal magnetite veinlets.

Variously altered (silica ± sericite ± hematite ± pyrite ± molybdenite) granitic rocks are exposed in the southern reaches of the eastern Avalon high-alumina belt and in rocks along strike to the southwest. An extensive area of hydrothermally altered granite, granodiorite and subaerial mafic to felsic volcanic float, considered to be derived from a nearby area of lithologically similar rocks, occurs at Butlers Pond, in a regional geological setting similar to that of the eastern Avalon high-alumina belt. Granodiorite and quartz monzonite boulders displaying sericitic alteration and hydrothermal brecciation, contain chalcopyrite as disseminations and veinlets (up to 6% Cu and up to 12.6 g/t Au; P. Crocker, written and oral communications, 1996, 1998; O'Brien *et al.*, 1997a, b). These occur with extensively altered (silica–sericite) chalcopyrite-bearing granitic rock, cut by zones of hydrothermal breccia with a magnetite-rich matrix. The nature of the alteration and mineralization at Butlers Pond compares favourably to that in porphyry-gold–copper systems (e.g., Sillitoe, 1979, 1993), and may imply that this region contains the mineralized magmatic roots of a hydrothermal system similar to that seen farther northeast, in the eastern Avalon high-alumina belt.

OTHER EXAMPLES OF 640–600 Ma HYDROTHERMAL ALTERATION AND MINERALIZATION

Epithermal-style hydrothermal alteration, locally associated with gold and copper mineralization, occurs in a number of areas on the central Avalon Peninsula outside the eastern Avalon high-alumina belt, in both the Harbour Main Group and adjacent intrusions. Alteration in volcanic rocks is typically found in close proximity to marine and terrestrial siliciclastic sedimentary rocks, and has a spatial relationship to intermediate and felsic intrusions. These plutons, which are themselves altered and mineralized, include phases of the Holyrood Intrusive Suite, and elements of a possibly younger suite of Neoproterozoic granites and distinctive magnetic monzonites. These intrusions have been emplaced into the volcanic rocks and – in the case of the younger suite – into marine sedimentary strata.

Volcanic rocks of similar facies and stratigraphic position to those in the eastern Avalon high-alumina belt reappear on the west side of the Holyrood Intrusive Suite, where pyrite-rich advanced argillic alteration, and extensive areas of massive silicic alteration, with or without elevated gold concentrations, have been documented (e.g., Holyrood pyrite zone; Chapels Cove and Holyrood access occurrences; *see* descriptions *in* O'Brien and O'Driscoll, 1996a and O'Brien *et al.*, 1997a). Alteration is spatially related to the contact area between the Harbour Main and Conception groups, and is locally remobilized by later movement along faults defining that boundary. In the southern part of the Holyrood Horst, andesite and rhyolite flows and tuffs have been affected by extensive silicic alteration, and the local development of siliceous hydrothermal breccia and copper sulphide mineralization associated with narrow zones of vuggy silicic alteration (O'Brien *et al.*, 1997a). Still farther south, volcanic and hypabyssal rocks affected by potassic, sericitic and silicic alteration and containing highly anomalous gold concentrations (up to 650 ppb) occur in the same stratigraphic position (Sparkes, 1986). In both cases, alteration occupies the same regional stratigraphic position as the eastern Avalon high-alumina belt, located about 40 km to the north. The intrusion-related Butlers Pond gold prospect lies in a similar setting.

Monzonitic intrusions and basaltic, andesitic and rhyolitic volcanic rocks along the western edge of the Holyrood Horst are host to discontinuous zones of advanced argillic, propylitic and silicic alteration and hydrothermal brecciation (e.g., Triangle belt; *see* O'Brien and O'Driscoll, 1996a and references therein). In the Triangle belt, mineralized float (up to 36g/t Au) and gold-bearing till (0.5 to 2 g/t Au) occurs over a 4-km-long, several-hundred-metre-wide zone (Rennie, 1989; Beischer, 1991). Gold values up to 10.2 g/t in drill core have been described from hydrothermal breccias, with reported intersections containing gold values up to 1.2 g/t over 10 m and 0.5 g/t over 10 m (Ace Developments Limited, 1995). Hydrothermal, chalcocite ± bornite-bearing, quartz-carbonate–chlorite veinlets and breccias in basaltic and andesitic flows occur along strike to the north in this area. These locally carry elevated gold values (up to 1 g/t) but are distinctive in their high Ag contents (up to 110 g/t, O'Brien and O'Driscoll, 1996b). The positive anomalies in the regional magnetic field in this area may indicate the presence of magnetite-bearing monzonitic intrusions at shallow depth along this belt, genetically related to mineralization in the host volcanic rocks.

COXHEATH DEPOSIT: AN AVALONIAN PORPHYRY Cu–Mo–Au SYSTEM

The potential for porphyry-style mineralization in 620 Ma (and other Neoproterozoic) intrusive rocks on the Avalon Peninsula and elsewhere in Newfoundland is underscored by known vein and stockwork Cu–Mo–Au mineralization in coeval intrusive rocks in the Appalachian Avalon belt in northeastern Nova Scotia. The Coxheath Cu–Mo–Au deposit on Cape Breton Island occurs in rocks similar in age, composition and facies to those on the central Avalon Peninsula. Mineralization at Coxheath was discovered in 1875, and this small deposit has been the focus of exploration and development at various times since (*see* Oldale, 1967 and review *in* Ortega, 1996). The most recent work on the deposit has been carried out by Ortega (1996), Lynch and Ortega (1997) and Thickle (1987). The following description is drawn principally from published work by Lynch and Ortega (1997).

Mineralization occurs in the Coxheath pluton, a composite 620 Ma granite, granodiorite, diorite and monzonite intrusion, emplaced into hydrothermally altered rhyolitic to basaltic flows and breccias. Ages in the range of ca. 625 to 615 Ma from the Coxheath pluton (^{40}Ar–^{39}Ar on igneous hornblende, Keppie *et al.,* 1990) and 613±15 Ma for the Coxheath rhyolite (U–Pb on zircon, Bevier *et al.*, 1993) have been reported. Zones of potassic and sodic alteration, concentrated in the intrusive rocks, pass into marginal zones of propylitic and phyllic alteration, that in turn give way to an outer zone of distal argillic alteration (Ortega, 1996). Vein and stockwork mineralization occurs mainly in the monzonite pluton and includes chalcopyrite, bornite, molybdenite and gold. The introduction of Cu, Mo and Au is associated with the potassic alteration and the formation of hydrothermal magnetite. Potassic-altered rocks are overprinted by tourmaline veins and breccia in a zone of sodic alteration. Diamond-drill hole data summarized in Ortega (1996) include intersections of 56 m of potassic alteration, and 18 m of 0.75% Cu and 1.8 g/t Au (Ave: 0.8% Cu, 1.5g/t Au).

Ortega (1996) and Lynch and Ortega (1997) interpret the hydrothermal alteration at Coxheath as representing a section through epithermal into the porphyry domain, with little or no apparent telescoping of the two systems. The higher level epithermal domain is marked by phyllic and argillic alteration; the deeper level or core of the system is a porphyry domain of potassic alteration, overprinted by a sodic, tourmaline-rich halo. Ortega's (1996) interpretation that erosion levels at Coxheath are at the top of a porphyry system have important exploration implications, and contrast with earlier views (e.g., Hollister *et al.*, 1974) that Coxheath represented the roots of a similar porphyry system.

600–560 Ma AVALONIAN ROCKS

Along the northeastern Appalachian Avalonian belt, inhomogeneous deformation of pre-600 Ma rocks was followed by a complex tectono-magmatic event, or series of events, that continued from approximately 600 million years to the end of the Proterozoic. Thick and extensive successions of post-600 Ma stratified rocks are best exposed on the Avalon Peninsula of eastern Newfoundland. Extensive tracts of volcanic rocks and sediments of this age are preserved throughout southeastern Newfoundland, where in many places they are intruded by coeval magmas (Hussey, 1979; King, 1988; O'Brien, 1993, 1994; O'Brien *et al.*, 1990, 1995). Lithologically similar successions of this same age are preserved on the southwest coast of Newfoundland, together with higher grade Neoproterozoic, and early- to mid-Paleozoic, metamorphic rocks (e.g., O'Brien *et al.*, 1993). Rocks of similar age and facies occur in southeastern Cape Breton Island (Barr *et al.*, 1996) and in parts of the coastal belt of southern New Brunswick (Rast *et al.*, 1976). Extensive magmatic arcs of similar age, facies and chemical affinity are the hallmark of the Carolina Slate Belt segment of the Appalachian Avalonian belt.

On the scale of the Appalachians, the Avalonian geological record for much of this time is dominated by arc-related magmatic activity. Existing geochronological data identify a protracted magmatic cycle from ca. 595 Ma to ca. 570–565 Ma, when calc-alkaline and tholeiitic volcanic suites and related calc-alkaline granites, tonalites, diorites and gabbros were generated (*see* O'Brien *et al.*, 1995, 1996; G. Dunning and T. Krogh, unpublished data). Terminal Neoproterozoic magmatism (from ca. 565–560 Ma to 545 Ma) produced plutons and volcanic rocks of alkaline to peralkaline composition in parts of the Newfoundland Avalonian belt. From ca. 570 Ma onward, a significant divergence in the record of the Newfoundland Avalonian belt was established (O'Brien *et al.*, 1996). In the Avalon Zone (*sensu stricto*), depositional linkages, without major discordance or hiatus, exist between ca. 570 Ma rocks and fossiliferous Cambrian to earliest Ordovician platformal strata. In contrast, Avalonian rocks exposed along parts of the belt's inboard Appalachian margin, record tectonothermal events of similar terminal Neoproterozoic–basal Cambrian age (Dunning and O'Brien, 1989; O'Brien *et al.*, 1991, 1993).

DISTRIBUTION AND NATURE OF 600–560 Ma ROCKS IN THE NEWFOUNDLAND AVALONIAN BELT

Terrestrial volcanic, high-level plutonic, and marine to deltaic and fluviatile sedimentary rocks formed in this interval (e.g., King, 1990; O'Brien *et al.*, 1996). Volcanic rocks of this age in eastern Newfoundland are more widespread and compositionally variable than previously thought, and occur interlayered with and overlain by volcaniclastic and arenaceous clastic successions. These volcanic-sedimentary units are particularly well developed in the Bonavista Bay and Fortune Bay areas, the Burin Peninsula and the Hermitage Flexure region (e.g., Marystown Group, Long Harbour Group, O'Brien *et al.*, 1984, 1985; O'Brien, 1993, 1994). Magmas generated at this time are most extensively preserved in the west part of the Avalon Zone (*sensu stricto*), where they were emplaced into coeval stratified successions and variably tectonized earlier Neoproterozoic rocks (e.g., Swift Current Granite). Calc-alkaline granite–gabbro complexes formed in the interval 590 to 570 Ma, whereas younger Neoproterozoic plutons include rocks of alkaline to peralkaline composition. Siliciclastic sedimentation in deltaic to terrestrial, and subsequently, open-marine environments continued from about 565 Ma to the end of the Proterozoic, and in the Fortune Bay area, through the Early and Middle Cambrian (O'Brien *et al.*, 1995, 1996). By the terminal Neoproterozoic, an extensional, terrestrial tectonic realm was firmly established in the Avalon Zone (*sensu stricto*), and alkaline to peralkaline magmatism locally accompanied alluvial and fluvial clastic deposition in pull-apart basins (e.g., parts of the Long Harbour Group, Cross Hills Intrusive Suite; O'Brien *et al.*, 1984, 1995). Local unconformities between upper Neoproterozoic redbeds and underlying marine successions reflect inhomogeneous deformation and low-grade dynamothermal metamorphism prior to, and during, these final Proterozoic events (e.g., O'Brien, 1993, 1994).

The Newfoundland Avalonian belt west of the Avalon Peninsula is host to Neoproterozoic hydrothermal alteration and gold mineralization that formed in the interval 600 to 560 Ma. Well-known examples of such mineralization include the Hickey's Pond and related gold prospects on the Burin Peninsula, and the Hope Brook gold deposit on the Newfoundland southwest coast. The main lithic components of this age, common to both the Burin Peninsula and the Hope Brook regions are: 1) subaerial calc-alkaline volcanic rocks, which interdigitate with, and are overlain by, volcanoclastic, arenaceous sedimentary rocks, and 2) comagmatic composite intrusions, that locally include quartz–feldspar–porphyry phases. In each area, gold mineralization occurs in relatively high-strain rocks, spatially and genetically related to regional scale zones of pyritic advanced argillic alteration (with alunite) and massive silicic alteration. The hydrothermally altered and mineralized zones in both areas display many characteristics of high-sulphidation epithermal systems.

HYDROTHERMAL ALTERATION AND GOLD MINERALIZATION IN 600–560 Ma ROCKS

NORTH-CENTRAL BURIN PENINSULA: HICKEY'S POND AND RELATED PROSPECTS

Belts of advanced argillic alteration with the mineral assemblage of pyrophyllite, alunite, quartz, sericite, pyrite, specularite, rutile, barite, chloritoid and lazulite are developed on a regional scale in late Neoproterozoic Avalonian volcanic rocks on the northern Burin Peninsula (Huard and O'Driscoll, 1986; O'Driscoll *et al.*, 1988; Huard, 1990; Dimmell and MacGillivray, 1993; Figure 4). Silicic alteration and hydrothermal breccias within this 100-km-long belt are associated with gold and, in some instances, copper and arsenic mineralization. Alteration and mineralization occurs within subaerial volcanic rocks of the Marystown Group, which elsewhere on the peninsula yields U–Pb ages in the range 590 to 570 Ma (T. Krogh, unpublished data; written communication, 1996).

The *Hickey's Pond prospect* and related *Headwaters*, *Eric's*, *Chimney Falls*, *Tower*, *Ridge*, *Monkstown Road*, *Little Pond*, *Bullwinkle* and *Strange showings* (*see* individual descriptions and assay results in Huard and O'Driscoll, 1986, and Huard, 1990) lie in two separate belts[2] of advanced argillic hydrothermal alteration, located on either side of, and spatially associated with, the 577±3 Ma (R. Tucker, unpublished data) Swift Current Granite. The mineralogically similar *Stewart prospect* occurs in an analogous setting, more than 50 km along strike to the southwest from the Hickey's Pond belt. Extensive areas of intense silicic alteration occur farther along strike to the southwest in the *Point Rosie prospect*. In these areas, gold mineralization occurs primarily in specular hematite-bearing hydrothermal breccias and/or in silicic-altered material of primarily volcanic protolith, in which pyrite occurs as disseminations or in veinlets, with quartz.

The most well-known gold showing of the northern Burin Peninsula occurs at Hickey's Pond, where gold values up to 12.4 g/t over 1.2 m have been reported from channel samples by Corona Corporation (Dimmell and MacGillivray, 1989). The Hickey's Pond specular hematite showing was known since the 1930s, when it was investigated and promoted as a potential source of iron (Dahl, 1934; Howland, 1940), although its gold potential was not recognized until the late 1970s (Hussey, 1978).

Highly strained, banded, quartz–specularite–alunite-bearing rocks of a subaerial felsic pyroclastic protolith are typical of the lithology of the Hickey's Pond gold prospect. These advanced argillic alteration zones are intermixed with more locally developed zones of massive silicic alteration, which locally contain in excess of 97.7% SiO_2. The silicic-altered rocks, which are in places pyritic, are pale brown to white-weathering, cut by vuggy quartz veins and display multiple silica flooding. The main alteration zone at Hickey's Pond is situated on a peninsula in the pond, and is approximately 100 m wide and continuous along strike for at least 225 m. The presence of alunite results in very pale pink colouration of some of the hydrothermally altered rocks. An intense, steeply dipping S_1 foliation that is characteristic of this zone is associated with major high-angle reverse-shear zones. This S_1 fabric is deformed by small-scale, steeply plunging F_2 folds. The alunite, pyrophyllite, quartz, pyrite and hematite are elongated along the S_1 foliation and are pre- or syn-D_1 deformation. Gold mineralization (up to 5.4 g/t Au) is present in a distinctive hydrothermal breccia containing angular silicic clasts in a specular hematite-rich matrix (Huard, 1990; Plate 6). Pyrite-rich, silicic-altered alunite-bearing rocks associated with vuggy silica pods contain the most gold (up to 12.4 g/t Au over 1.2 m; Dimmell and MacGillivray, 1989).

A chalcopyrite-bearing zone within the silicic-altered material at Hickey's Pond contains up to 3.18 g/t Au, 76 g/t Ag, 1040 g/t Cu, 4600 g/t As and 2077 g/t Sb (Dimmell and MacGillivray, 1989). Our new data from this prospect, indicates this zone contains up to 1.86% As and 3.41% Cu. Such a metallic signature is typical of high-sulphidation, epithermal gold mineralization (cf., White and Hedenquist, 1995). Dimmell and MacGillivray (1989) note an increase in gold concentrations with increasing proximity to areas of most intense silicic alteration at Hickey's Pond.

Auriferous hydrothermal breccias similar to those at Hickey's Pond reappear along strike in a high-strain zone with pyrophyllite–sericite schist, approximately 4 km along strike to the south, at Chimney Falls (Huard, 1990). Farther south, the Tower showing has a similar advanced argillic assemblage as Hickey's Pond, and includes poorly exposed zones of massive silicic alteration. The western belt of advanced argillic alteration includes five occurrences of specular hematite, with or without pyrophyllite, alunite, rutile and lazulite (the Ridge, Monkstown Road, Little Pond, Bullwinkle and Strange showings). Like the Hickey's Pond belt to the east, alteration is associated with specular hematite breccia, massive silicic-altered rocks, and locally elevated gold values.

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[2] Eastern belt (from north to south): Eric's and Headwaters showings, Hickey's Pond prospect, and the Chimney Falls and Tower showings; Western belt (from north to south): Ridge, Monkstown Road, Little Pond, Bullwinkle and Strange showings.

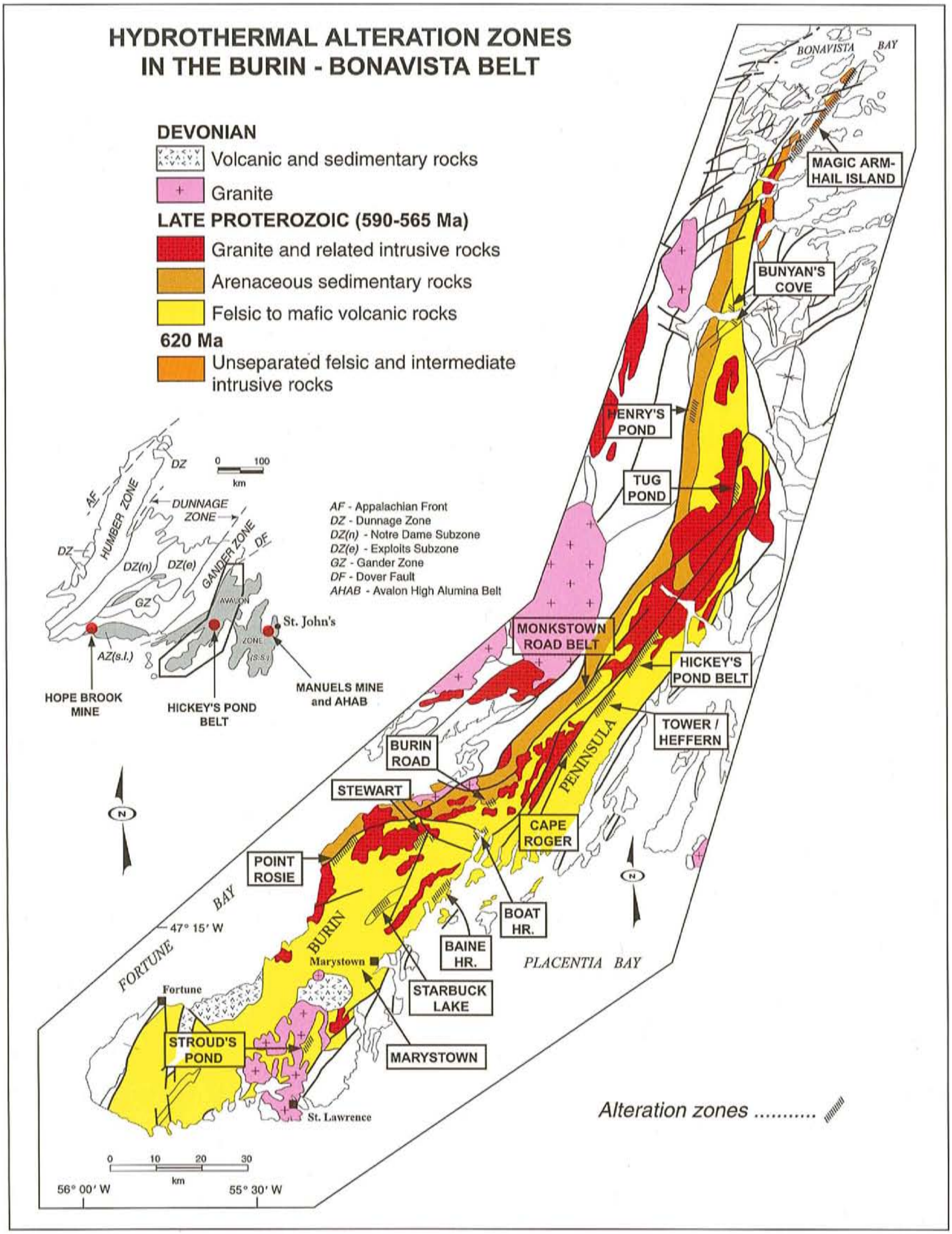


Figure 4. *Major hydrothermal alteration zones hosted by 590–560 Ma rocks in the core of the Burin–Bonavista belt.*

Plate 6. *Auriferous (5.4 g/t Au), specular hematite-bearing hydrothermal breccia, Hickey's Pond prospect.*

At the Stewart prospect, a locally auriferous, 4-km-long and 400- to 700-m-wide composite zone of deformed silicic and aluminous alteration is located in felsic volcanic rocks proximal to the contact with hornblende–biotite granite (Dimmell and MacGillvray, 1993), near an extensive belt of high-level granite, felsite and quartz–porphyry (O'Brien and Taylor, 1983). The zone includes weakly pyritic and silicic-altered subzones, characterized by the assemblage quartz–pyrophyllite–sericite–kaolinite–pyrite–hematite–chlorite. Gold mineralization (0.25 g/t over 63 m, 0.84 g/t over 5 m and 2.9 g/t over 1 m; all in drill core) is associated with chalcopyrite, azurite, cuprite and molybdenite in alunite-bearing altered (silica–sericite–pyrophyllite) rocks in the southern parts of the alteration zone (Dimmell and MacGillvray, 1993).

HERMITAGE FLEXURE AREA: HOPE BROOK MINE

The Hope Brook gold mine (McKenzie, 1986; Yule *et al.*, 1990; Stewart, 1992; Dubé and Dunning, 1998), the largest gold deposit (50 t Au) in the Canadian Appalachians, occurs in late Neoproterozoic Avalonian rocks located in the Hermitage Flexure region of southern Newfoundland. In that area, a composite suite of Avalonian rocks between ca. 680 and 560 Ma overthrusts and lies unconformably below a thick cover sequence of Early to Late Silurian terrestrial volcano-sedimentary rocks; the latter separates the Avalonian rocks from Ordovician rocks of the Appalachian Dunnage Zone (O'Brien *et al.*, 1991; Tucker *et al.*, 1994). The Hope Brook deposit is located in the hanging wall of the Late Silurian, reverse sinistral, Cinq Cerf Fault Zone, which separates the Avalonian basement from its Silurian cover (O'Brien *et al.*, 1991). The deposit is enclosed within a zone of hydrothermal alteration more than 3 km long and up to 400 m wide. It is hosted by arenaceous sedimentary and related subaerial tuffaceous volcanic rocks (Whittle Hill Sandstone) that are intruded by a 300-m-wide quartz–feldspar porphyry sill-dyke complex of the late Neoproterozoic Roti Intrusive Suite (O'Brien *et al.*, 1991; Dubé and Dunning, 1998, *in press*; Figure 5). The alteration zone, the deposit and the host rocks are strongly deformed, in large part during Silurian reverse sinistral motion on the Cinq Cerf Fault Zone. The Devonian Chetwynd Granite (390 ± 3 Ma) and associated contact metamorphism overprint the Hope Brook deposit and the adjacent Cinq Cerf Fault Zone (McKenzie, 1986; Dubé, 1990; Yule *et al.*, 1990; O'Brien *et al.*, 1991; Stewart, 1992; Dubé and Dunning, 1998).

The Hope Brook alteration zone is characterized by, first, extensive advanced argillic alteration with pyrophyllite, kaolinite, andalusite, sericite, quartz, diaspore, and alunite, which is developed mostly in the structural hanging wall of the ore zone (McKenzie, 1986; Yule *et al.*, 1990; Stewart, 1992; Dubé and Dunning, 1998, Figure 6). Its second characteristic is the existence of two stages of massive silicic alteration. The first stage is represented by a buff-colour massive silicic zone that extends for more than 3 km laterally, away from the deposit. It is barren to weakly auriferous, and is likely the result of pervasive acid leaching of the original hosts. However, gold (and copper) mineralization is hosted by rocks displaying the second stage of silicic alteration (Dubé and Dunning, 1998). The latter is clearly superimposed on first-stage silicic alteration (Plate 7) and is characterized by a grey to dark-grey colour, vuggy silica and several percent pyrite. Also present are lesser amounts of chalcopyrite, bornite and traces of tennantite, either as disseminations, impregnations or veinlets, and local traces of enargite. The deposit also contains geochemically anomalous concentrations of Sb, Bi, Pb and As (Dubé and Dunning, 1998). The second stage of massive silica alteration also contains a weakly auriferous (≤1 g/t Au), pyrite-rich subzone known as the "pyrite cap". This subzone is characterized by 15 to 30 percent pyrite, which occurs as disseminations in the matrix or, more commonly, as anastomosing veinlets and semi-massive (cm- to m-wide) pyritic bands or lenses, oriented subparallel to the main foliation.

Various interpretations of the origin of the Hope Brook gold deposit have been proposed. Swinden (1984), Kilbourne (1985) and McKenzie (1986) proposed that mineralization was of epithermal origin and related to Ordovician felsic volcanism and/or high-level magmatism. Dubé (1990) classified Hope Brook as a deformed, disseminated strata-bound sulphide–gold deposit of pre-Late Silurian age, having similarities to Romberger's (1986) disseminated gold subtype of epithermal deposit. Yule *et al.* (1990) proposed that Hope Brook represents a pre-metamorphic and pre-shearing, modified mesothermal gold deposit of probable Cambrian age, although they noted similarities with acid-sulphate epithermal style deposits. Stewart (1992) interpreted Hope Brook as a multistage syntectonic shear-hosted acid-sulphate-type gold deposit related to a protracted hydrothermal history from late Neoproterozoic to Devonian times.

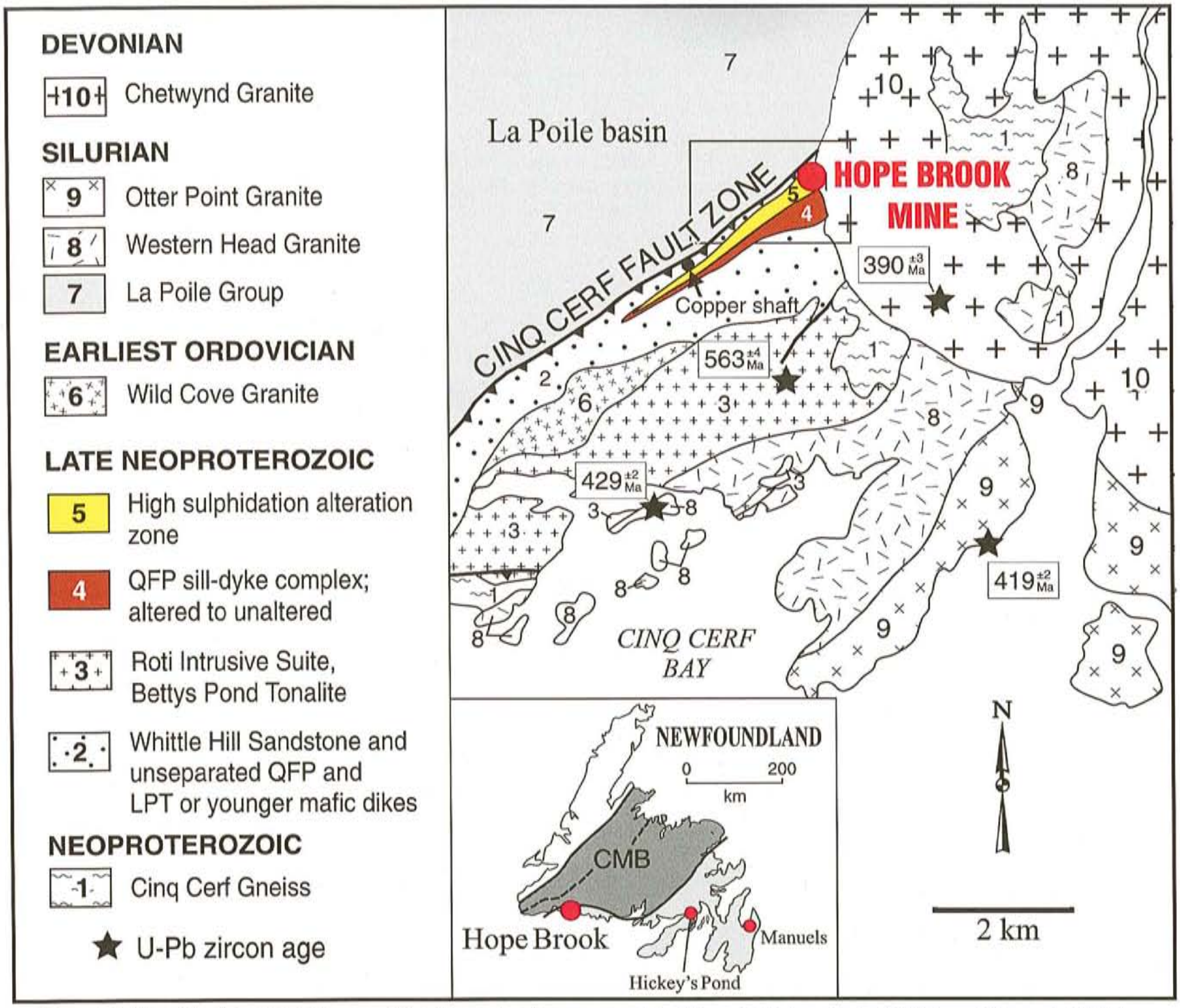


Figure 5. *Simplified geological map of the Hope Brook area, modified from O'Brien* et al. *(1991) and Stewart (1992); from Dubé and Dunning (1998,* in press). *CMB = Central Mobile Belt; box delimits area shown in Figure 6.*

Recent U–Pb dating of altered and unaltered rocks, coupled with establishment of crosscutting relationships, brackets alteration and mineralization at Hope Brook between 578 and 574 Ma (Dunning and Dubé, *in press*). These data, coupled with the presence of pre-alteration quartz–feldspar porphyry and late- to post-alteration quartz–feldspar porphyry link (in both space and time) the mineralization and the emplacement of the subvolcanic sill-dyke complex, demonstrate that high-sulphidation-type gold deposition at Hope Brook is of late Neoproterozoic age.

LATE NEOPROTEROZOIC (AVALONIAN) GOLD DEPOSITS IN THE CAROLINA SLATE BELT

Regional Setting and Major Styles of Gold Mineralization

The Carolina Slate Belt, part of the larger Carolina Terrane (Secor *et al.*, 1983), extends approximately 600 km from southern Virginia to northern Georgia, embodying the principal and best-known area of late Neoproterozoic Avalonian rocks in the southeastern Appalachian orogen (Butler and Secor, 1991). Avalonian successions of the Carolina Slate Belt, like those of the northern Appalachians, consist primarily of late Neoproterozoic volcanic, sedimentary and plutonic rocks, relicts of a subduction-related magmatic arc (e.g., Feiss *et al.*, 1993), capped by fossiliferous (Acado-Baltic) Cambrian strata (Sampson *et al.*, 1990). The Carolina Slate Belt lies outboard of Appalachian terranes that expose the Iapetan miogeocline and the vestiges of Iapetan margins, and has been affected by ductile deformation, metamorphic recrystallization and granite intrusion during the late Paleozoic Alleghenian orogeny (Secor *et al.*, 1986). As is the case in the northern segment of the Appalachian Avalonian belt, hydrothermal alteration and gold mineralization linked to late Neo-

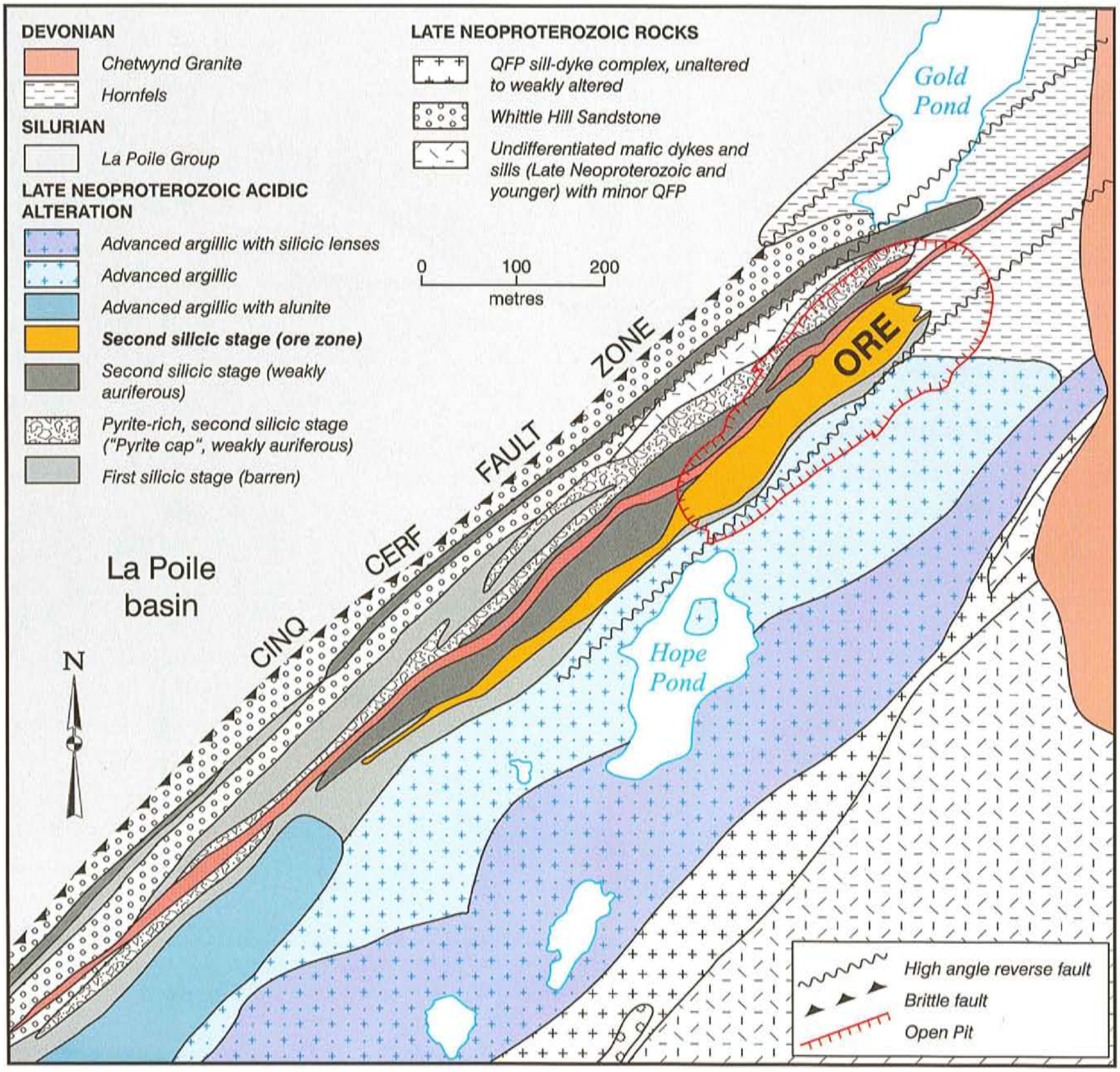


Figure 6. *Simplified geological map of Hope Brook gold deposit showing the nature and distribution of alteration and lithotectonic units. Modified from Stewart (1992) and unpublished BP-Selco and Royal Oak Mines maps. Note that for simplification, the younger and unaltered mafic dykes and sills are not shown. Based on detailed field mapping and surface projection of drillholes (from Dubé and Dunning,* in press*).*

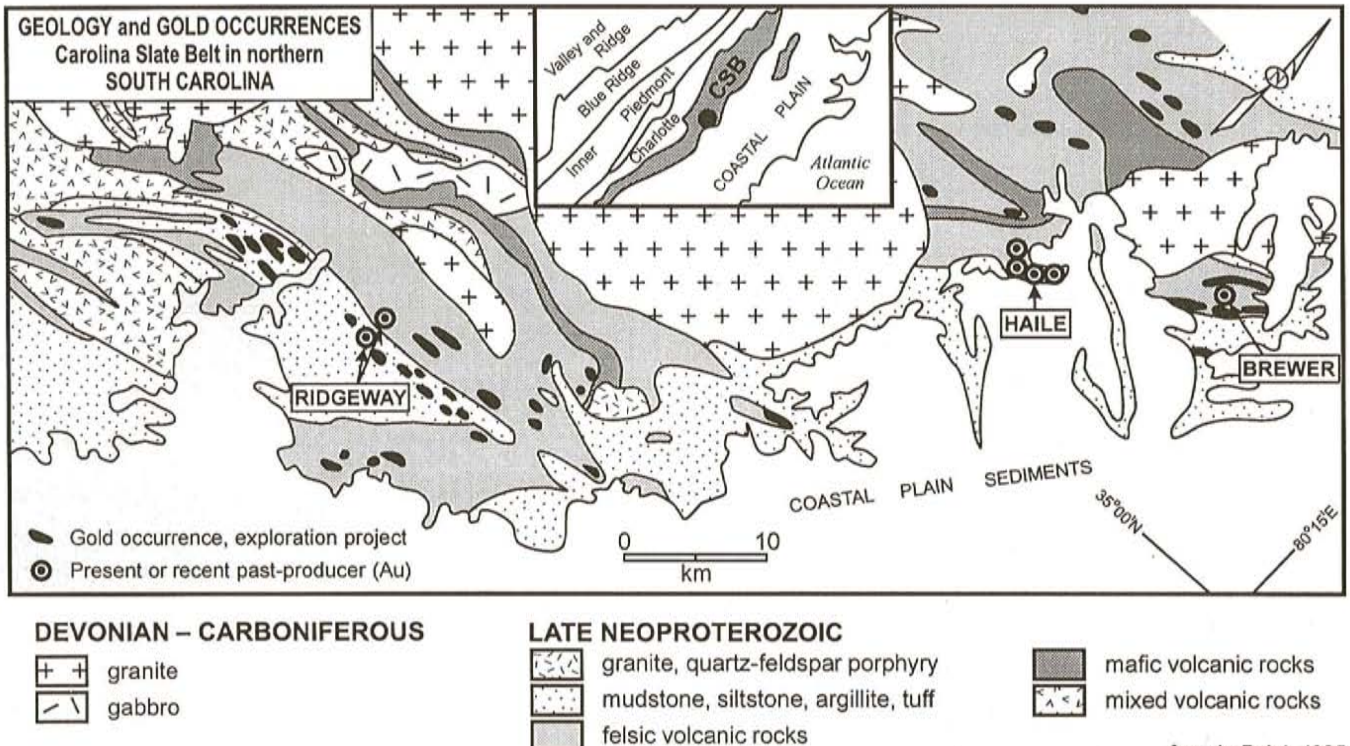
proterozoic magmatism are major facets of the pre-Paleozoic history of this region (e.g., Worthington and Kiff, 1970; Schmidt, 1985; Feiss *et al.*, 1993).

Unlike much of eastern Newfoundland, auriferous Avalonian rocks of the Carolina Slate Belt have undergone extensive late Paleozoic deformation and recrystallization, which in many cases have masked or obliterated original relationships. In addition, this region escaped the affects of late Wisconsinan glaciation. The resultant remobilization and subsequent deep supergene weathering of gold bears on the nature of the early discovery and mining of that metal in the Carolina Slate Belt. These first discoveries dating from the late 1700s and early 1800s, were of remobilized Bonanza-style, lode quartz-gold and supergene-enriched gold in deeply weathered sapprolite. From 1825, up to the mid-1900s, more that 2.5 million ounces of gold were produced from such deposits. Mining of low-grade bulk tonnage deposits in the Carolina Slate Belt became feasible only with the advent of heap leach technology for gold extraction.

Plate 7. *Crosscutting first (light) and second (dark) stages of silicic alteration, Hope Brook gold deposit.*

Since 1985, four gold mines have been brought into production in the South Carolina segment of the Carolina Slate Belt, having a total production of 1.5 million ounces of gold between 1985 to 1993. The largest producers (or past-producers) are the Brewer, Haile and Ridgeway mines. These deposits, and a large number of smaller gold prospects, are located near the same boundary between two regional volcanic and sedimentary units of the eastern Carolina Slate Belt (Figure 7). The late Neoproterozoic host rocks are intruded by mainly posttectonic Alleghenian granites, which are not seen as a major factor in the overall evolution of the gold-bearing hydrothermal systems.

Gold mineralization typically occurs at or near the transition between late Neoproterozoic (to ?Cambrian) subaerial, intermediate to felsic volcanic rocks (Persimmon Fork Formation), that are unconformably overlain by the subaqueous epiclastic-rich metasedimentary rocks (Richtex Formation), all of which are metamorphosed at lower greenschist facies (Bell, 1980; Secor, 1988). The gold mineralization is disseminated and hosted by pyritized and highly siliceous units interpreted to be Late Proterozoic (to ?Cambrian) felsic flows or quartz porphyry at Brewer (Scheetz, 1991), felsic volcanic and pyroclastics and sedimentary rocks at Ridgeway (Gillon *et al.*, 1995) and silica-rich siltstone at Haile (Maddry and Kilbey, 1995). Ririe (1990) has interpreted these three deposits as acid–sulphate type. Whereas, there is a general consensus that the Brewer Mines represents a Neoproterozoic high-sulphidation deposit, contrasting views abound on the origin of the Haile and Ridgeway deposits (*see* below). It is also noteworthy that, like Newfoundland, the Carolina Slate Belt is host to several significant pyrophyllite deposits (e.g., Feiss and Slack, 1989), which are clear manifestations of the existence of large-scale advanced argillic alteration systems. The age of gold mineralization in the Carolina Slate Belt has not been accurately constrained. Recent Re–Os dating on molybdenite has indicated ages of 596±2 Ma and 563±2 Ma for the mineralization at the Haile Mine (Maddry and Kilbey, 1995).



from LaPoint, 1995

Figure 7. *Auriferous hydrothermal systems and major gold deposits in late Neoproterozoic (Avalonian) rocks of northern South Carolina (reproduced with minor modification from LaPoint, 1995).*

High-Sulphidation Gold Mineralization: Brewer Deposit

The best preserved and largest unequivocal example of high-sulphidation-style gold mineralization in the Carolina Slate Belt is the Brewer Gold Mine, which has reserves of 5.6 Mt of 1.2 g/t Au (Scheetz, 1991; Zwaschka and Scheetz, 1995). Mineralization at the Brewer deposit occurs within a multistage hydrothemal breccia complex located in a larger high-alumina alteration zone, hosted by felsic tuffs, flows and breccias. Alteration is situated near the boundary with an overlying sequence of fine-grained siliciclastic rocks interlayered with volcaniclastic beds (Lu *et al.*, 1993). These rocks were affected by lower greenschist-facies metamorphism and were isoclinally folded prior to the intrusion of posttectonic Alleghenian granite (Secor, 1988). The thermal effects of nearby Alleghenian plutons on mineralization are apparently minimal.

The auriferous ore breccias form the central core of an advanced argillic alteration zone with the following mineralogy: quartz–andalusite–pyrite–alunite–dickite–topaz. The advanced argillic zone is ringed by an outer zone of sericitic (quartz – sericite – pyrite – chloritoid – ilmenite) alteration (Scheetz *et al.*, 1991; Zwaschka and Scheetz, 1995). Four main breccia types are present at Brewer (Zwaschka and Scheetz, 1995): grey silica, beige "cafe au lait" silica, pyrite–silica, and pyrite–enargite. Multiply brecciated zones within the complex contain highest grades of copper (as enargite and covellite) and gold. Zwaschka and Scheetz (1995) emphasize the genetic importance of the silicic-altered and brecciated quartz porphyry plugs and sill-like bodies that outcrop in the Brewer Pit, in the formation of the main Brewer deposit. They suggest that the generation and emplacement of the porphyry is the driving force behind alteration, mineralization and hydrothermal brecciation.

Deformed, Disseminated/Stockwork Gold Mineralization of Equivocal Origin: Haile and Ridgeway Deposits

The Haile and Ridgeway gold deposits are located in a polydeformed, lower greenschist-facies volcaniclastic succession of interlayered tuffs, breccias, feldspar porphyry, arenite and siltstone, stratigraphically below latest Neoproterozoic marine sedimentary rocks. Both deposits are strongly deformed and lack high-sulphidation mineralogical and chemical signatures. At the Haile Mine, gold mineralization forms 20 separate orebodies[4] in a 4-km-long zone, hosted mainly by fine-grained, locally chert-like, sedimentary rocks (Haile siltstone) and, less so, by volcanic rocks. The two ore bodies[5] mined at the Ridgeway Gold Mine occur in both volcanic and sedimentary successions, adjacent to the same regional volcanic-sedimentary boundary with which the Haile and Brewer deposits are associated. Gold mineralization at Ridgeway occurs in two stratigraphically separate settings (Gillon *et al.*, 1995). The Ridgeway North deposit lies in the contact zone between a sequence of tuffs and coarse-grained breccias, cut by hypabyssal quartz–feldspar porphyry, and an overlying sequence of laminated siltstones and pyritic cherts containing interlayered ash flows and debris flows. The Ridgeway South deposit is hosted by a sequence of cyclically bedded turbidites and local debris flows, which overlie the volcanogenic package (Figure 8). The turbidite-like rocks are capped by a separate group of thin-bedded mudstone and siltstone.

The Haile deposits and the host stratified succession are isoclinally folded and display a near-ubiquitous moderate to steeply dipping east–west- to northeast-trending S_2 penetrative tectonic fabric (*see* Hayward, 1992). At Ridgeway, a similarly penetrative, shallowly dipping S_2 tectonic fabric that overprints a bedding-parallel fabric is developed throughout the gold deposits (Gillon *et al.*, 1995).

Gold mineralization at Haile is disseminated and occurs in silicic pyrite-rich rocks together with rutile, K-feldspar and traces of molybdenite. More extensive areas of silicic alteration are locally present, particularly where ore is hosted by hydrothermal breccia (e.g., Champion deposit). Haile ore typically contains 4 to 10 percent pyrite and lesser pyrrhotite (Maddry and Kilbey, 1995), and trace amounts of sphalerite, chalcopyrite, arsenopyrite, cassiterite and galena (Hayward, 1992). Maddry *et al.* (1993) report a positive correlation of gold with silver, arsenic, antimony and tellurium. Bedded pyrite is common within, and adjacent to, the Haile gold deposits (Speer and Maddry, 1993), where it is transposed into the regional S_2 tectonic fabric (Plate 8). Pyrite veinlets are developed subparallel to the S_2 fabric and like the bedded pyrite, are locally transposed and crenulated by S_2. Molybdenite is locally present as disseminations or in veinlets that are crenulated by the S_2 fabric.

Typical gold ore in the Ridgeway North deposit is a grey, fine-grained, silica-rich cherty rock, which is locally associated with gold-rich breccia. The Ridgeway South ore is developed in laminated sedimentary rocks and in several fragmental units of uncertain origin; ore grades are primarily

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[4] Total pre-1991 gold production from Haile Mine is estimated at 360 000 oz (Speer and Maddry, 1993). Ore reserves (1991) totalled 8.7 million tons at 0.089 ounces/ton (ca. 3.1 g/t Au; 780 000 oz Au); total gold resource (1991) is ca. 1.5 M oz (Maddry *et al.*, 1993, and Maddry and Kilbey, 1995).

[5] The Ridgeway North and Ridgeway South orebodies had reserves (as of 1986) of 57 million tons of 0.032 oz/ton (ca 1.1 g/t Au) and 0.031 oz/ton Ag (Gillon *et al.*, 1995).

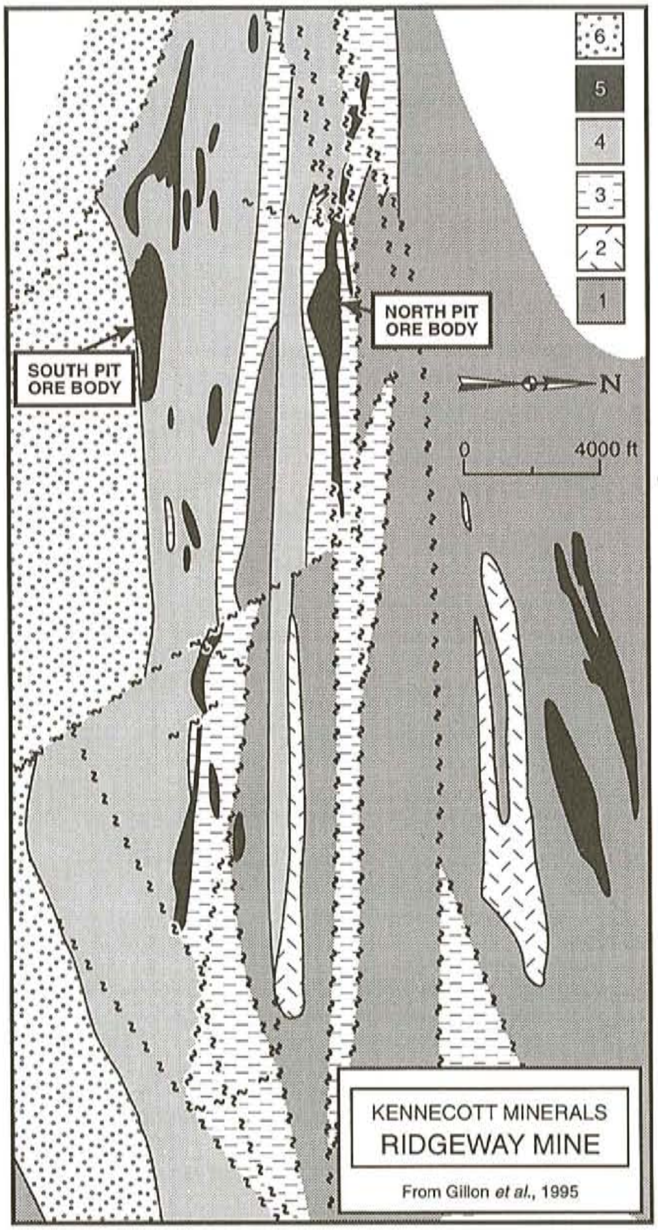

Figure 8. *Geological map of the late Neoproterozoic rocks in the Ridgeway Mine area, South Carolina, reproduced from Gillon* et al., *1995. 1 = mainly felsic volcanic rocks; 2 = quartz-feldspar porphyry; 3 = transitional zone of interlayered volcanic and sedimentary rocks; 4 = turbidites; 5 = mineralized and/or hydrothermally altered zones; 6 = thin-bedded siltstone and mudstone (Neoproterozoic to Cambrian age).*

in rocks displaying pervasive tectonic fabric, silicification, multiple quartz veining, and widespread sericite–pyrite alteration (Gillon *et al.*, 1995).

Plate 8. *Bedded pyrite, transposed into regional S2 tectonic fabric, Haile Mine.*

The origin of the Haile–Ridgeway type of Avalonian gold deposit is controversial and its ready assignment to existing classifications remains elusive. Both the Haile and Ridgeway deposits have been variously interpreted as auriferous marine exhalative gold mineralization, formed in a submarine hot-spring environment (Spence *et al.*, 1980; Kiff and Spence, 1987), syntectonic and epithermal (Gillon and Duckett, 1988), or structurally controlled (e.g., syntectonic) and metamorphic (Hayward, 1992). The origin of supergene-enriched kaolinite and/or sericite-rich material (the industrial mineral Mineralite®) associated with some of the Haile orebodies is equally enigmatic and has been interpreted either as hydrothermal alteration (Spence *et al.*, 1980; Kiff and Spence, 1988) or as supergene argillation and saprolitization (Maddry and Kilbey, 1995). The most recent model for the geological setting of the Ridgeway deposits is that it formed at the evolving margin of a late Neoproterozoic sedimentary basin adjacent to an active volcanic arc that was dominated by felsic and subsequently bimodal mafic–felsic volcanism (Gillon *et al.*, 1995). It is unclear whether the primary gold mineralization and host silica-rich rocks formed entirely as chemical precipitates, or that they were hydrothermally altered during submarine epithermal processes (Gillon *et al.*, 1995). The degree of metamorphic remobilization of gold also remains a point of contention.

Both the Ridgeway and Haile deposits appear to share many important features with the intrusion-related, non-carbonate stockwork, disseminated-style classification of gold mineralization (cf. Sillitoe, 1991; *see* also Robert *et al.*, 1997). These include the nature of mineralization, the styles of alteration, the geological setting, the abundance of pyrite and the presence of molybdenite. In such a case, the Ridgeway and Haile mineralization would be the products of a deeper level hydrothermal system than that responsible for mineralization at Brewer (*see* Summary and Discussion).

Gold-rich Volcanogenic Massive Sulphide Mineralization: Barite Hill Deposit

The Barite Hill gold deposit is located in the southern Carolina Slate Belt near the South Carolina–Georgia border, approximately 100 km southwest of the Brewer Gold Mine. Mineralization at Barite Hill is located in greenschist-facies pyroclastic rocks, overlain by sedimentary rocks, correlative with the Persimmon Fork and Richtex formations, respectively, of northern South Carolina, which host the Ridgeway, Haile and Brewer deposits (Carpenter *et al.*, 1982; Clark *et al.*, 1993). Mineralization occurs in interlayered tuffs and volcaniclastic sedimentary rocks, associated with feldspar porphyry, mafic sills and quartz–barite rock. Gold is typically associated with quartz–pyrite–barite-altered rocks. Clark *et al.*, (1993) state that the highest gold values are in quartz–barite rock and fragmental volcanic rocks cut by quartz–pyrite veinlets. Three stages of mineralization are present at Barite Hill: base-metal-rich; gold-poor (≤ 1 g/t), base-metal-rich; and gold-rich, base-metal-poor (Gunter and Padgett, 1988; Clark *et al.*, 1993). The abundance of barite and the association of gold with the massive sulfide assemblage pyrite–chalcopyrite–galena–sphalerite seen at Barite Hill are characteristic features of submarine, high-sulphidation VMS deposits (*see* Sillitoe *et al.*, 1996).

SUMMARY AND DISCUSSION

THE AVALONIAN BELT

- Much of the southeastern margin of the Appalachian orogen is defined by tectonically disrupted, internally complex assemblages of late Neoproterozoic age, which are vestiges of volcano-plutonic arcs and related sedimentary basins, all of peri-Gondwanan paleogeographic affinity. These Avalonian rocks share a common signature defined by a four-stage late Neoproterozoic tectonomagmatic history. The Appalachian Avalonian belt extends southwestward from Newfoundland to Georgia; the same rocks continue northeastward into the Caledonides of the United Kingdom. Beyond the Appalachian–Caledonian orogen, relicts of the Avalonian system occur in the Variscan and Pan-African belts. Together, these Avalonian rocks record the development of an extensive Neoproteozoic orogenic system analogous in many respects to many of the metallogenically important magmatic arcs disposed around the present-day Pacific rim.

- Complex continental margin-style magmatic arcs that developed in a variety of arc and back-arc or analogous continental arc settings from 640 Ma to the beginning of the Paleozoic are preserved primarily as extensive late Neoproterozoic subaerial, caldera-vented volcanic fields. These are intruded by coeval, near-surface porphyritic intrusions of chiefly calc-alkaline composition.

- These Neoproterozoic magma chambers were likely the driving force behind large-scale hydrothermal convective systems active at high crustal levels. The Avalonian belt, particularly in Newfoundland and the Carolina Slate Belt, contains late Neoproterozoic gold, copper–gold, and pyrophyllite deposits that formed in a variety of (primarily magmatic) settings. Many of these mineralized hydrothermal alteration systems formed as a response to magmatic degassing and related epithermal and/or porphyry-style alteration during the ascent, final emplacement and cooling of these high-level composite plutons.

THE EASTERN AVALON HIGH-ALUMINA BELT

- The advanced argillic alteration zones and associated pyrophyllite and gold mineralization in the eastern Avalon high-alumina belt most probably constitute parts of a large, tilted hydrothermal system spatially and genetically related to one or more phases of the Holyrood Intrusive Suite.

- Alteration is most likely linked to the original magmatic 'plumbing' system of the host volcanic field. Synvolcanic structural and lithological controls of alteration appear to be similarly linked to primary volcanic architecture. Alteration is primarily pretectonic, although the silica–sericite alteration (by the nature of its internal and inherent ductility contrast) has focussed later high-strain deformation.

- Gold-bearing veins in the northern part of the eastern Avalon high-alumina belt are characterized by crustiform and colloform bands of quartz, adularia and hematite, which are the result of phase separation or boiling. These veins are similar to those found in low-sulphidation epithermal hydrothermal systems. The relationship of these veins (in time and in space) to the advanced argillic alteration zones elsewhere in the eastern Avalon high-alumina belt remains to be defined. Their presence may reflect the existence of a larger low-sulphidation system related to the waning of the eastern Avalon hydrothermal system, distal to the main centre of high-sulphidation alteration or, alternatively, to a younger unrelated alteration system.

- Presence of diaspore and pyrophyllite within the advanced argillic alteration, coupled with the almost complete lack of kaolinite, implies fluid temperatures too high (260 to 280°C) to have been formed in a steam-heated alteration environment. This assemblage is consistent with alteration formed within a magmatically derived high-sulphidation system. The presence within the alteration zone of hydrothermally altered intrusions containing traces of Mo and Cu further supports such a hypothesis.

THE POTENTIAL FOR AVALONIAN PORPHYRY Au–Cu–Mo

- Porphyry-style Cu, Cu–Mo and Cu–Mo–Au deposits potentially represent the roots of high-sulphidation epi-

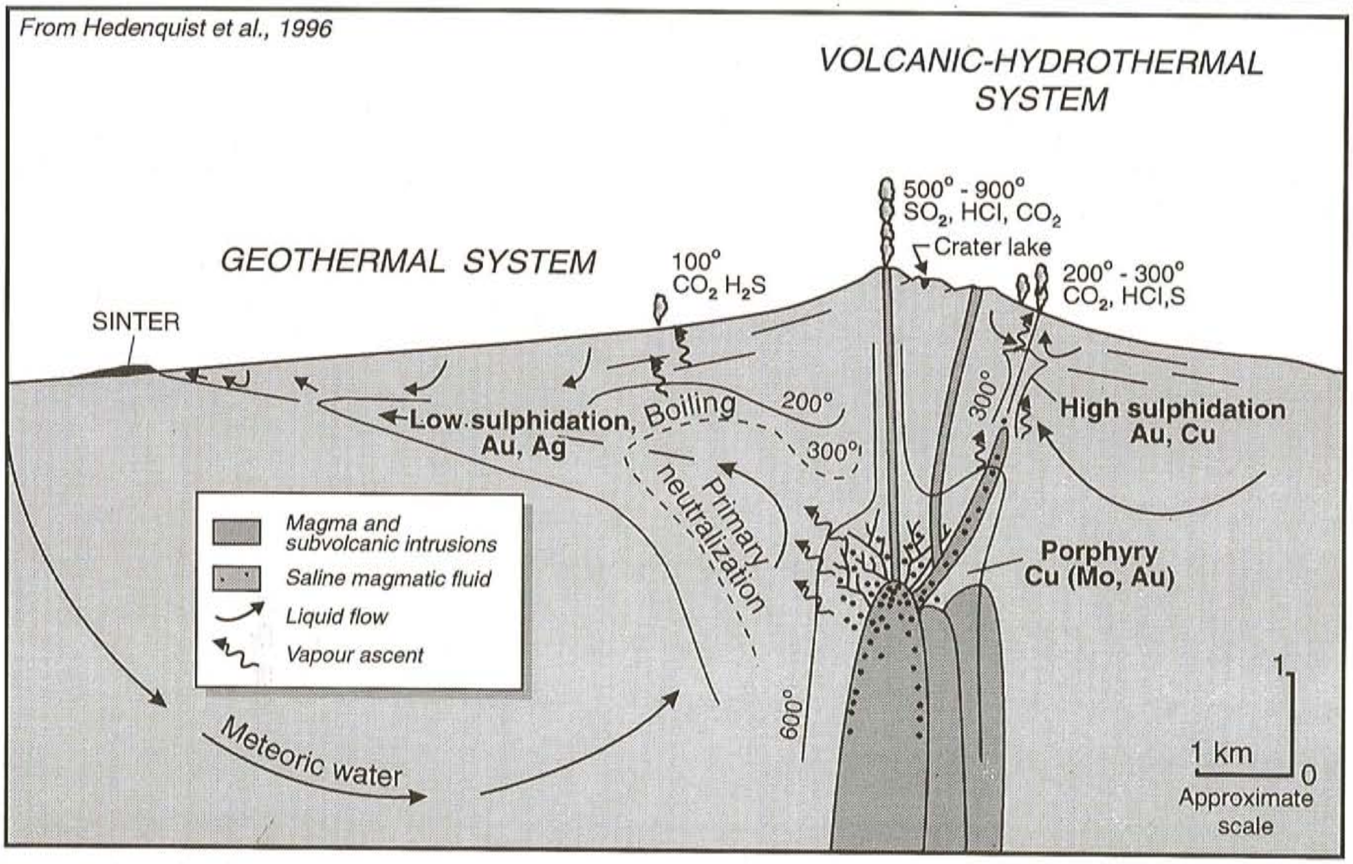

Figure 9. *Spatial and genetic relationships amongst high-sulphidation, low-sulphidation and porphyry-type gold mineralization; from Hedenquist* et al., *1996.*

thermal systems (*see* Arribas, Jr., 1995; Figure 9). The existence of such epithermal systems and their spatial association with coeval, high-level comagmatic intrusions of calc-alkaline affinity indicates that such porphyry deposits are important exploration targets within the Avalonian belt in Newfoundland, both in the Avalon Peninsula and the Burin–Bonavista belt. Erosion level may be a key factor in exploration for such porphyry systems. Regions of extensive granitoid exposure may prove less prospective (e.g., deeper level) than regions where much of the comagmatic volcanic carapace is still preserved.

- The hydrothermal alteration associated with porphyry gold (±Cu±Mo) systems, which can often be subtle, includes secondary K-feldspar, hydrothermal biotite, and clay mineral alteration. Recognition of alteration styles and zonations are critically important to exploration success. Hydrothermal magnetite is a key and readily identifiable alteration phase and is useful in identifying potential targets. With respect to evaluating the significance of gold values in altered intrusions, it is noteworthy that many Au-porphyry deposits are typically low grade and bulk tonnage. In typical porphyry systems, the grade ranges between 0.5 and 2.0 g/t Au and ≤0.8% Cu; tonnages are typically high, namely, tens to several hundreds of million tonnes (Sillitoe, 1991).

THE HICKEYS POND–HOPE BROOK–BREWER CONNECTION

- Hydrothermal alteration and gold mineralization in 600 to 560 Ma Neoproterozoic Avalonian rocks share several common features. They are found mainly within belts characterized by subaerial volcanic rocks, which interdigitate with and/or are overlain by arenaceous sedimentary rocks. They are intruded by comagmatic composite plutons, which include quartz–feldspar porphyry phases. Gold in many instances occurs in high- to moderate-strain rocks including breccias and massive silicic-altered material; much of the strain postdates the alteration and mineralization. Many of the deposits have geochemical and mineralogical signatures characteristic of high-sulphidation epithermal-style mineralization. The Hope Brook Mine, the gold-bearing hydrothermal alteration zones of the Burin Peninsula, and the Brewer Mine of the Carolina Slate Belt, share strong similarities in terms of geological setting, age and lithology of host rocks, and style, distribution and mineralogy of alteration.
- The extensive zones of advanced argillic alteration on the Burin Peninsula (tens of kilometres in length) are characterized by pyrophyllite, alunite, quartz, hematite and pyrite with local associated gold mineralization and represent a *major* regional-scale high-sulphidation hydro-

showings are located in the vicinity of the 577±3 Ma Swift Current Granite. These gold-bearing zones share strong analogies with the Hope Brook gold deposit in terms of alteration, nature and age of the host rocks.

- The widespread quartz–alunite–pyrite schist present at the Hickey's Pond and related prospects of the Burin Peninsula are very similar to the alunite-bearing advanced argillic alteration zone at the Hope Brook gold deposit. At Hope Brook, the advanced argillic zone lies adjacent to massive silicic alteration that is host to the mineralization. Massive silicic alteration zones having up to 98.3% SiO_2 are present on the Burin Peninsula, most notably at the Tower and Strange showings. Although apparently devoid of significant mineralization at surface, these zones are clear indications that residual massive silicic alteration produced by intense acid leaching is present in the Hickey's Pond belt. Their distribution relative to the geometry of the advanced argillic alteration zones and localization of the known gold showings may help to better define the entire hydrothermal system and localize exploration targets within the overall belt. The alteration pattern defined at Hope Brook could be used to help define such exploration targets.

- The recent discoveries of extensive gold-bearing (5 g/t Au) hematite-rich alteration hosted by rocks broadly coeval with those of the Hickey's Pond belt on the southern Burin Peninsula at Marystown (A. Stone and D. Kelly, written communication, 1997), coupled with the presence of pyrophyllite–andalusite–dumortierite hydrothermal alteration on-strike to the southwest at Strouds Pond (Van Alstine, 1948), further underscore the gold exploration potential of the Burin Peninsula. Other recent discoveries of volcanic- and intrusive-hosted Au–Cu mineralization in correlative rocks of similar age and facies, have been made on-strike to the north of the Burin Peninsula in the Traytown (M. Sparkes, personal communication, 1997) and Musgravetown areas (Cornerstone Resources Inc., personal communication, 1997). Along with earlier discoveries of extensive auriferous alteration in the extension of these rocks even farther north in the western Bonavista Bay area (O'Brien and Knight, 1988), these new discoveries point to the high precious-metal potential of the entire Burin–Bonavista belt.

- Identification of clear, crosscutting geological relationships at the Hope Brook deposit, combined with precise U–Pb zircon age determinations of altered and unaltered rocks, has bracketed the age of mineralization and alteration between 578 and 574 Ma (Dubé and Dunning, 1998, *in press*). Combined with the nature and distribution of the lithological and alteration units, these ages temporally and genetically link mineralization and alteration at Hope Brook with plutonism of the Roti Intrusive Suite (Dubé and Dunning, *in press*). Formation of the Hope Brook deposit predates both Silurian ductile shearing along the Cinq Cerf Fault Zone and Devonian thermal metamorphism. Hope Brook is a high-sulphidation-type gold deposit genetically related to a Late Proterozoic subvolcanic sill-dyke complex. The deposit was likely formed by a metal-rich magmatic hydrothermal fluid phase exsolved during cooling and degassing of the ascending sill-dyke complex.

- The Haile–Ridgeway type deposits of the Carolina Slate Belt share features similar to those of intrusion-related, non-carbonate stockwork, disseminated style of gold mineralization (*see* Sillitoe, 1991; Robert *et al.*, 1997). Such mineralization could represent one component of a larger intrusive-centred hydrothermal system, and may indicate potential for porphyry and true epithermal styles of mineralization in the vicinity. The presence of volcanogenic massive sulphide deposits in the Carolina Slate Belt (e.g., Feiss *et al.*, 1993) may indicate a similar potential in the northern Appalachian Avalonian belt. Of particular importance are gold-rich volcanogenic massive sulphides believed to be the submarine equivalent of subaerial, high-sulphidation gold deposits.

CONCLUSIONS

1. Hydrothermal alteration and related epithermal gold mineralization are integral aspects of the Avalonian belt of the Appalachian orogen. In the Newfoundland Avalonian belt, in particular, auriferous alteration of three types is recognized: high sulphidation, low sulphidation and porphyry. Those discussed above formed in Neoproterozoic (ca. 640 to 560 Ma) magmatic systems that fall into two broad age groupings. The potential for significant intrusion-related gold mineralization of both ages is high.

2. The Hope Brook Mine, the gold-bearing hydrothermal alteration zones of the Burin Peninsula, and the Brewer Mine of the Carolina Slate Belt all share strong similarities – at various levels of detail – in their regional, local and detailed geological setting, in age and lithology of host rocks, and in style, distribution and mineralogy of hydrothermal alteration. All are intrusion-related high-sulphidation systems.

3. The Late Proterozoic Avalonian belt of the Appalachians has significant potential for precious-metal mineralization and represents a large, little-explored gold–copper metallogenic belt. Styles of gold mineralization encountered along the length of the Appalachian segment of the Avalonian belt are analogous to epithermal high-sulphidation and related porphyry–gold–copper deposits in much of the Pacific Rim.

ACKNOWLEDGMENTS

The authors acknowledge the help and cooperation of the following individuals: M. Dawe, H. Kennel and G. Keller of Armstrong World Industries Canada Limited, for logistical support and access to mine property and unpublished information; M. Hibbits, S. Lendrum and R. Burns of Royal Oak Mines, and Y. McWilliams, J. Harris and C. McKenzie, formerly of BP Selco, for scientific collaboration and logistic support, as well as providing access to the mines and confidential and unpublished reports and information. We thank P. Stewart, B. O'Brien and S. Swinden for sharing their knowledge through discussions in the field and office, and for many thoughtful and stimulating comments. We also thank J. Scheetz M. Zwaschka (formerly of Brewer Gold Co.), J. Maddry (Piedmont Mining Co.), K. Gillon and W. Spence (Kennecott Explorations), and D. LaPoint for helping us appreciate, through field excursions and discussions, the complexities of Carolina Slate Belt gold mineralization. Final versions of figures and plates were prepared by D. Leonard, T. Paltanavage and T. Sears. The manuscript was reviewed by W.L. Dickson.

REFERENCES

Ace Developments Ltd.
1995: News Release, June 13, 1995.

Arribas, A., Jr.
1995: Characteristics of high-sulfidation epithermal deposits, and their relation to magmatic fluid. *In* Magmas, Fluids, and Ore Deposits. *Edited by* J.F.H. Thompson. Mineralogical Association of Canada Short Course, Volume 23, pages 419-454.

Barr, S.M., White, C.E. and Macdonald, A.S.
1996: Stratigraphy, tectonic setting, and geological history of Late Precambrian volcanic-sedimentary-plutonic belts in southeastern Cape Breton Island, Nova Scotia. Geological Survey of Canada, Bulletin 468, 84 pages.

Barr, S.M. and Kerr, A.
1997: Late Precambrian plutons in the Avalon terrane of New Brunswick, Nova Scotia and Newfoundland. *In* Nature of Magmatism in the Appalachian Orogen. *Edited by* A.K. Sinha, J.B. Whalen and A.J. Hogan. Geological Society of America, Memoir 191, pages 45-74.

Batten R. and Hume, D.
1978: Geological report for licence 12036 on claim 12422, Newfoundland. Unpublished report, Newfoundland Minerals Ltd. [001N/07/0410]

Beischer, G.
1991: Report on geological, geophysical and geochemical surveys and diamond drilling (License 4093), Chislett Option, Newfoundland. Unpublished assessment report (with 33 maps), Inco Exploration and Technical Services Inc. [001N/06/0519].

Bell, H.
1980: Preliminary geologic map and sections of the Kershaw quadrangle, Kershaw and Lancaster counties, South Carolina. United States Geological Survey, Open File report 226, map.

Bevier, M. and Barr, S.M.
1990: U-Pb age constraints on the stratigraphy and tectonic history of the Avalon Terrane, New Brunswick, Canada. Journal of Geology, Volume 98, pages 53-63.

Bevier, M., Barr, S.M., White, C.E. and MacDonald
1993: U–Pb geochronologic constraints on the volcanic evolution of the Mira (Avalon) Terrane, southeastern Cape Breton Island, Nova Scotia. Canadian Journal of Earth Sciences, Volume 30, pages 1-10.

Buddington, A.F.
1916: Pyrophyllitization, pinitization and silicification of rocks around Conception Bay, Newfoundland. Journal of Geology, Volume 24, pages 130-152.

Butler, J.R. and Secor, D.T., Jr.
1991: The Central Piedmont. *In* The Geology of the Carolinas. *Edited by* J.W. Horton and V.A. Zullo. Carolina Geological Society Fiftieth Anniversary Volume, University of Tennessee Press, pages 59-78.

Carpenter, P.A.
1972: Gold resources of North Carolina. North Carolina Department of Natural and Economic Resources, Information Circular 21, 56 pages.

Carpenter, R.H., Odom, A.L. and Hartley, M.E.
1982: Geochronological investigation of the Lincolnton metadacite, Georgia and South Carolina. *In* Tectonic Studies in the Talledega and Carolina Slate Belts, Southern Appalachian Orogen. *Edited by* D.N. Bearse, W.W. Black, S.A. Kish, and J.F. Tull. Geological Society of America, Special Paper 191, pages 145-152.

Clark, S.H.B., Bryan, N.L., Greig, D.D., Padgett, J.P. and Watkins, D.R.
1993: Geochemical profiles of six reverse-circulation drill holes from the Barite Hill gold deposit, South Carolina. South Carolina Geology, Volume 35, pages 55-66.

Dahl, O.M.
1934: Third report on the iron deposits at Hickey's Pond, Placentia Bay, Newfoundland. Davenport and Company,

Aldwych, London, England. Unpublished Report, 9 pages.

D'Lemos, R.S., Strachan, R.A. and Topley, C.G. (Editors)
1990: The Cadomian Orogeny. Geological Society of London Special Publication 51, 423 pages.

Dec, T., O'Brien, S. J. and Knight, I.
1992: Late Precambrian volcaniclastic deposits of the Avalonian Eastport Basin (Newfoundland Appalachians): Petrofacies, detrital clinopyroxene geochemistry and paleotectonic implications. Precambrian Research, Volume 59, pages 243-262.

Dimmell, P. and MacGillivray, G.
1989: First year assessment report on the Project 7427 Hickey's Pond Property, Burin Peninsula area, Newfoundland. Unpublished report, Corona Corporation, 9 pages plus maps and appendices.

1993: The Stewart gold zone, Burin Peninsula, eastern Newfoundland. *In* Ore Horizons, Volume 2. *Edited by* H.S. Swinden and A. Hogan. Newfoundland Department of Mines and Energy, Geological Survey, Miscellaneous publication, pages 19-36.

Dubé, B.
1990: A preliminary report on contrasting styles of gold-only deposits in western Newfoundland. *In* Current Research, Part B. Geological Survey of Canada Paper 90-1B, pages 77-90.

1996: The Hope Brook gold deposit: An example of an acid-sulphate epithermal gold deposit in Newfoundland and its significance for the Au–Cu potential of the Avalon Zone. *In* Report of Activities. Newfoundland Department of Mines and Energy, Geological Survey, pages 13-15.

Dubé, B. and Dunning, G.
1998: Potential for high sulfidation epithermal gold deposits in Canada: the example of the Hope Brook Au–Cu deposit, Newfoundland. The Gangue Newsletter, Mineral Deposit Division, Geological Association of Canada, Issue 57, pages 13-15.

In press: Geology of the Hope Brook Mine, Newfoundland, Canada: a preserved Late Proterozoic high-sulfidation epithermal gold deposit. Economic Geology.

Dubé, B., Lauziere, K. and Boisvert, E.
1995: Preliminary report on the geological setting of the acid-sulfate Hope Brook Gold Deposit, SW Newfoundland. *In* Report of Activities. Newfoundland Department of Natural Resources, Geological Survey, pages 49-50.

Dunning, G.R. and O'Brien, S.J.
1989: Late Proterozoic–early Paleozoic crust in the Hermitage Flexure, Newfoundland Appalachians: U/Pb ages and tectonic significance. Geology, Volume 17, pages 548-551.

Egal, E., LeGoff, E., Thielblemont, D. and Chantraine, J.
1996: The Cadomian orogeny revisited in northern Brittany (France). *In* Avalonian and Related Peri-Gondwanan Terranes of the North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America Special Paper 304, pages 281-318.

Feiss, P.G. and Slack, J.F.
1989: Mineral deposits of the U.S. Appalachians. *In* The Geology of North America, Volume F-2: The Appalachians–Ouachita orogen in the United States. The Geological Society of America, pages 471-494.

Feiss, P.G., Vance, R.K. and Wesolowski, D.J
1993: Volcanic rock hosted gold and base metal mineralization associated with Neoproterozoic–Early Paleozoic back-arc extension in the Carolina terrane, southern Appalachian Piedmont. Geology, Volume 21, pages 439-442.

Gibbons, W.
1990: Transcurrent ductile shear zones and the dispersal of the Avalon superterrane. *In* The Cadomian Orogeny. *Edited by* R.S. D'Lemos, R.A. Strachan, and C.G. Topley. Geological Society of London, Special Publication 51, pages 407-423.

Gibbons, W. and Horak, J.
1996: Evolution of the Neoproterozoic Avalonian subduction system: Evidence from the British Isles. *In* Avalonian and Related Terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304, pages 269-280.

Gillon, K.A. and Duckett, R.P.
1988: Geology of the Ridgeway gold deposits, Fairfax County, South Carolina. Geology Society of America, Abstracts with Programs, Volume 20, page 267.

Gillon, K.A., Spence, W.H., Duckett, R.P. and Benson, C.J.
1995: Geology of the Ridgeway gold deposits, Ridgeway, South Carolina. *In* Selected Mineral Deposits of the Gulf Coast and Southeastern United States; Part 2: Gold Deposits of the Carolina Slate Belt. *Edited by* D.E. Crowe. Society of Economic Geologists, Guidebook Series, Volume 24, pages 53-87.

Deposits of the Carolina Slate Belt. *Edited by* D.E. Crowe. Society of Economic Geologists, Guidebook Series, Volume 24, pages 53-87.

Gunter, W.L. and Padgett, J.P.
1988: Barite Hill: a new gold deposit in McCormick County, South Carolina. Geological Society of America, Abstracts with Programs, Volume 20, number 4, page 268.

Harland, W.B. and Gayer, R.A.
1972: The Arctic Caledonides and earlier oceans. Geological Magazine, Volume 109, pages 289-314.

Harris, C.W. and Glover, L.
1988: The regional extent of ca. 600 Ma Virgilina deformation: Implications for stratigraphic correlations in the Carolina Terrane. Geological Society of America Bulletin, Volume 100, pages 200-217.

Hayes, J.P.
1996: Geological setting and genesis of the eastern Avalon high-alumina belt. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 189 pages.

Hayes, J.P. and O'Driscoll, C.F.
1990: Regional setting and alteration within the eastern Avalon high-alumina belt, Avalon Peninsula, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 90-1, pages 145-155.

Hayward, N
1992: Controls on syn-tectonic replacement mineralization on parasitic antiforms, Haile Gold Mine, Carolina Slate Belt, Economic Geology, Volume 87, pages 91-112.

Heatherington, A.L., Mueller, P.A., and Nutman, A.P.
1996: Neoproterozoic magmatism in the Suwannee terrane: implications for terrane correlation. *In* Avalonian and Related Terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304, pages 257-268.

Hedenquist, J.W., Izawa, K., Arribas, A. and White, N.C.
1996: Epithermal gold deposits, styles, characteristics and exploration. Resource Geology. Society of Resource Geology, Special Publication Number 1, 16 pages.

Hepburn, J.C., Hon, R., Dunning, G.R., Bailey, R.H. and Galli, K.
1993: The Avalon and Nashoba terranes (eastern margin of the Appalachians in New England). *In* Field Trip Guidebook for the northeastern United States: 1993 Boston GSA (Volume 2). *Edited by* J.T. Cheney and J.C. Hepburn. Contribution 67, Department of Geology and Geography, University of Massachusetts, Amherst, Massachusetts, pages X1-X31.

Hermes, O.D. and Zartman, R.E.
1985: Late Proterozoic and Devonian plutonic terrane within the Avalon Zone of Rhode Island. Geological Society of America Bulletin, Volume 96, pages 272-282.

Hollister, V.F., Potter, R.R. and Barker, A.L.
1974: Porphyry deposits of the Appalachian orogen. Economic Geology, Volume 69, pages 618-630.

Howland, A.L.
1940: Specularite–alunite mineralization at Hickey's Pond, Newfoundland. American Mineralogist, Volume 25, pages 34-45.

Huard, A.
1990: Epithermal alteration and gold mineralization in Late Precambrian volcanic rocks on the northern Burin Peninsula, southeastern Newfoundland, Canada. Unpublished M.Sc. thesis. Memorial University of Newfoundland, St. John's, Newfoundland, 273 pages.

Huard, A. and O'Driscoll, C.F.
1986: Epithermal gold mineralization in Late Precambrian volcanic rocks on the Burin Peninsula. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 65-78.

Hussey, E.M.
1978: Geology of the Sound Island map area, (west half), Newfoundland. *In* Report of Activities. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-1, pages 110-115.

1979: Geology of the Clode Sound area, Newfoundland. Unpublished M.Sc. thesis. Memorial University of Newfoundland, St. John's, Newfoundland, 312 pages.

Kaye, C.A. and Zartman, R.E.
1980: A Late Proterozoic Z to Cambrian age for the stratified rocks of the Boston Basin, Massachusetts, U.S.A. *In* The Caledonides in the U.S.A., International Geological Correlations Project 27, Blacksburg, Virginia, Virginia Polytechnical Institute and State University Memoir 2, pages 257-261.

Keats, H.F.
1970: Geology and mineralogy of the pyrophyllite deposits south of Manuels, Avalon Peninsula, Newfoundland. Unpublished M.Sc. thesis, Memorial University of

composite terrane, Nova Scotia. Geological Society of America Bulletin, Volume 102, pages 516-528.

Kiff, I.T. and Spence, W.H.
1987: Volcanogenic epithermal-exhalative gold deposits of the Haile type in the Carolina Slate Belt. Geological Society of America, Abstracts with Programs, Volume 19, page 394.

1988: Gold mineralization and associated alteration patterns at the Haile mine, Lancaster County, South Carolina. *In* Southeastern Geological Excursions: Geological Society of America, Southeastern Section 1988 Field Trip Guidebook. *Edited by* D.T. Secor, Jr., pages 29-39.

Kilbourne, M.W.
1985: Nature and significance of the quartz–andalusite–pyrophyllite zone, Chetwynd gold prospect, southwestern Newfoundland. Unpublished B.Sc. thesis, University of Western Ontario, London, Ontario, 73 pages.

King, A.F.
1980: The birth of the Caledonides: late Precambrian rocks of the Avalon Peninsula, Newfoundland and their correlatives in the Appalachian–Caledonian orogen. *In* The Caledonides in the U.S.A. *Edited by* D.R.Wones. Blacksburg, Department of Geological Sciences, Virginia Polytechnical Institute and State University Memoir 2, pages 3-8.

1988: Geology of the Avalon Peninsula, Newfoundland: Department of Mines and Energy, Geological Survey Branch, Map 88-01, scale 1:250 000.

1990: Geology of the St. John's area. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 90-2, 88 pages.

Knight, I. and O'Brien, S.J.
1988: Stratigraphy and sedimentology of the Connecting Point Group, Eastport (2C/12) and St. Brendan's (2C/13) areas. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 207-228.

Krogh, T.E., Strong, D.F., O'Brien, S.J. and Papezik, V.S.
1988: Precise U–Pb zircon dates from the Avalon Terrane in Newfoundland. Canadian Journal of Earth Sciences, Volume 25, pages 442-453.

Kroner, A.
1980: Pan African crustal evolution. Episodes, Volume 2, pages 3-8.

LaPoint, D.J.
1995: Successful exploration techniques for Haile–Ridgeway type gold deposits in South Carolina. *In* Selected Mineral Deposits of the Gulf Coast and Southeastern United States; Part 2: Gold Deposits of the Carolina Slate Belt. *Edited by* D.E. Crowe. Society of Economic Geologists, Guidebook Series, Volume 24, pages 21-52.

LaPoint, D.J. and Cherrywell, C.H.
1995: The potential for new gold discoveries in southeastern USA. Unpublished report. Appalachian Resources, Chapel Hill, North Carolina, 6 pages.

Leblanc, M. and Lancelot, J.R.
1980: Interprétation géodynamique du domaine panafrican (Précambrian terminal) de l'Anti-Atlas (Maroc) à partir de données géologiques et géochronologiques. Canadian Journal of Earth Sciences, Volume 17, pages 142-155.

Lee, B.W.
1958: Newfoundland Minerals Ltd, Manuels area, Conception Bay, Newfoundland, report on pyrophyllite zone at Mine Hill and 10 diamond drill hole records. Unpublished internal report, Newfoundland Department of Mines, Agriculture and Resources, Mineral Resources Division. [001N/07/0052]

Lu, C., Misra, K.C., Stonehouse, J.M. and Zwaschka, M.R.
1993: Geochemical signature of alteration at the Brewer Gold Mine, Jefferson, South Carolina. South Carolina Geology, Volume 35, pages 37-54.

Lynch, G. and Ortega, J.
1997: Hydrothermal alteration and tourmaline–albite equilibria at the Coxheath porphyry Cu–Mo–Au deposit, Nova Scotia. The Canadian Mineralogist, Volume 35, pages 79-94.

Maddry, J.W. and Kilbey, T.R.
1995: Geology of the Haile gold mine. *In* Selected Mineral Deposits of the Gulf Coast and Southeastern United States; Part 2: Gold Deposits of the Carolina Slate Belt. *Edited by* D.E. Crowe. Society of Economic Geologists, Guidebook Series, Volume 24, pages 147-172.

Maddry, J.W., Speer, W.E. and Rucker, P.W.
1993: Whole rock and trace element geochemistry of rocks from the Snake Deposit, Haile Gold Mine, Lancaster County, South Carolina. South Carolina Geology, Volume 35, pages 27-36.

McKenzie, C.B.

1986: Geology and mineralization of the Chetwynd deposit, southwestern Newfoundland, Canada. *In* Proceedings of Gold '86, an international symposium on the geology of gold. *Edited by* A.J. Macdonald. Gold `86, Toronto, pages 137-148.

Murphy, J.B., Keppie, J.D., Nance, R.D. and Dostal, J.

1990: The Avalon composite terrane of Nova Scotia. *In* Avalonian and Cadomian Geology of the North Atlantic. *Edited by* R.A. Strachan and G.K.Taylor. Blackie, Glasgow and London, pages 195-213.

Nance, R.D., Currie, K.L. and Murphy, J.B.

1990: The Avalon Zone of New Brunswick. *In* Avalonian and Cadomian Geology of the North Atlantic. *Edited by* R.A. Strachan and G.K.Taylor. Blackie, Glasgow and London, pages 214-236.

Nance, R.D., Murphy, J.B., Strachan, R.A., D'Lemos, R.S. and Taylor, G.K.

1991: Late Proterozoic tectonostratigraphic evolution of Avalonian and Cadomian terranes. Precambrian Geology, Volume 53, pages 41-78.

Nance, R.D. and Thompson, M.D.

1996a: Avalonian and related terranes of the circum-North Atlantic: an introduction. *In* Avalonian and Related Terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304, pages 1-7.

Nance, R.D. and Thompson, M.D. (Editors)

1996b: Avalonian and Related Terranes of the Circum-North Atlantic. Geological Society of America, Special Paper 304, 390 pages.

O'Brien, B.H., O'Brien, S.J. and Dunning, G.R.

1991: Silurian cover, Late Precambrian–Early Ordovician basement, and the chronology of Silurian orogenesis in the Hermitage Flexure (Newfoundland Appalachians). American Journal of Science, Volume 291, pages 760-799.

O'Brien, B.H., O'Brien, S.J., Dunning, G.R. and Tucker, R.E.

1993: Episodic reactivation of a Late Precambrian mylonite zone on the Gondwanan margin of the Appalachians, southern Newfoundland. Tectonics, Volume 12, pages 1043-1055.

O'Brien, S.J.

1993: A preliminary account of geological investigations in the Clode Sound–Goose Bay region, Bonavista Bay, Newfoundland (NTS 2C5/NW and 2D8/NE). *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 93-1, pages 293-309.

1994: On the geological development of the Avalon Zone in the area between Ocean Pond and Long Islands, Bonavista Bay (parts of NTS 2C/5 and NTS 2C/12). *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 94-1, pages 187-200.

O'Brien, S.J., Dubé, B., O'Driscoll, C.F., Mills, J. and Dawe, M.

1997b: Gold mineralization, hydrothermal alteration and volcanic facies in the eastern Avalon Zone, Newfoundland Appalachians. Canadian Institute of Mining, Metallurgy and Petroleum, District 1 Meeting, Field trip guidebook, St. John's, Newfoundland, 22 pages.

O'Brien, S.J., King, A.F. and O'Driscoll, C.F.

1997a: Late Neoproterozoic geology of the central Avalon Peninsula, Newfoundland, with an overview of mineralization and hydrothermal alteration. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 97-1, pages 257-282.

O'Brien, S.J. and Knight, I.

1988: Avalonian geology of southwest Bonavista Bay: Parts of the St. Brendans's (2C/13) and Eastport (2C/13) map areas. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 193-205.

O'Brien, S.J., Nunn, G.A.G., Dickson, W.L. and Tuach, J.

1984: Geology of the Terrenceville (1M/10) and Gisborne Lake (1M/15) map areas, southeast Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 84-4, 54 pages.

O'Brien, S.J., O'Brien, B.H., Dunning, G.R. and Tucker, R.D.

1996: Late Neoproterozoic Avalonian and related peri-Gondwanan rocks of the Newfoundland Appalachians. *In* Avalonian and Related Terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304, pages 9-28.

O'Brien, S.J. and O'Driscoll, C.F.

1996a: Preliminary investigation of Neoproterozoic (Avalonian) rocks, northeastern Holyrood (NTS 1N/6) map area: notes on geology, mineralization and mineral exploration potential. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, pages 311-327.

1996b: Geochemical data listing: 1996 field season (parts of 1N/3,6,7,10, and 11). Newfoundland Department of Mines and Energy, Geological Survey, Open File 001N/0579.

O'Brien, S.J., O'Driscoll, C.F., Greene, B.A. and Tucker, R.D.
1995: Pre-Carboniferous geology of the Connaigre Peninsula and the adjacent coast of Fortune Bay, southern Newfoundland. *In* Current Research. Newfoundland Department of Natural Resources, Geological Survey Branch, Report 95-1, pages 267-297.

O'Brien, S.J. and Taylor, S.W.
1983: Geology of the Baine Harbour (1M/7) and Point Enragée (1M/6) map areas, southeastern Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-5, 70 pages.

O'Brien, S.J., Strong, D.F. and King, A.F.
1990: The Avalon Zone type area: southeastern Newfoundland Appalachians. *In* Avalonian and Cadomian Geology of the North Atlantic. *Edited by* R.A. Strachan and G.K. Taylor. Glasgow, Blackies and Son, pages 166-193.

O'Brien, S.J., Wardle, R.J. and King, A.F.
1983: The Avalon Zone: A Pan-African terrane in the Appalachian Orogen of Canada. Geological Journal, Volume 18, pages 195-222.

O'Driscoll, C.F., Collins, C.J. and Tuach, J.
1988: Volcanic-hosted, high-alumina, epithermal environments and the St. Lawrence fluorite deposit in the Avalon Zone, eastern Newfoundland. Field Trip Guidebook A5. GAC-MAC Annual Meeting, St. John's, Newfoundland, 76 pages.

O'Driscoll, C.F. and Strong, D.F.
1979: Geology and geochemistry of the Late Precambrian volcanic and intrusive rocks of the southwestern Avalon Zone in Newfoundland. Precambrian Research, Volume 8, pages 19-48.

Oldale, H.R.
1967: A centennial of mining exploration and development - Coxheath Hills, Cape Breton. Canadian Institute of Mining and Metallurgy Bulletin, Volume 60, pages 1411-1419.

Ortega, J.
1996: Le gîte de Coxheath: Un système hydrothermal magmatique à Cu–Mo–Au d'âge Protérozoïque tardif dans la zone d'Avalon des Appalaches du Nord. Unpublished Msc thesis, Université du Québec, INRS-Géoressources, 147 pages.

Papezik, V.S. and Hume, W.D.
1984: The pyrophyllite deposit on the Avalon Peninsula, Newfoundland. *In* The Geology of Industrial Minerals in Canada. Canadian Institute of Mining and Metallurgy, Special Volume 29, pages 9-11. [NFLD/1650]

Papezik, V.S. and Keats, H.F.
1976: Diaspore in a pyrophyllite deposit on the Avalon Peninsula, Newfoundland. Canadian Mineralogist, Volume 14, pages 442-449.

Papezik, V.S., Keats, H.F. and Vahtra, J.
1978: Geology of the Foxtrap pyrophyllite deposit, Avalon Peninsula, Newfoundland. Canadian Institute of Mining and Metallurgy Bulletin, Volume 71, pages 152-160.

Pé-Piper, G., Piper, D.J.W. and Koukouvelas, I.
1996: Precambrian plutons of the Cobequid Highlands, Nova Scotia, Canada. *In* Avalonian and Related Terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304, pages 121-132.

Quesada, C.
1990: Precambrian terranes in the Iberian Variscan fold belt. *In* Avalonian and Cadomian Geology of the North Atlantic. *Edited by* R.A. Strachan and G.K. Taylor. Glasgow, Blackies and Son, pages 109-133.

Rast, N., O'Brien, B.H. and Wardle, R.J.
1976: Relationships between Precambrian and lower Paleozoic rocks of the Avalon Platform in New Brunswick, the northeast Appalachians and the British Isles. Tectonophysics, Volume 30, pages 315-338.

Rennie, C.T.
1989: Triangle Property, Avalon Peninsula, Newfoundland. 1989 year-end report. Unpublished assessment report, (3 maps) Cominco Ltd.[001N/06/0500].

Ririe, C.T.
1990: A comparison of alteration assemblages associated with Archean deposits in Western Australia and Paleozoic gold deposits in the southeast United States. Canadian Journal of Earth Sciences, Volume 27, pages 1560-1575.

Robert, F., Poulsen, K.H. and Dubé, B.
1997: Gold deposits and their geological classification. *In* Proceedings of Exploration 97, *Edited by* Gubins, A.G. Fourth Deccenial International Conference on Mineral Exploration, Toronto, GEO/FX, pages 209-220.

Romberger, S.B.
1986: Disseminated gold deposits. Geoscience Canada, Volume 13, pages 23-34.

Sampson, S., Palmer, A.R., Robison, R.A. and Secor, D.T.
1990: Biogeographical significance of Cambrian trilobites from the Carolina Slate Belt. Geological Society of America Bulletin, Volume 102, pages 1459-1470.

Saunders, P.
1986: Geological and rock geochemical surveys on the Foxtrap claims, Newfoundland, licence 2551, 2557, October 1985 to January 1986. Apex Geological Consultants Ltd, unpublished report [001N/07/468].

Scheetz, J.W.
1991: The geology and alteration of the Brewer gold mine, Jefferson, South Carolina. Unpublished M.S. thesis, University of North Carolina, Chapel Hill, North Carolina, 180 pages.

Scheetz, J.W., Stonehouse, J.M. and Zwaschka, M.R.
1991: Geology of the Brewer Gold Mine in South Carolina. Mining Engineering, Volume 43, pages 38-42.

Schmidt, R.G.
1985: High-alumina hydrothermal systems in volcanic rocks and their significance in mineral prospecting in the Carolina slate belt. United States Geological Survey, Bulletin 1562, 59 pages.

Sears, W.A.
1990: A geochemical, petrographic and metallogenic analysis of volcanogenic sulphide deposition within the Connaigre Bay Group, Hermitage Peninsula, southern Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 282 pages.

Secor, D.T., Jr.
1988: Review of the geology of the Carolina Slate Belt. *In* Southeastern Geological Excursions. *Edited by* Secor, D.T., Jr. Geological Society of America, Southeastern Section 1988 Field Trip Guidebook, pages 5-18.

Secor, D.T., Sampson, S.L., Snoke, A.W. and Palmer, A.R.
1983: Confirmation of the Carolina Slate Belt as an exotic terrane. Science, Volume 221, pages 649-651.

Secor, D.T., Jr., Snoke, A.W., Wright, J.E., Bramlett, K.W., Costello, O.P. and Kimbrell, O.P.
1986: Character of the Alleghenian orogeny in the southern Appalachians: Part 1. Alleghenian deformation in the eastern Piedmont of South Carolina. Geological Society of America Bulletin, Volume 97, pages 1319-1328.

Sillitoe, R.H.
1979: Some thoughts on gold-rich porphyry copper deposits. Mineralium Deposita, Volume 14, pages 161-174

1991: Intrusion related gold deposits. *In* Gold Metallogeny and Exploration. *Edited by* R.P. Foster. London, Blackies, pages 165-209.

1993: Gold-rich porphyry deposits: geological model and exploration implications. *In* Mineral Deposit Modelling. *Edited by* R.V. Kirkham, W.D. Sinclair, R.I. Thorpe, and J.M. Duke. Geological Association of Canada, Special Paper 40, pages 465-478.

Sillitoe, R.H., Hannington, M.D. and Thompson, J.F.
1996: High sulfidation deposits in the volcanogenic massive sulfide environment. Economic Geology, Volume 91, pages 204-212.

Skeehan, J.W. and Rast, N.
1991: Pre-Mesozoic evolution of Avalon terranes of southern New England. *In* Geology of the Composite Avalon Terrane of Southern New England. *Edited by* A.D. Socci, J.W. Skeehan and G.W. Smith. Geological Society of America Special Paper 245, pages 55-74.

Sparkes, K.E.
1986: Geology, geochemistry and economic potential of altered Harbour Main volcanics near Mikes Pond, Avalon Peninsula. Unpublished B.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 103 pages. [001N/0469]

Speer, W.E. and Maddrey, J.W.
1993: Geology and recent discoveries at the Haile Gold Mine, Lancaster County, South Carolina. South Carolina Geology, Volume 35, pages 9-26.

Spence, H.
1940: Talc, steatite, soapstone and pyrophyllite. Bureau of Mines, Department of Mines and Resources, 146 pages.

Spence, W.H., Worthington, J.E., Jones, E.M. and Kiff, I.T.
1980: Origin of the gold mineralization at the Haile gold mine, Lancaster County, South Carolina. Mining Engineering, Volume 32, page 70-73.

Stewart, P.W.
1992: The origin of the Hope Brook Mine, Newfoundland: a shear-zone-hosted acid sulfate gold deposit. Unpublished Ph.D. thesis, University of Western Ontario, London, Ontario, 398 pages.

Strong, D.F., O'Brien, S.J., Strong, P.G., Taylor, S.W. and Wilton, D.H.C.

1978a: Aborted Proterozoic rifting in Newfoundland. Canadian Journal of Earth Sciences, Volume 15, pages 117-131.

1978b: Geology of the Marystown (1M/13) and St. Lawrence (1L/14) map areas, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-7, 81 pages.

Swinden, H.S.

1984: The Chetwynd prospect, southwestern Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File (11O/09/148), 10 pages.

Thickle, M.J.

1987: The geology of Late Hadrynian metavolcanic and granitoid rocks of the Coxheath - northern East Bay area, Cape Breton Island, Nova Scotia. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia, 300 pages.

Tucker, R.E., O'Brien, S.J. and O'Brien, B.H.

1994: Age and implications of Early Ordovician (Arenig) plutonism in the type area of the Bay du Nord Group, Dunnage Zone, southern Newfoundland Appalachians. Canadian Journal of Earth Sciences, Volume 31, pages 351-357.

Tucker, R.D. and Pharoah, T.C.

1991: U–Pb zircon ages for late Precambrian igneous rocks in southern Britain. Geological Society of London Journal, Volume 148, pages 435-443.

Van Alstine, R.E.

1948: Geology and mineral deposits of the St. Lawrence area, Burin Peninsula, Newfoundland. Geological Survey of Newfoundland, Bulletin 23, 64 pages.

Vhay, J.S.

1937: Pyrophyllite deposits of Manuels, Conception Bay, Newfoundland. Department of Natural Resources, Geological Section, Bulletin 7, 33 pages.

White, N.C. and Hedenquist, J.W.

1995: Epithermal gold deposits: styles, characteristics and exploration: Society of Economic Geologists Newsletter, No. 23, 1, pages 9-13.

Williams, H.

1971: Geology of the Belleoram map area, Newfoundland. Geological Survey of Canada, Paper 70-65, 39 pages.

1979: Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, Volume 16, pages 792-807.

Williams, H. and Hatcher, R.D.

1983: Appalachian suspect terranes. *In* Contributions to the Tectonics and Geophysics of Mountain Chains. *Edited by* R.D. Hatcher, H. Williams and I. Zeitz. Geological Society of America, Memoir 158, pages 33-53.

Wilson, J.T.

1966: Did the Atlantic close and then re-open? Nature, Volume 211, pages 676-681.

Worthington, J.E. and Kiff, I.T.

1970: A suggested volcanogenic origin for certain gold deposits in the slate belt of the North Carolina Piedmont. Economic Geology, Volume 65, pages 529-537.

Yule, A., McKenzie, C. and Zentilli, M.

1990: Hope Brook: a new Appalachian gold deposit in Newfoundland, Canada, and the significance of hydrothermally altered mafic dikes. Chronique de la Récherche Minière, numéro 498, pages 29-42.

Zwaschka, M. and Scheetz, J.W.

1995: Detailed mine geology of the Brewer gold mine, Jefferson, South Carolina. *In* Selected Mineral Deposits of the Gulf Coast and Southeastern United States; Part 2: Gold Deposits of the Carolina Slate Belt. *Edited by* D.E. Crowe. Society of Economic Geologists, Guidebook Series, Volume 24, pages 95-146.

Note: Geological Survey file number are included in square brackets.