

THE NATURE AND TIMING OF NEOPROTEROZOIC HIGH-SULPHIDATION GOLD MINERALIZATION FROM THE NEWFOUNDLAND AVALON ZONE: INSIGHTS FROM NEW U–Pb AGES, ORE PETROGRAPHY AND SPECTRAL DATA FROM THE HICKEY’S POND PROSPECT

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ABSTRACT

The Hickey’s Pond gold prospect is an example of Neoproterozoic, high-sulphidation epithermal mineralization that is extensively developed, within the Avalon Zone of the Newfoundland Appalachians. The new geochronological, petrographic and spectral data presented provide further insight as to the formation, distribution and timing of the advanced argillic alteration and accompanying mineralization at Hickey’s Pond, and the style and composition of the mineralizing fluids. Data highlight the complexity of the mineralized zone, which remains a highly prospective exploration target, both along strike and at depth.

Detailed investigations of the gold mineralization (up to 60.4 g/t in vuggy silica) have identified the presence of numerous sulphide, telluride and selenide mineral phases. Visible/infrared reflectance spectroscopy (VIRS) of archived drillcore provides insight into the distribution of the advanced argillic alteration within the subsurface and in relation to the gold mineralization intersected at depth. Spectral data (collected at 1 m spacing) confirm that the (sodic) alunite-bearing auriferous advanced argillic alteration and accompanying mineralization, together form a steep, west-dipping package, confined to the footwall of the Hickey’s Brook Fault, extending to a minimum depth of 130 m. At depth, the advanced argillic alteration assemblage is dominated by pyrophyllite and dickite, whereas at shallower depths, the predominant phase is alunite.

U–Pb geochronological determinations by chemical abrasion-thermal ionization mass spectrometry (CA-TIMS) from both the advanced argillic alteration and less-altered felsic volcanic rocks displaying primary volcanic textures provide overlapping ages of 586 ± 3 Ma and 585.8 ± 1.7 Ma, respectively. The age of 586 ± 3 Ma from the advanced argillic alteration provides a new maximum age limit for the mineralization at Hickey’s Pond.

INTRODUCTION

NEOPROTEROZOIC EPITHERMAL SYSTEMS IN THE APPALACHIAN OROGEN

Mineralized epithermal systems of Neoproterozoic age are a metallogenic hallmark of the magmatic arcs characteristic of accreted peri-Gondwanan terranes along the length of the Paleozoic Appalachian orogen, from Newfoundland to South Carolina (e.g., see reviews in O’Brien *et al.*, 1998; Foley and Ayuso, 2012 and references therein). Some of the largest and best preserved examples of these ancient epithermal systems are in southern and eastern Newfoundland, notably the western Hermitage Flexure region, the Burin Peninsula and the eastern Avalon Peninsula. Here, gold- and

silver-bearing high-, low- and intermediate-sulphidation systems occur within late Neoproterozoic volcanic and plutonic uplifts and intervening shallow marine to terrestrial siliciclastic basins. These were tectonically amalgamated and then dispersed over a period of some 220 Ma, prior to the Early Cambrian (O’Brien *et al.*, 1996, 1998, 1999; Dubé *et al.*, 1998).

These peri-Gondwanan magmatic arcs host some of the Appalachian orogen’s largest gold deposits. Examples include metamorphosed high-sulphidation epithermal systems (Hope Brook, Brewer, Manuels: see Dubé *et al.*, 1998; Scheetz, 1991; O’Brien *et al.*, 1998), and possible high-sulphidation-style, gold-rich, exhalative (*cf.* Spence *et al.*, 1980) or volcanogenic massive sulphide systems (e.g.,

Barite Hill, Pastureland Road and Peter Snout: Feiss *et al.*, 1993; O'Brien *et al.*, 2001). At Hope Brook and Brewer, mineralization is associated with advanced argillic alteration assemblages that include variably developed andalusite, topaz, diaspore, alunite and pyrophyllite in association with pyrite–chalcopyrite–gold $\pm$ enargite–tennantite (Dubé *et al.*, 1998; Foley and Ayuso, 2012 and references therein). Deeper level, intrusion-related systems characterized by stockwork-disseminated mineralization, including gold-rich porphyry-related mineralization (*e.g.*, Coxheath, Butlers Pond, Lodestar and Stewart: Lynch and Ortega, 1997; O'Brien *et al.*, 1998; Sparkes *et al.*, 2002; Sparkes, 2012; Sparkes and Dunning, 2014) are preserved but much less extensive than the epithermal deposits.

In Newfoundland, latest Neoproterozoic Avalonian volcanic and sedimentary rocks also host well-preserved examples of classic low-sulphidation-style precious metal systems (*e.g.*, Bergs, Steep Nap and Big Easy: Mills *et al.*, 1999; O'Brien *et al.*, 2001; O'Brien and Sparkes, 2004; Sparkes, 2012) as well as systems exhibiting characteristics of low- and intermediate-sulphidation systems (Heritage, Forty Creek and Creston North). The largest of the Neoproterozoic peri-Gondwanan epithermal systems is the Haile deposit, in South Carolina, where OceanaGold have identified a gold resource of *ca.* 4 million ounces (Foley and Ayuso, 2012; Mobley *et al.*, 2014).

AGES OF HYDROTHERMAL ALTERATION AND GOLD MINERALIZATION: NEWFOUNDLAND EXAMPLES

High-sulphidation alteration and gold mineralization at the Hope Brook Mine have been bracketed by U–Pb ages on syn- and post-mineral quartz–feldspar–porphyry dykes (578 and 574 Ma, respectively) emplaced in *ca.* 585 Ma volcanoclastic and sedimentary rocks that host the deposit (Dubé *et al.*, 1998). This magmatism is, in part, coeval with the 577 ± 1.4 Ma and 575.5 ± 1.4 Ma emplacement of syn-mineral intrusions at the Stewart prospect (Sparkes and Dunning, 2014) and with the formation of pyrophyllite–sericite–diaspore ore deposits at Manuels, where U–Pb data constrain the formation, uplift and erosion of high-sulphidation alteration to a period from 585 to 580.5 Ma (Sparkes *et al.*, 2005).

In contrast, the peri-Gondwanan host rocks at the Brewer deposit have been dated at 550 ± 3 Ma (U–Pb zircon), an age inferred to represent that of the gold mineralization also (Ayuso *et al.*, 2005). This mineralization may be broadly coeval with low-sulphidation systems in Newfoundland, which occur in rocks as young as 550 Ma, including the upper Long Harbour Group in northern Fortune Bay (O'Brien *et al.*, 1995; O'Brien, 1998).

REGIONAL SETTING: GEOLOGY OF THE WESTERN AVALON ZONE

The Burin Peninsula region of Newfoundland is host to an extensive sequence of late Neoproterozoic arc-related rocks along with marine to terrestrial sedimentary rocks of per-Gondwanan affinity (O'Brien *et al.*, 1996, 1999). Within the volcanic succession, high-level intrusions generated regional-scale magmatic–hydrothermal systems that were locally accompanied by precious-metal deposition (O'Brien *et al.*, 1999). Several high-level granitoid plutons intrude along the length of the Burin Peninsula, forming a broad, semi-continuous, north-northeast-trending belt composed of hornblende–biotite granite, diorite and gabbro (Figure 1). The largest of these bodies, the Swift Current Granite (Figure 1) is locally dated at 577 ± 3 Ma (O'Brien *et al.*, 1998), the Burin Knee granite is dated at 575.5 ± 1 Ma (Sparkes and Dunning, 2014) and others, such as the Cape Roger Mountain granite, are inferred to represent coeval Precambrian intrusions (O'Brien and Taylor, 1983; O'Brien *et al.*, 1984). The youngest plutonic rocks in the area are the Devonian Ackley and St. Lawrence granites, the latter of which is dated at 374 ± 3 Ma (Kerr *et al.*, 1993); other small plutonic units of undeformed character in the region are also inferred to be of this age.

Epithermal-style alteration and mineralization developed within the Burin Peninsula region is most abundant in volcanic rocks of the 590–570 Ma Marystown Group (Strong *et al.*, 1978a, b; O'Brien *et al.*, 1999). These volcanic successions consist of greenschist-facies subaerial flows, and related pyroclastic and volcanoclastic rocks ranging in composition from basalt, through andesite and rhyodacite, to rhyolite and are of both calc-alkaline and tholeiitic affinity (Hussey, 1979; O'Brien *et al.*, 1990, 1996, 1999). The Marystown Group occupies the core of the Burin Peninsula, forming a broad-scale anticlinorium, which is flanked to the east by the upward-shoaling sequence of marine to terrestrial sedimentary rocks of the Neoproterozoic Musgravetown Group (O'Brien *et al.*, 1999; Figure 1); volcanic rocks near the base of the Musgravetown Group (at the transition between the Bull Arm and Rocky Harbour formations) are dated at $570 +5/-3$ Ma (O'Brien *et al.*, 1989).

To the west and north, the Marystown Group is overlain by the *ca.* 570 to 550 Ma Long Harbour Group. The latter succession is characterized by subaerial felsic volcanic rocks of alkaline to peralkaline affinity along with lesser mafic volcanic rocks and siliciclastic sedimentary rocks (Williams, 1971; O'Brien *et al.*, 1984, 1995). The late Neoproterozoic succession is, in turn, overlain by a Cambrian platformal sedimentary cover sequence that postdates the waning of volcanic activity and related epithermal systems (O'Brien *et al.*, 1996 and references therein).

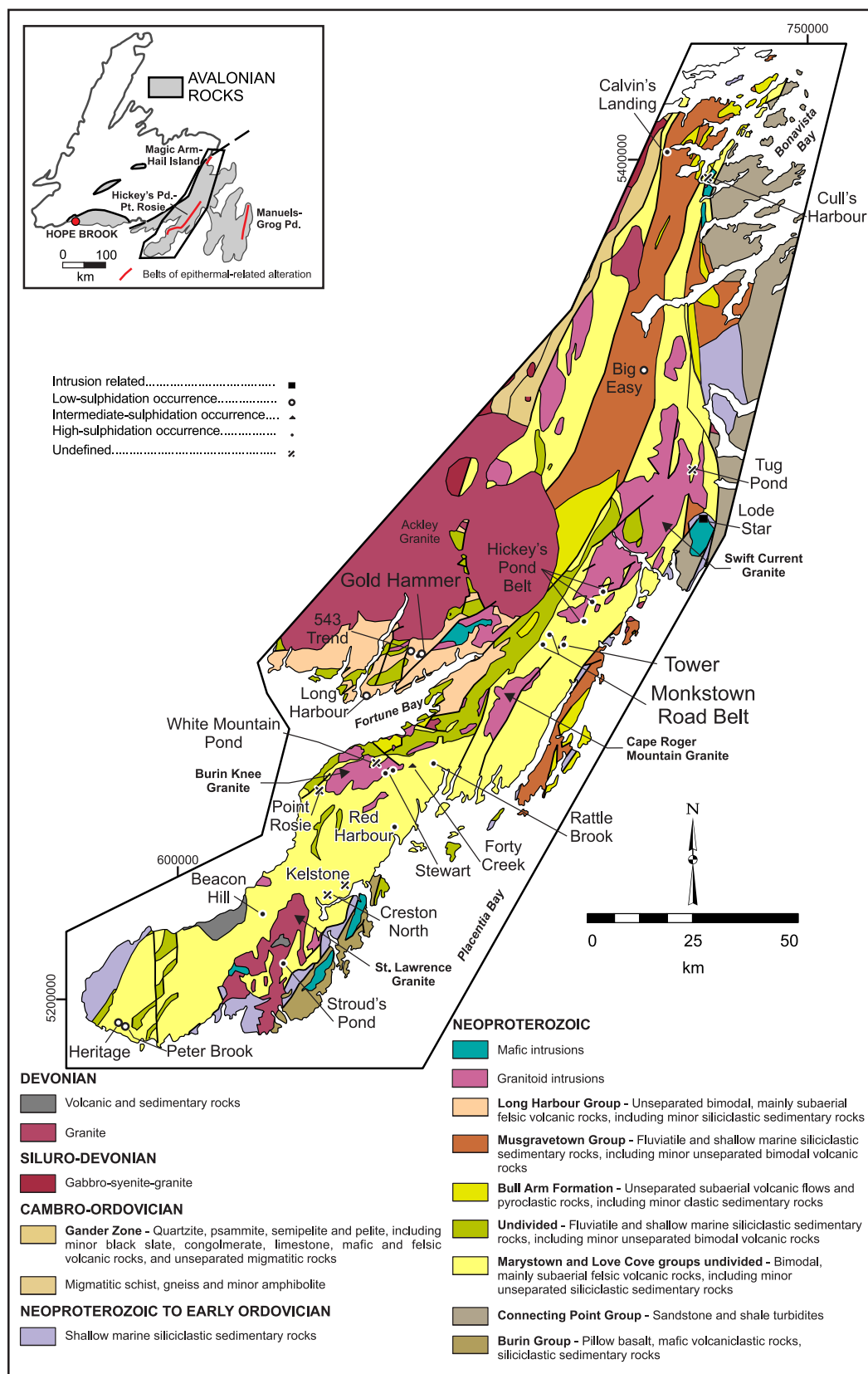


Figure 1. Regional geology map of the western Avalon Zone outlining the distribution of known epithermal prospects (modified from O'Brien et al., 1998; coordinates are listed in NAD 27, Zone 21).

Zones of relatively intense Paleozoic deformation are more common in the western Avalon Zone than in the east in Newfoundland. In the northwestern part of the zone, the high-strain deformation is linked to Silurian transpression and the development of the Dover Fault, which marks the tectonic contact with the adjacent Gander Zone (Blackwood and Kennedy, 1975; Kennedy *et al.*, 1982; O'Brien and Holdsworth, 1992). Epithermal systems along the western margin of the Avalon Zone commonly display moderate to strong deformation. Most of this deformation overprinting the epithermal systems of the Burin Peninsula is inferred to be Late Silurian–Devonian and is attributed to the Acadian Orogeny (Dallmeyer *et al.*, 1983; Dunning *et al.*, 1990; O'Brien *et al.*, 1991, 1999; van Staal, 2007).

THE HICKEY'S POND PROSPECT

Located in the north and centre of the Burin Peninsula, the Hickey's Pond prospect is a small but well-exposed example of auriferous epithermal alteration that forms a regional-scale belt extending some 100 km along the Burin Peninsula between Swift Current and Point Enragée (*cf.* Dubé *et al.*, 1998; O'Brien *et al.*, 1998, 1999; Sparkes, 2012; Sparkes and Dunning, 2014). Within this belt, discrete zones of advanced argillic alteration, hosting variably developed zones of silica, pyrophyllite, alunite, dickite, muscovite and locally topaz and diaspore alteration, can be traced intermittently for as much as 16 km along strike (Sparkes and Dunning, 2014; Figure 1). Locally, these zones of advanced argillic alteration contain gold mineralization; the highest grade gold values (from grab samples) are from the Hickey's Pond prospect (O'Brien *et al.*, 1999; Sparkes and Dunning, 2014). Bonanza-grade assays, up to 60.4 g/t Au (Table 1), have been returned from zones of vuggy silica enveloped by more extensive alunite–specularite-dominated advanced argillic alteration. These gold-bearing zones also display anomalous enrichment of Ag, As, Bi, Cu, Hg, Sb, Se, Sn and Te (Sparkes and Dunning, 2014).

PREVIOUS WORK

The Hickey's Pond prospect was originally investigated as a source of iron, due to an abundance of specularite contained in quartz veins in the area (Dahl, 1934; Bainbridge, 1934). Howland (1938) identified the presence of alunite at Hickey's Pond, but it was decades later when pyrophyllite was first identified at the prospect that the implications of this alteration for regional-scale epithermal precious-metal mineralization was recognized (Hussey, 1978a, b). This helped spark industry activity in the region, and in 1982, BP-Selco, who were engaged in advanced gold exploration at the epithermal Chetwynd gold prospect (later to be the

Hope Brook Mine), acquired mineral rights to the Hickey's Pond area. BP-Selco conducted the first diamond drilling on the property; however, the results were generally poor, with the highest gold value returning 630 ppb Au over 2 m, and no further work was recommended (Gubins and McKenzie, 1983).

Follow-up work in the area by the Geological Survey of Newfoundland and Labrador identified the presence of elevated gold values in association with the advanced argillic alteration (up to 5.4 g/t; Huard and O'Driscoll, 1985). In the late 1980s, the area was investigated by International Corona Corporation, who carried out additional surface sampling and diamond drilling. Results from this exploration produced gold values of up to 12.4 g/t Au over 1.2 m from channel sampling, and up to 1.9 g/t Au over 3.1 m in drill-core (Dimmell *et al.*, 1992). Since the late 1990s, exploration work on the property has been relatively limited, and has largely consisted of compilation work combined with limited surface sampling (*e.g.*, Dimmell, 1998; Sexton *et al.*, 2002, 2003; Dyke, 2007; Dyke and Pratt, 2008; Labonte, 2010).

O'Driscoll (1984) highlighted the mineralogical and geochemical similarities between the advanced argillic alteration at Hickey's Pond with that of similar occurrences in the Carolina Slate Belt summarized by Spence *et al.* (1980) and others. He also noted the absence of alunite alteration in the Carolina Slate Belt, but highlighted that the mineral is a common feature of other near-surface epithermal environments. Huard (1989) investigated epithermal prospects on the Burin Peninsula, including those in the Hickey's Pond area. This work identified two main mineralizing events consisting of an early silicification event associated with the development of quartz–pyrite veins, followed by the development of a specularite-rich hydrothermal breccia, both of which contain anomalous gold mineralization. In addition, Huard (1989) identified the presence of tellurium-bearing minerals in the area, noting the occurrence of what was inferred to be calaverite (AuTe₂) at the nearby Chimney Falls prospect (Figure 2). Huard also identified the thrust fault separating the Swift Current Granite to the northwest from adjacent volcanic rocks to the southeast, which he termed the Hickey's Brook Fault (Figures 2 and 3).

The Hickey's Pond area was examined as part of a regional metallogenic synthesis conducted by the Geological Survey in the late 1990s (*cf.* O'Brien *et al.*, 1999). These authors divided the high-sulphidation alteration into seven facies on the basis of the dominant alteration mineralogy, which included a zone of massive silicic alteration with grab samples up to 15.4 g/t Au. This work also identified two periods of folding within the advanced argillic alteration. From this study it was inferred that the alteration is pre-D₁

Table 1. Geochemical data from three samples collected from the vuggy silica alteration within the main mineralized zone at the Hickey's Pond prospect. Samples were analyzed *via* neutron activation analysis (NAA) and also include Ag values from the Department of Natural Resources GSNL laboratory that were obtained by Inductively Coupled Plasma-Emission Spectrometry (ICP-ES). Note that the NAA values for samples SF-12-150 and 152 should be taken as semi-quantitative due to high Au. - = below detection limit; coordinates are listed in NAD27, Zone 21

Sample	UTME	UTMN	Prospect	Au ppb NAA ICP-ES	Ag ppm NAA	As ppm NAA	Ba ppm NAA	Br ppm NAA	Ce ppm NAA	Co ppm NAA	Cr ppm NAA	Cs ppm NAA	Eu ppm NAA	Fe % NAA	Hf ppm NAA
				1	0.05	1	50	1	3	2	10	0.5	0.5	0.1	1
SF-12-150	699314	5295023	Hickey's Pond	10500	9.98	259.0	180	-	12	140	38	-	1.5	1.2	2
SF-12-151	699317	5295024	Hickey's Pond	3830	8.58	202.0	200	-	-	120	66	-	1.6	0.6	-
SF-12-152	699319	5295026	Hickey's Pond	60400	43.99	1310.0	145	78	370	88	36	9.7	-	6.4	-

Sample	UTME	UTMN	Prospect	La ppm NAA	Lu ppm NAA	Mo ppm NAA	Na % NAA	Rb ppm NAA	Sb ppm NAA	Sc ppm NAA	Se ppm NAA	Sm ppm NAA	Ta ppm NAA	Tb ppm NAA	Th ppm NAA
				1	0.05	1	0.05	5	0.1	0	1	0.1	0.2	0.5	0.1
SF-12-150	699314	5295023	Hickey's Pond	6	0.30	5	0.13	-	364.0	5.6	12	1.1	3.9	-	4.0
SF-12-151	699317	5295024	Hickey's Pond	3	0.38	7	0.41	-	411.0	4.7	15	0.3	2.3	-	1.1
SF-12-152	699319	5295026	Hickey's Pond	19	1.90	46	2.60	14	1400.0	4.0	66	0.8	1.8	-	1.6

Sample	UTME	UTMN	Prospect	U ppm NAA	W ppm NAA	Yb ppm NAA	Zr ppm NAA
				0.1	1	0.5	100
SF-12-150	699314	5295023	Hickey's Pond	1.0	548	1.9	-
SF-12-151	699317	5295024	Hickey's Pond	0.9	460	1.9	360
SF-12-152	699319	5295026	Hickey's Pond	12.3	260	64.8	-

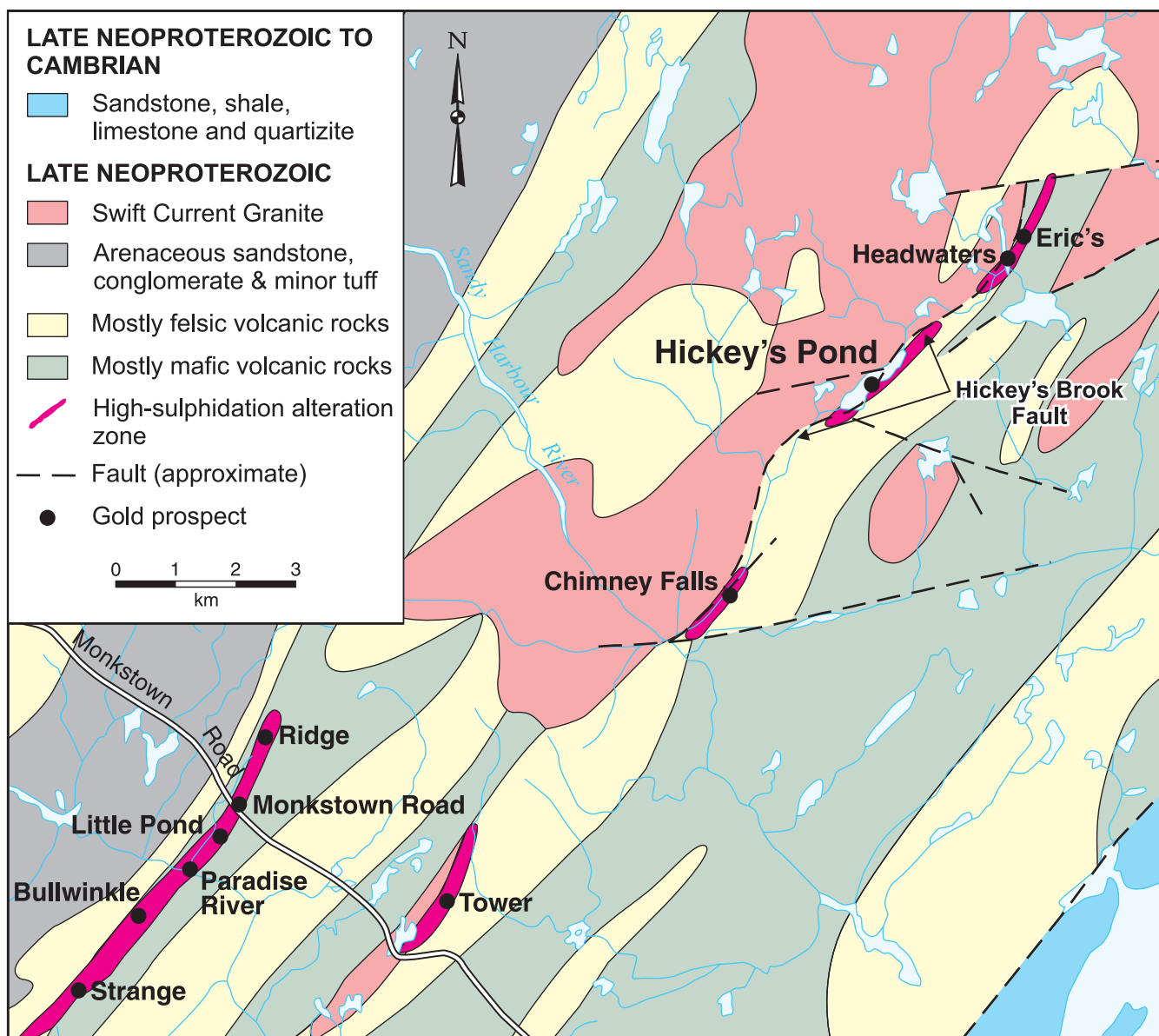


Figure 2. Regional geology map outlining the distribution of units and high-sulphidation related alteration along the southern margin of the Swift Current Granite (from Huard and O'Driscoll, 1986; modified from O'Brien *et al.*, 1999).

and that the S_1 foliation within the alteration is associated with local C-S fabrics, which indicate a reverse sense of motion compatible with that inferred along the Hickey's Brook Fault (O'Brien *et al.*, 1999).

GEOLOGICAL SETTING AND LIMITS OF HIGH-SULPHIDATION ALTERATION AT HICKEY'S POND

The Hickey's Pond prospect is one of several zones of specularite-bearing, locally auriferous high-sulphidation alteration located in the Marystown Group, at or near the

southeast margin of the regionally extensive, late Neoproterozoic Swift Current Granite (Huard, 1989; O'Brien *et al.*, 1999 and references therein; Figure 2).

Most of the advanced argillic alteration at Hickey's Pond occurs within the footwall of a westerly dipping high-strain zone known as the Hickey's Brook Fault (Huard, 1989). Hydrothermal alteration and mineralization at the prospect are hosted within highly strained, greenschist-grade pyroclastic rocks (O'Brien *et al.*, 1999) affected by a strong, northeast-southwest-trending, steeply northwesterly dipping S_1 foliation, which contains a moderate to steeply southwest-plunging stretching lineation. This post-mineral

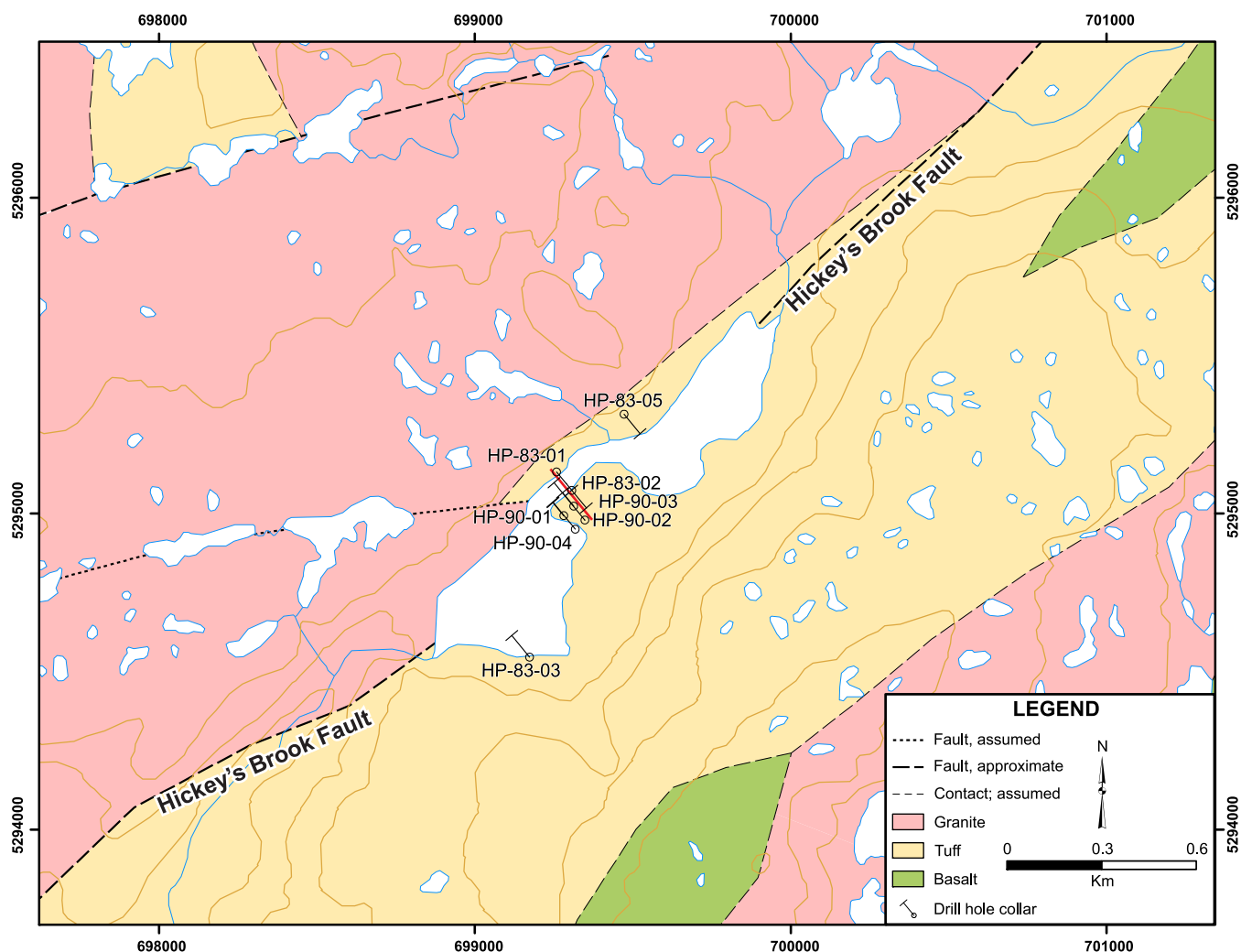


Figure 3. Compilation map outlining the geology surrounding the Hickey's Pond prospect (data from Huard and O'Driscoll, 1986; O'Brien *et al.*, 1999; Sexton *et al.*, 2003); note the red line through the Hickey's Pond prospect denotes the location of the cross-section shown in Figure 4.

S₁ foliation is locally axial planar to isoclinal F₁ folds, which plunge steeply to the southwest (O'Brien *et al.*, 1999). The local development of a C-S fabric indicates a reverse sense of motion, similar to that noted along the main Hickey's Brook Fault by Huard (1989). The D₁ structures are, in turn, deformed by open, moderately to steeply northeast-plunging F_{2a} folds and well-developed small-scale, moderately to shallow southwest-plunging F_{2b} folds (O'Brien *et al.*, 1999).

Detailed geology maps of the Hickey's Pond area show the northwestern side of the pond as being underlain entirely by the Swift Current Granite, which elsewhere has been shown to intrude the volcanic succession hosting the Hickey's Pond prospect (*e.g.*, Huard, 1989; O'Brien *et al.*, 1999). Our recent re-logging of archived drillcore from the prospect, however, indicated the presence of volcanic rocks in the hanging wall of the Hickey's Brook Fault, on the west

side of Hickey's Pond (Figure 3). The volcanic rocks in the upper portions of diamond-drill holes collared in this area are less deformed and less altered than the volcanic rocks encountered farther downhole. They contain recognizable cm-scale, structurally attenuated, fragments of pyroclastic origin (Plate 1A) and subhedral to euhedral phenocrysts of feldspar and lesser amounts of quartz within a fine-grained, quartz-predominant matrix (Plate 1B, C). Rocks within the hanging wall display propylitic alteration assemblages consisting of phengite, iron-magnesium chlorite and epidote, part of a regional metamorphic assemblage developed within the host volcanic succession, and similar to that noted elsewhere in the region (*cf.* Sparkes and Dunning, 2014).

Drillhole HP-83-01, located on the northwestern side of Hickey's Pond (Figure 3), records a distinct and sharp transition, approximately 30 m down-hole, whereby the pene-

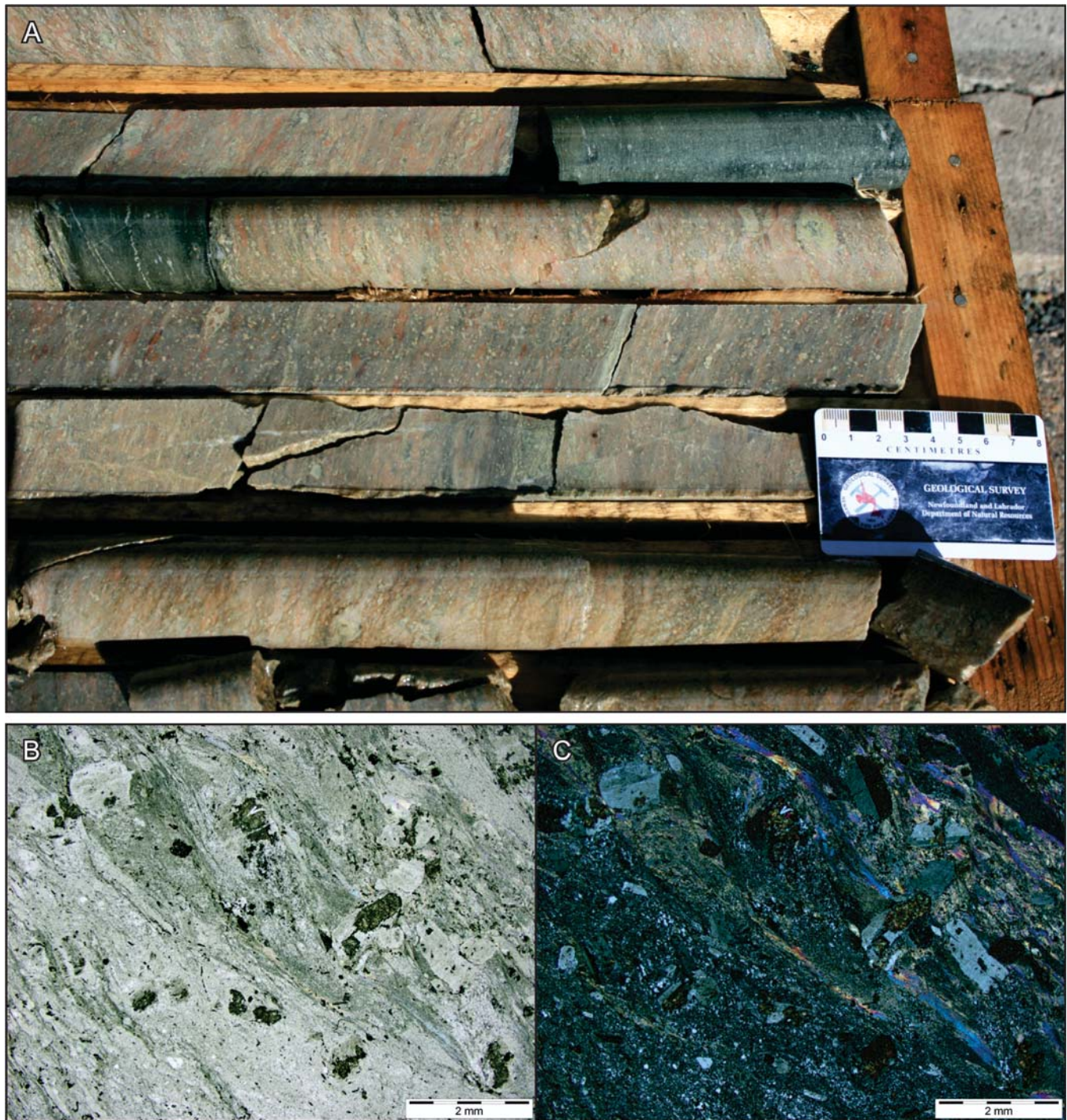


Plate 1. A) Moderately foliated fragmental volcanic unit (northwestern side of Hickey's Pond) sampled for geochronological study (DDH HP-83-01, ~22 m depth). Note the dark-green chlorite-rich material represents foliated mafic dykes that intrude the volcanic succession. B) Plane-polarized light photograph of the fragmental volcanic unit illustrating the distribution of feldspar phenocrysts and white mica alteration within the sample. C) Cross-polarized light view of (B).

trative fabric becomes more intense and muscovite becomes the predominant alteration mineral (Figure 4). This transition marks the beginning of a structurally controlled zone of muscovite–pyrite alteration, bounding the zone of advanced

argillic alteration (Figure 4). A similar relationship whereby zones of advanced argillic alteration are bound by structurally controlled muscovite–pyrite alteration has also been reported farther to the south in the area of the Monkstown

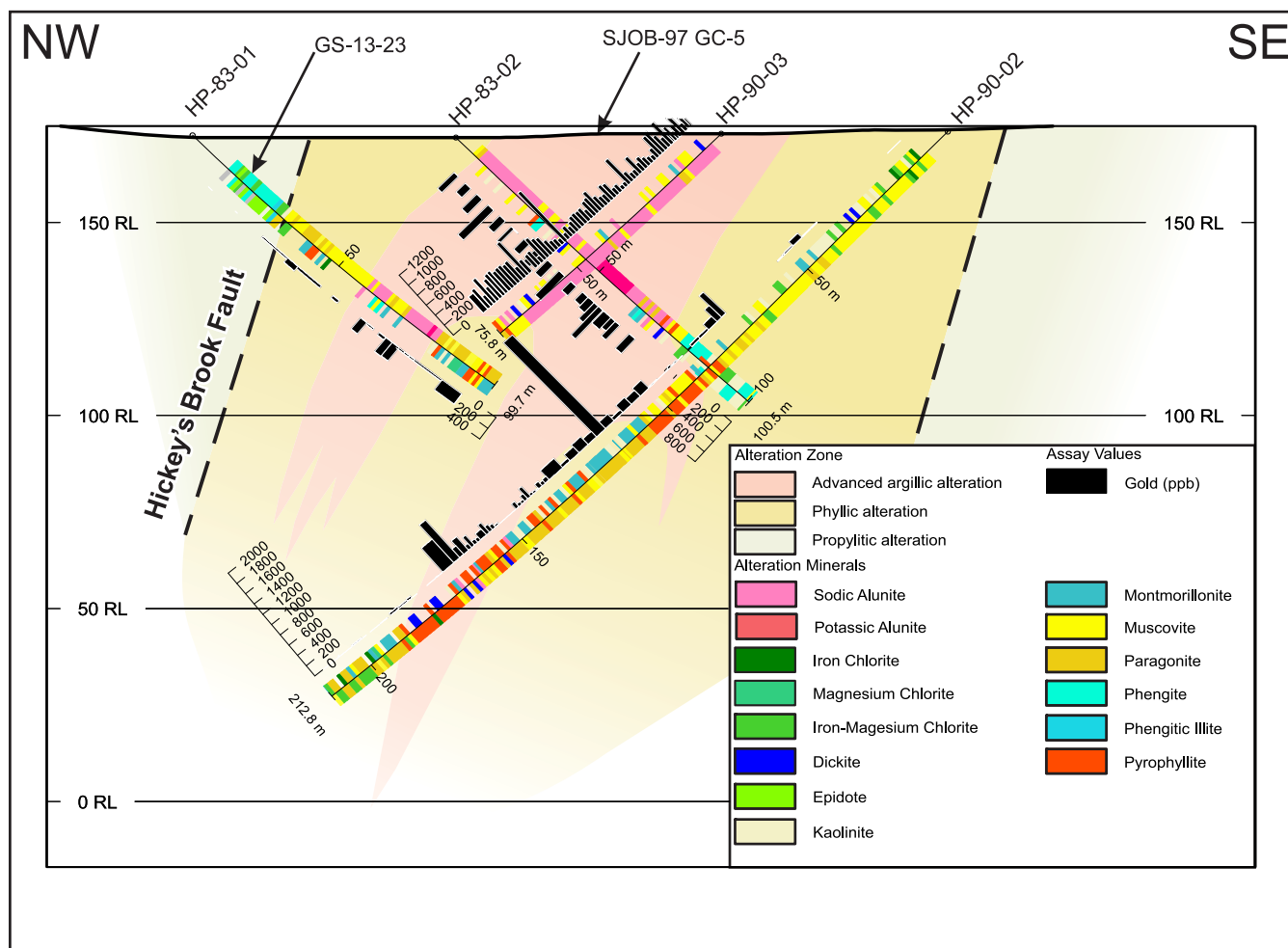


Figure 4. Schematic cross-section illustrating the subsurface distribution of the main alteration assemblages present at the Hickey's Pond prospect. VIRS data collected within individual drillholes display a 1-m-sampling interval, which is colour-coded to the predominant mineral phase present as outlined in the legend. The dominant mineral phase is shown on the right-hand side, and the secondary mineral, if present, is shown on the left-hand side of the drillhole trace. For a location of the cross-section refer to Figure 3. Also shown are the relative locations for the two geochronological samples discussed in the text.

Road and Tower prospects (e.g., Sparkes and Dunning, 2014). The muscovite–pyrite alteration is barren with respect to any appreciable gold mineralization and may be linked with younger deformation and metamorphism, such as the 400–353 Ma tectonothermal events documented by the whole-rock ^{40}Ar – ^{39}Ar data of Dallmeyer *et al.* (1983).

The main zone of alunite-predominant alteration can be broadly outlined on the basis of VIRS data and is structurally interleaved with the later muscovite–pyrite alteration (Figure 4). Paragonite alteration is observed marginal to the main zone of advanced argillic alteration, forming part of a phyllic alteration zone, which is rarely host to gold mineralization (Figure 4; *see below*). The eastern margin of the alteration at Hickey's Pond is unexposed but is inferred to be

a faulted contact, as is observed farther south in the area of the Tower prospect (*cf.* Sparkes and Dunning, 2014).

MINERALIZATION AND ALTERATION ASSEMBLAGES

The highest gold grades at the Hickey's Pond prospect (up to 60.4 g/t from grab samples) occur at surface within massive silica alteration, locally displaying vuggy textures, accompanied by alunite and pyrite (Plate 2; Table 1). Anomalous gold values have been encountered at depth within a similar, although less siliceous, alteration assemblage that also displays vuggy silica textures. However, the best drill intersection of this style of alteration is 1 g/t Au over 1 m (DDH HP-90-03; Dimmell *et al.*, 1992).



Plate 2. Representative photograph of the oxidized, vuggy-textured, silica alteration at surface.

Within 100 m of the massive silica zone at surface, significant gold (up to 5.4 g/t) has also been identified in a localized zone of hydrothermal brecciation, in which silicified fragments are encompassed by a specularite and quartz matrix (Huard, 1989; O'Brien *et al.*, 1999). Although the brecciation is localized, the associated quartz–specularite–white mica alteration assemblage can be traced at depth, where it has yielded up to 1.96 g/t Au over 3.1 m (DDH HP-90-02; Dimmell *et al.*, 1992). Variably developed vuggy silica textures can also be identified across this intersection.

Gold mineralization at the Hickey's Pond prospect most commonly occurs as pure native gold. Other gold-bearing phases include fischesserite (Au–Ag–selenide), minor electrum, and precious metal tellurides and selenides such as calaverite (AuTe₂) and petrovskaita (AuAg(S,Se)).

The opaque mineral phases observed in thin section are largely representative of a typical high-sulphidation assemblage. The assemblage is typically dominated by either pyrite or specularite, and includes copper-sulphosalts (tennantite and enargite) and copper-sulphides, as well as a wide range of tellurides. Opaque minerals are mostly present as fine disseminations in abundance of 1–5%, but locally reach up to ~35%.

The following summary outlines four zones of anomalous gold mineralization, highlighting the opaque mineral and alteration assemblages present, and the occurrence of gold (also *see* Table 2). Identification of the various mineral phases was conducted using an FEI MLA 650F scanning electron microscope (SEM), which was equipped with energy dispersive x-ray (EDX) analysis for elemental quantification.

VUGGY MASSIVE SILICA (SURFACE EXPOSURE)

Of the four gold-bearing zones at Hickey's Pond, the

massive silica zone exposed at surface is the most economically significant. It primarily consists of grey to beige massive silica, containing discontinuous patches of vuggy silica that is host to rutile, variable amounts of alunite, and minor disseminated pyrite, most of which has been replaced by iron-oxides; total pyrite and iron-oxide content of this style of vuggy silica is approximately 1 wt.%. Trace acanthite (Ag₂S) and naumannite (Ag₂Se) locally occur as linings within the vugs. Gold mineralization within the sulphide-poor variant of the vuggy silica occurs as relatively coarse (up to 40 µm) grains of native gold, contained within pockets of colloform hematite, which occur as a pseudomorphic replacement of pyrite (Plate 4).

The vuggy silica is locally enriched in sulphides, which are highly oxidized due to weathering, with up to 20% pyrite and tennantite occurring together with alunite and rutile. Pyrite and tennantite occur as disseminations in the matrix, as blebby vug fill, and in small (<1 cm wide) folded veins with quartz. Pyrite contains common inclusions of bornite. Tennantite hosts a wide variety of inclusions including bornite, hessite (Ag₂Te), calaverite (AuTe₂), native tellurium, tsumoite (BiTe), and less commonly naumannite (Ag₂Se), and native gold (Plate 3A). Minor enargite occurs with pyrite and tennantite in some of the finer vugs, where primary copper minerals have been largely replaced by bornite, chalcopyrite, covellite and chalcocite (Plate 3B, C). Tennantite is commonly replaced by As–Fe–Sb-oxide.

The highest gold concentrations (60.4 g/t) are found within the pyrite–tennantite-rich portions of the vuggy silica zone, where a variety of gold phases are present. Of these, fischesserite (Ag₃AuSe₂) is the most abundant. It occurs 1) within fine scorodite (FeAsO₄·2(H₂O))–hematite (–angelellite (Fe₄(AsO₄)₂O₃)) breccias with naumannite and minor native gold (Plates 5 and 6A), and 2) within colloform layers of hematite and scorodite, which line fractures and cavities (Plate 6B). Native gold is less common, occurring in association with tennantite, as fine (<4 µm) irregularly shaped inclusions (Plate 6C), as well as in fractures in tennantite grains. Gold also occurs as the gold-telluride calaverite, which occurs as tiny (<1 µm) inclusions in tennantite (Plates 3A and 6D). More rarely, gold occurs as fine (~2 µm) electrum in oxidized fractures.

QUARTZ–ALUNITE–PYRITE (AT DEPTH)

Anomalous gold grades occur throughout drillhole HP-90-03 (Figure 4). The interval from about 61 to 64 m was examined in detail and the mineralogy of this interval forms the basis of this section. This zone is similar in mineralogy to the massive silica at surface, composed of an advanced argillic alteration assemblage dominated by quartz, alunite,

Table 2. Summary of the gold, telluride, selenide, and sulphide minerals present at Hickey's Pond within the four main zones associated with anomalous gold mineralization. The zones are; 1) Vuggy Massive Silica (surface exposure); 2) Pyrite–Quartz–Alunite (from drillhole HP-90-03; 61-64 m); 3) Hydrothermal Specularite Breccia (surface exposure); 4) Specularite–Quartz–White Mica (from drillhole HP-90-02; ~117 m)

	Pyrite Dominated		Specularite Dominated	
	Vuggy Massive Silica	Pyrite-Quartz-Alunite	Hydrothermal Specularite Breccia	Specularite-Quartz-White Mica
AU MINERALIZATION				
Native Au	X	X	X	X
Calaverite AuTe ₂	X			
Fischesserite Ag ₃ AuSe ₂	X			
Electrum (Au, Ag)	X			X
Petrovskaita AuAg(Se, S)				X
SULPHIDES				
Tennantite Cu ₆ [Cu ₄ (Fe,Zn) ₂]As ₄ S ₁₃	X	X		
Te-rich Tennantite		X		
As-rich Pyrite		X		
Enargite Cu ₃ AsS ₄	X			
Wittichenite Cu ₃ BiS ₃		X		
Bornite Cu ₅ FeS ₄	X	X		
Chalcopyrite CuFeS ₂	X	X		
Covellite CuS	X	X		
Chalcocite Cu ₂ S	X			
Acanthite Ag ₂ S	X			X
Cinnabar HgS		X		X
TELLURIDES				
Tsumoite BiTe	X	X	X	X
Hessite Ag ₂ Te	X	X		X
Native Te	X			X
Coloradoite HgTe				X
SELENIDES				
Klockmannite CuSe				X
Bohdanowiczite BiAgSe ₂				X
Grundmannite CuBiSe ₂				X
Clausthalite PbSe				X
Naumannite Ag ₂ Se	X			X
Tiemannite HgSe		X		X
Native Se		X		X

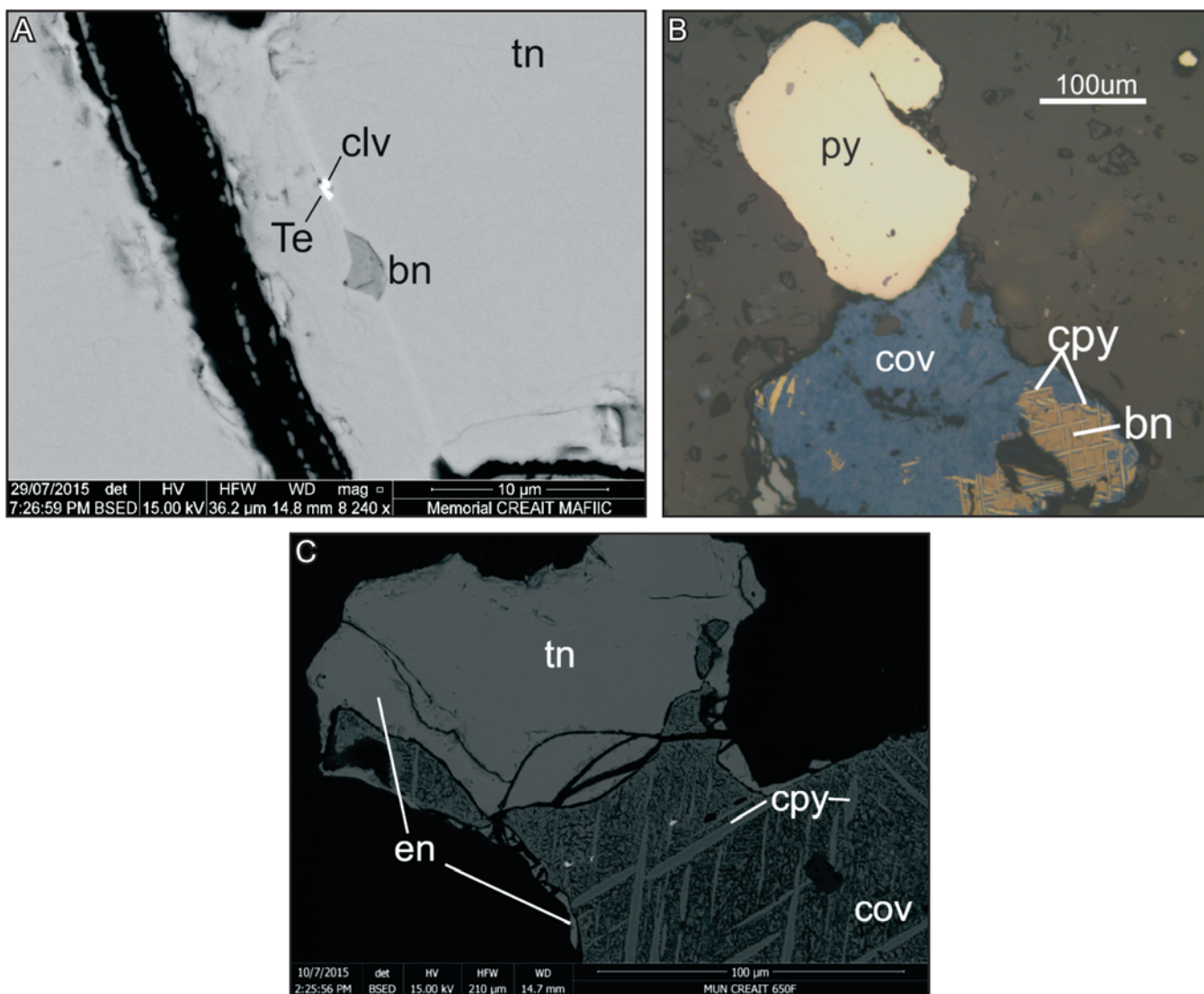


Plate 3. Representative photomicrographs of the various opaque minerals present in the vuggy silica zone (SF-12-152); A) BSE SEM image of bornite (bn), and intergrown calaverite (clv) and tellurium (Te) inclusions within tennantite (tn); B) reflected light image of pyrite (py) and a Cu-rich assemblage filling a small vug. Copper minerals are bornite (bn; primary, or replacing tennantite) displaying fine exsolution lamellae of chalcopyrite (cpy), and covellite (cov), which replaces copper-sulphides and surrounding pyrite; C) BSE SEM image showing tennantite (tn), minor enargite (en), and a copper-replacement assemblage of chalcopyrite (cpy; lamellae) and covellite (cov) filling a small vug.

pyrite and abundant rutile. However, it contains significantly more alunite than the former, ranging in abundance from 30–90%. The predominant alunite is the sodic variety, but minor potassic-alunite also occurs. Quartz is fine grained and pervasive throughout the matrix, and is also present as coarser comb-textured quartz lining and filling cavities, indicative of vuggy silica; however, strong deformation across this interval creates some ambiguity in identifying such textures.

Pyrite is the most prevalent opaque mineral phase (~1–10%), occurring as fine disseminations along the folia-

tion, and clustered with coarser quartz and alunite within vugs. Pyrite grains commonly display distinct cores and rims, and cores enriched in As (Plate 7A). Minor amounts of chalcopyrite, covellite, and a tellurium-rich variety of tennantite ($\pm$ BiTe) fill fractures within, and locally surround, pyrite grains (Plate 7B, C, D). Inclusions are common in pyrite and include bornite, tsumoite (BiTe), tennantite, tellurium-rich tennantite, wittichenite (Cu_3BiS_3), and hessite (Ag_2Te ; Plate 7A, D, E). Gold mineralization occurs in the form of very fine-grained native gold, directly associated with both pyrite and alunite (Plate 7C, F).

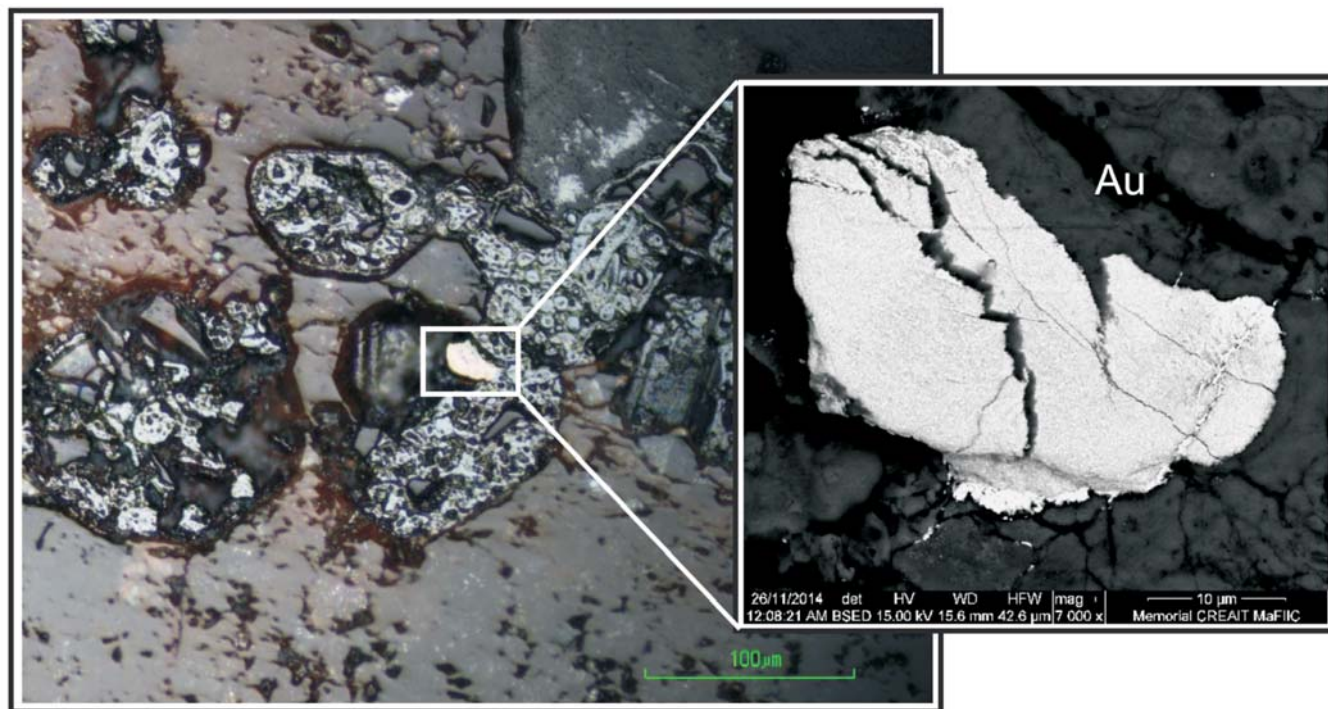


Plate 4. Representative reflected light and BSE SEM (inset) photomicrographs of gold mineralization at surface in the vuggy massive silica zone (SF-12-150). Native gold grain sits within colloform hematite that occurs as a replacement pseudomorph of pyrite. BSE SEM image of the grain shows a weak microcrystalline texture, which is crosscut by fractures filled with pure native gold, which appears white.

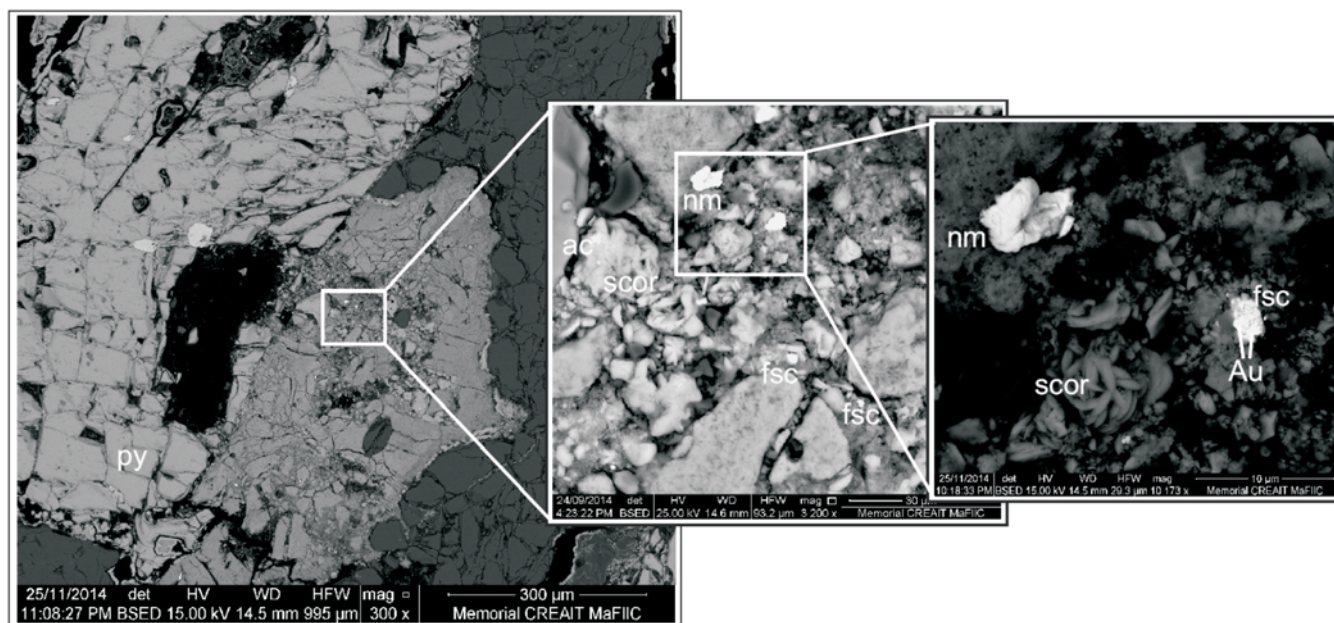


Plate 5. Representative BSE SEM photomicrographs of gold mineralization at surface within a sulphide-rich portion of the vuggy massive silica zone (SF-12-152). Brecciated fragments of Fe-As-Sb-oxide (presumably former tennantite) are surrounded by a scorodite-rich (scor) matrix, containing precious-metal mineralization, primarily in the form of selenides. Minerals include fischerite (fsc), minor native gold (Au), naumannite (nm), pyrite (py) and acanthite (ac).

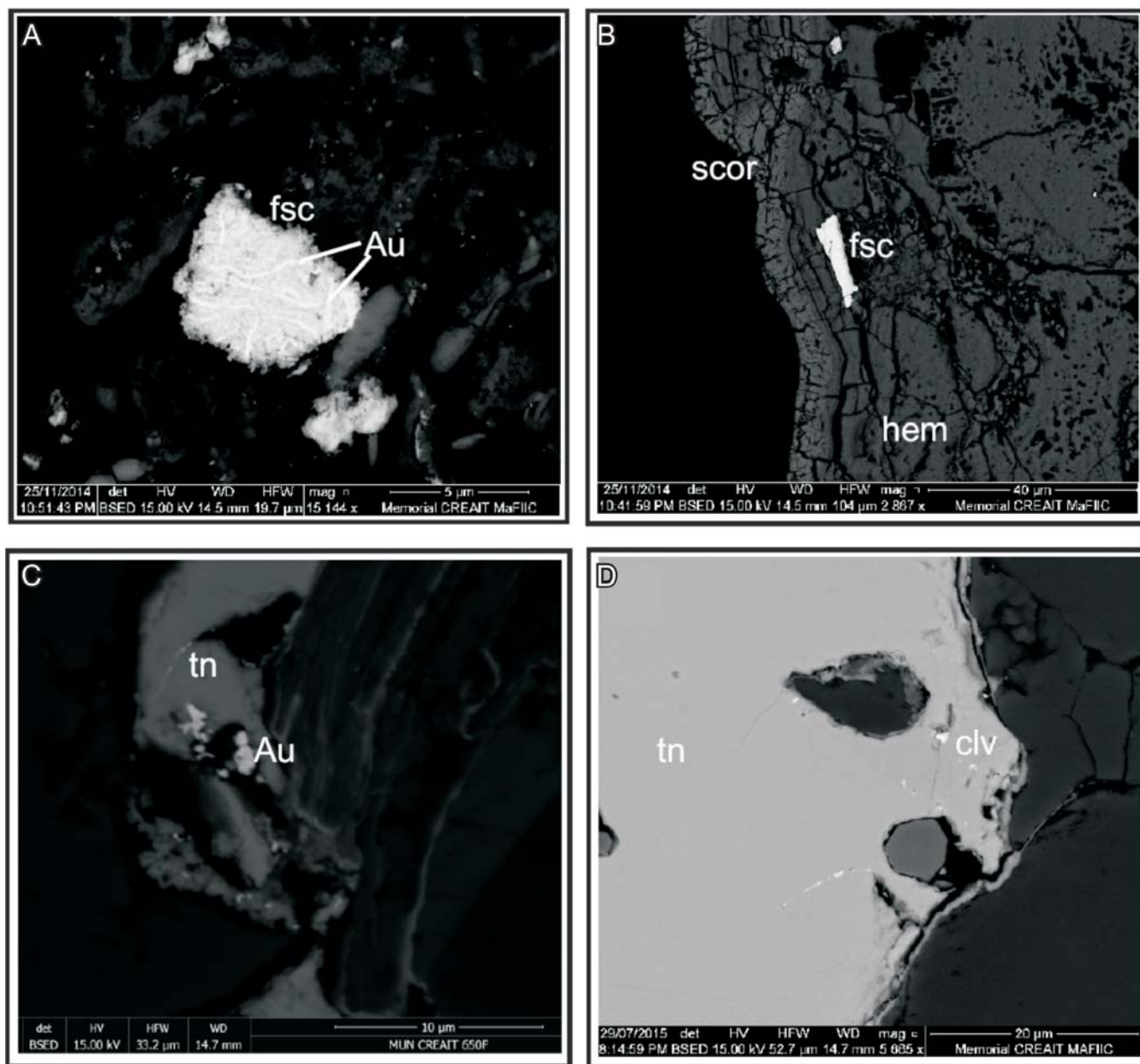


Plate 6. BSE SEM photomicrographs showing the various associations of gold mineralization identified at surface within a sulphide-rich portion of the vuggy massive silica zone (SF-12-152); A) grain of fischesserite (fsc) with white ribbons of native gold (Au) occurring within a very fine, oxidized hematite breccia; B) elongate grain of fischesserite (fsc), contained within colloform layers of hematite (hem) and scorodite (scor) lining a fracture; C) very fine native gold (Au) inclusions within tennantite (tn); D) fine calaverite (clv) inclusions within tennantite (tn).

Locally, breccias are developed, in which hydrothermally altered fragments are surrounded by fine, colloform-banded iron-oxides and lesser kaolinite; the iron-oxides also pseudomorph pyrite in areas proximal to the oxidized breccias. Native selenium, tiemannite (HgSe), and cinnabar (HgS) also occur in association with the oxidized breccias, and are most commonly found concentrated along thin fractures within the iron-oxides (Plate 8).

HYDROTHERMAL SPECULARITE BRECCIA (SURFACE EXPOSURE)

Huard (1989) described specularite-rich breccia zones as being relatively undeformed, with small, angular breccia fragments occurring within a black, specularite-rich matrix (Plate 9). The fragments are predominantly composed of quartz and alunite, with minor specularite, rutile, and pyro-

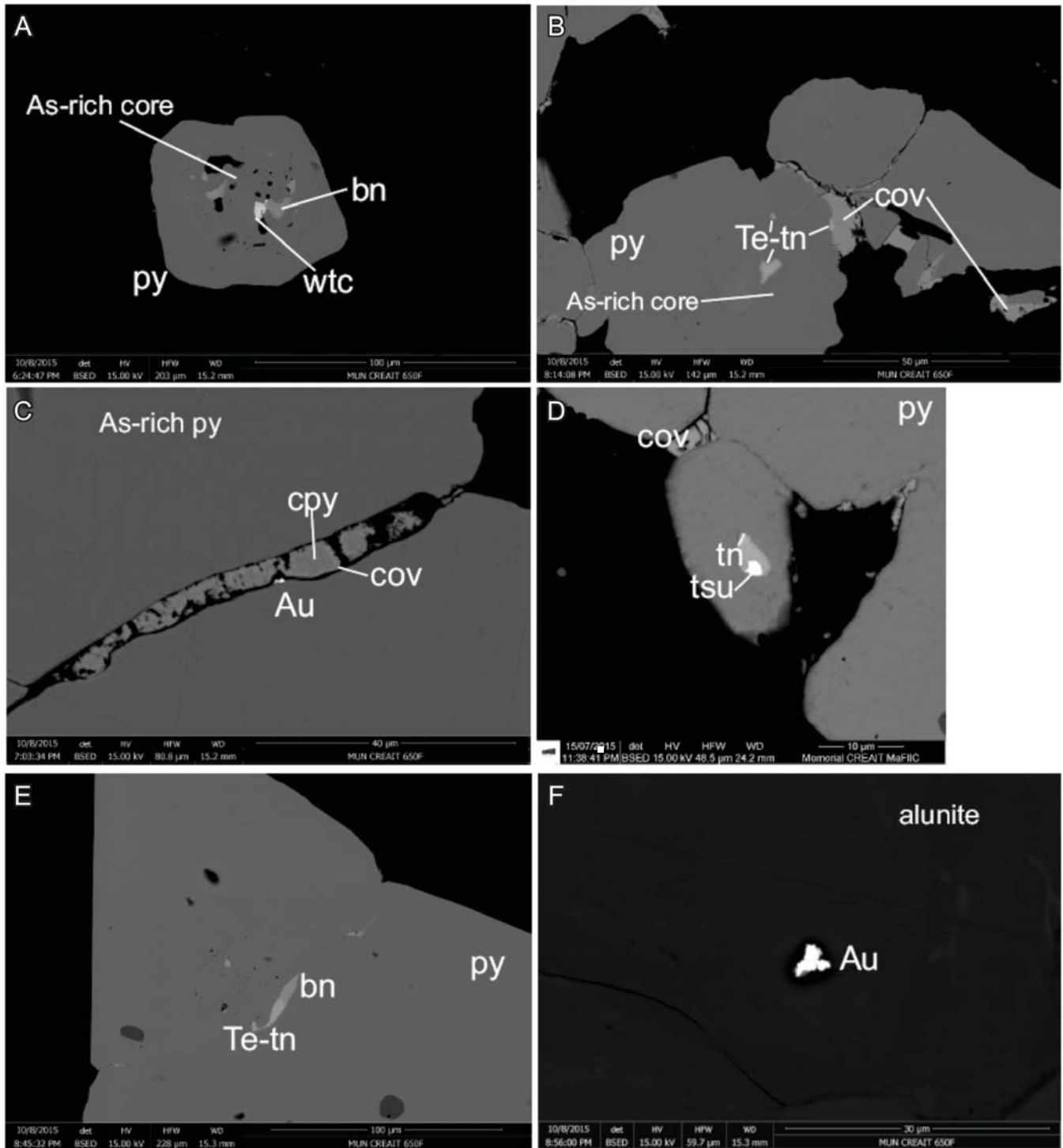


Plate 7. Representative BSE SEM photomicrographs of the various sulphides, sulphosalts, and tellurides that occur in the pyrite-quartz-alunite zone (DDH HP-90-03; 61-64 m); A) pyrite (py) grain displaying an arsenic-rich core containing inclusions of bornite (bn) and wittichenite (wtc); B) pyrite (py) grains with arsenic-rich cores, containing inclusions of tellurium-rich tennantite (Te-tn), crosscut by fractures filled with covellite (cov); C) arsenic-rich pyrite, with crosscutting fractures filled with chalcopyrite (cpy) and covellite (cov), and containing a fine inclusion of native gold (Au) along the fracture boundary; D) pyrite (py) with inclusion of intergrown tennantite (tn) and tsumoite (tsu), and surrounded by covellite (cov); E) inclusion of intergrown tellurium-rich tennantite (Te-tn) and bornite (bn) within pyrite (py); F) fine native gold (Au) within a coarse grain of alunite.

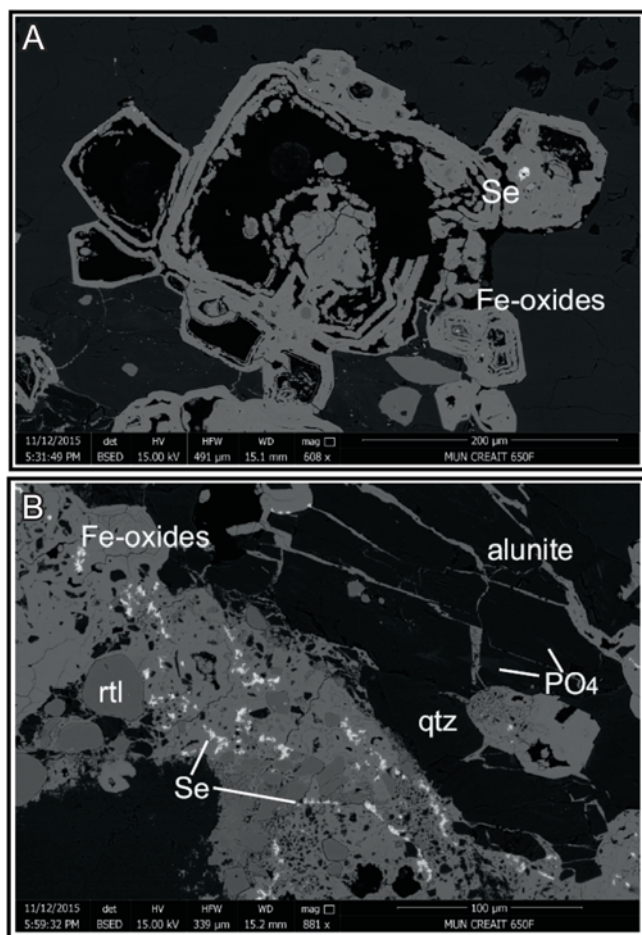


Plate 8. Representative BSE SEM photomicrographs of localized brecciation and iron-oxide replacement associated with the occurrence of native selenium, within the pyrite-quartz-alunite zone (DDH HP-90-03; 61-64 m); A) colloform-banded iron-oxides, pseudomorphically replacing pyrite grains proximal to breccias and associated with localized patches of native selenium (Se; shown in white); B) brecciated fragments of hydrothermal alteration minerals including rutile (rtl), quartz (qtz) and alunite, surrounded by a matrix of fine, colloform-banded iron-oxides, which also locally contains laths of kaolinite (not shown). Iron-oxides are crosscut by fine fractures filled with native selenium (Se). Lighter patches in alunite represent phosphate-rich zonation within the crystal.

phyllite. The matrix is microcrystalline and primarily composed of specularite (up to 90%), with lesser quartz, and alunite. Gold mineralization in this zone occurs as native gold, commonly associated with specularite. Bismuth-tellurides were also identified in trace amounts within the specularite breccia.

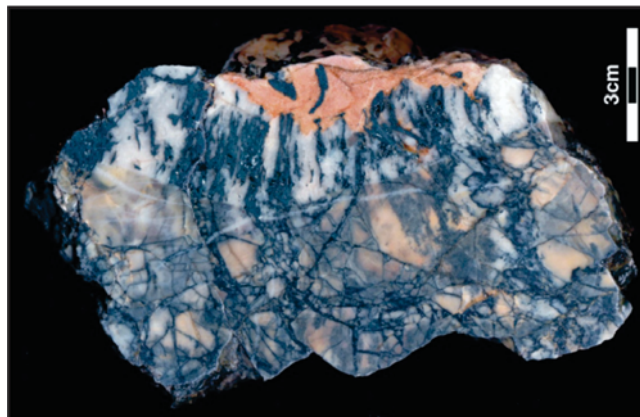


Plate 9. Cut slab from the hydrothermal specularite breccia zone found at surface at Hickey's Pond (4-5 g/t Au). Angular quartz-alunite fragments occur within a specularite-rich matrix (from O'Brien et al., 1999).

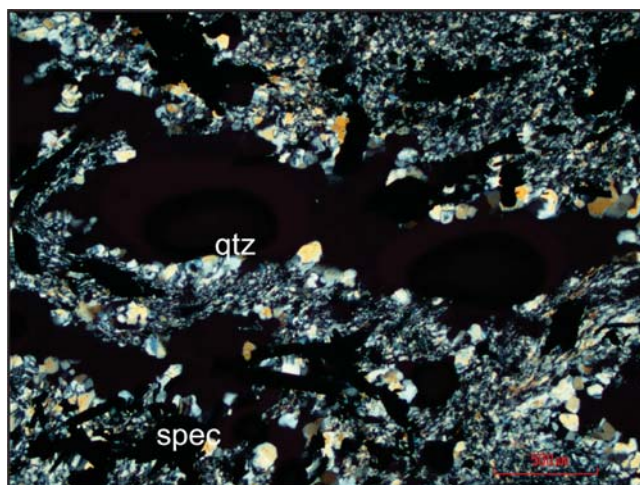


Plate 10. Cross-polarized light photomicrograph of vuggy silica texture from the specularite-quartz-white mica zone (DDH HP-90-02; ~117 m), showing coarse comb-textured quartz (qtz) and specularite (spec) lining and filling rounded, irregularly shaped cavities.

SPECULARITE-QUARTZ-WHITE MICA (AT DEPTH)

The highest gold grades encountered during drilling, occur in drillhole HP-90-02 (Figure 4), at a depth of ~117 m, within a specularite-quartz-white mica alteration assemblage. Texturally, this zone is very similar to the quartz-alunite-pyrite zone documented in drillhole HP-90-03, composed of a fine quartz groundmass and coarser comb-textured quartz lining rounded and irregularly shaped cavities, characteristic of vuggy silica (Plate 10). In contrast to the quartz-alunite-pyrite altered zone, this alteration assemblage has an abundance of specularite occurring in lieu of pyrite, and lacks alunite. The assemblage contains wood-

houseite and minor svanbergite, which are calcium- and strontium-phosphates, respectively, and are isostructural with alunite. Abundant white mica is also present, further separating this zone from the other mineralized zones mentioned above. On the basis of data from both Terra Spec and SEM-EDX analysis, the white mica alteration generally associated with gold mineralization is dominated by paragonite, and possibly illite and smectite (the latter identified using atomic ratios acquired by SEM-EDX analysis). Muscovite is abundant, but is of a younger origin than the hydrothermal alteration associated with the gold mineralization. The muscovite occurs as a fine-grained, evenly distributed alteration throughout the quartz matrix, and as a coarser overprint in the mineralized zone.

Specularite accounts for up to 35% of the alteration assemblage, mainly occurring as relatively coarse acicular grains. It is concentrated in discontinuous seams defined by the deformation fabric along with rutile, white mica, and phosphates, and also within clusters associated with coarse-grained quartz infilling vugs. In some places, it defines a weak breccia texture where it encompasses rounded quartz-rich fragments, but this is difficult to discern due to the deformation. Minor specularite also occurs as fine-grained, subhedral grains disseminated within a quartz-rich groundmass.

A diverse assemblage of fine-grained opaque minerals is present, and these are rich in Hg, Ag, Bi, Cu, Te, and Se. An early stage assemblage of Hg-, Ag-, Bi-tellurides, and Cu-, Bi-, Ag-selenides occurs as disseminations in the quartz matrix and as inclusions in specularite (Plate 11), whereas a late assemblage of Hg-, Ag-selenides and sulphides is found along later fractures and lining cavities (Plate 11B).

Gold predominantly occurs as native gold, and is most commonly found in the coarse-grained specularite-quartz-filled vugs, and the specularite-rutile-white mica-phosphate seams (Plate 12). It typically occurs adjacent to grains of specularite, but also shows a close affinity with rutile (Plate 12D). The native gold in the specularite seams is often rimmed by later tiemannite and cinnabar (Plates 12F and 13C). Minor amounts of native gold are also found in the quartz-rich groundmass, alongside the finer grained, disseminated specularite (Plates 11A and 12E). Native gold appears as microcrystalline aggregates and as layered grains, ranging in size from 2-10 μm (Plate 13). Locally, gold is also found as electrum and petrovskaitaite (Au,Ag(S,Se)) filling fine fractures through quartz grains.

SPECTRAL DATA

The fine-grained nature of most epithermal-related

alteration assemblages makes visual, and even petrographic, identification of some phases problematic. The recognition of the various alteration minerals developed within such systems is greatly aided by visible/infrared reflectance spectroscopy (VIRS); a detailed discussion of this technique is found in Kerr *et al.* (2011). Data obtained from drillcore from the Hickey's Pond prospect (collected at 1 m intervals), provide quantitative information with respect to the dominant mineral phases present, which can be modelled to illustrate the overall spatial distribution of the various alteration assemblages. The spectral data incorporated in this paper was initially released as an open-file report by Sparkes *et al.* (2015).

Within the Hickey's Pond area, propylitic alteration assemblages are dominated by phengite, iron-magnesium chlorite and epidote. Muscovite-predominant alteration is primarily structurally controlled, occurring in the vicinity of the Hickey's Brook Fault, and is observed to mark the limit of the advanced argillic alteration to the northwest. The main zone of advanced argillic alteration has an alunite-rich core, of a primarily sodic-rich composition, based on its spectral characteristics. However, a small zone of potassic-rich alunite was noted within drillhole HP-83-02 (Figure 4). The alunite alteration is also locally associated with lesser amounts of kaolinite and dickite as illustrated in Figure 4.

In deeper intersections of the advanced argillic alteration, below approximately 50–60 m vertical depth, pyrophyllite and dickite are predominant. The main zone of advanced argillic alteration, consisting of alunite, pyrophyllite and dickite, is primarily enveloped by a zone of paragonite-dominated alteration; the latter representing a phyllic alteration assemblage within the overall larger epithermal system. The phyllic alteration zone is locally host to the highest grade gold mineralization intersected in drillcore (Figure 4). However, more detailed petrographic investigation of this area indicates the presence of high-sulphidation-related features (*see* above section on specularite-quartz-white mica mineralization), which are not evident in the 1-m-sampling interval of the VIRS data shown in Figure 4.

GEOCHRONOLOGY SAMPLES AND RESULTS

Two geochronological samples have been analyzed from the Hickey's Pond area. One sample was originally collected as part of an earlier study (SJOB-97 GC-05); this sample was processed following the procedure outlined in Sánchez-García *et al.* (2008). The second sample (GS-13-23) was collected during more recent studies and was processed and analyzed following the procedure outlined in

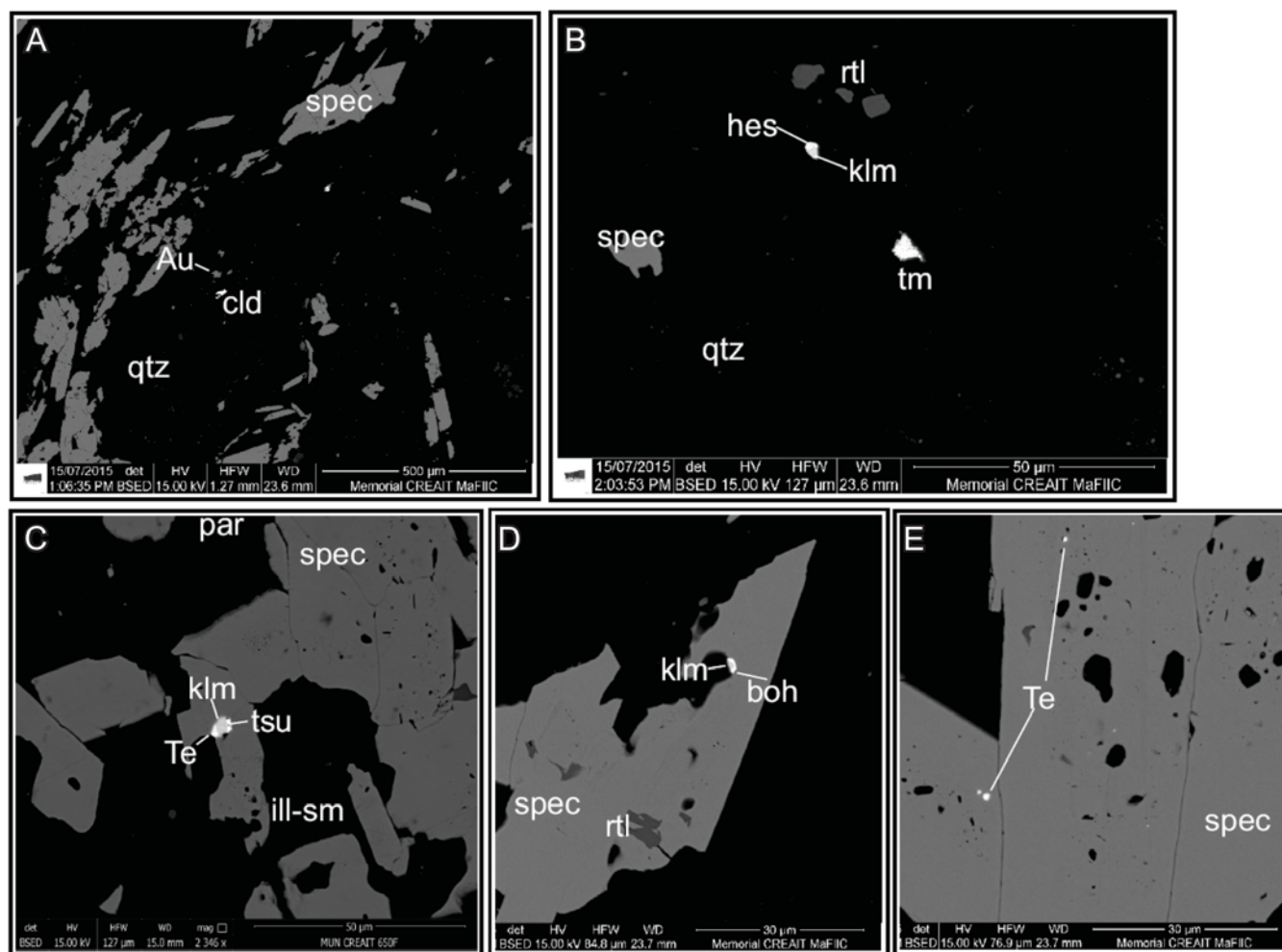


Plate 11. Representative BSE-SEM photomicrographs of the opaque mineral assemblage present within the specularite-quartz-white mica zone (DDH HP-90-02; ~117m); A) fine-grained coloradoite (cld) and very fine native gold (Au) occurring within the quartz (qtz) matrix, in association with bands of coarse specularite (spec); B) intergrown hessite (hes) and klockmannite (klm) inclusion within the quartz (qtz) matrix, occurring with specularite (spec) and rutile (rtl). Cross-cutting fracture locally filled by tiemannite (tm); C) inclusion of intergrown native tellurium (Te), klockmannite (Klm), and tsumoite (tsu) within coarse specularite (spec) associated with paragonite (par) and illite-smectite (ill-sm); D) klockmannite (Klm) and bohdanowiczite (boh) occurring along the specularite-gangue interface; E) inclusions of native tellurium (Te) within coarse specularite (spec).

Sparkes and Dunning (2014). Lead and U isotopic ratios were measured by thermal ionization mass spectrometry (TIMS), and results calculated using ISOPLOT. Uncertainties on both ages are reported at the 95% confidence interval.

The first sample (SJOB-97 GC-05) collected from the Hickey's Pond area consisted of typical alunite-specularite-dominated alteration. This sample was collected to determine the age of the host rock to the advanced argillic alteration. Multigrain zircon fractions from the sample, consisting of *ca.* 20 crystals each, were physically abraded following the procedure of Krogh (1982) and analyzed in 1998.

Two of these analyses (Z1, Z2) overlapped the concordia curve and gave a weighted average $^{206}\text{Pb}/^{238}\text{U}$ age of 572 ± 1.5 Ma. This age was considered correct until 2015, when new analyses of small grain number fractions (consisting of 3 to 4 grains) of the best crystals were carried out with the modern chemical abrasion (CA-TIMS) technique (Mattinson, 2005). These yielded ages of 586.6, 585.7 and 586.3 Ma (Z3, Z4 and Z5) and together provide a weighted average $^{206}\text{Pb}/^{238}\text{U}$ age of 586 ± 3 Ma (Figure 5, MSWD = 0.026). The younger age of 572 Ma determined in the earlier study is interpreted to be a result of domains in the crystals with lead-loss not removed by physical abrasion.

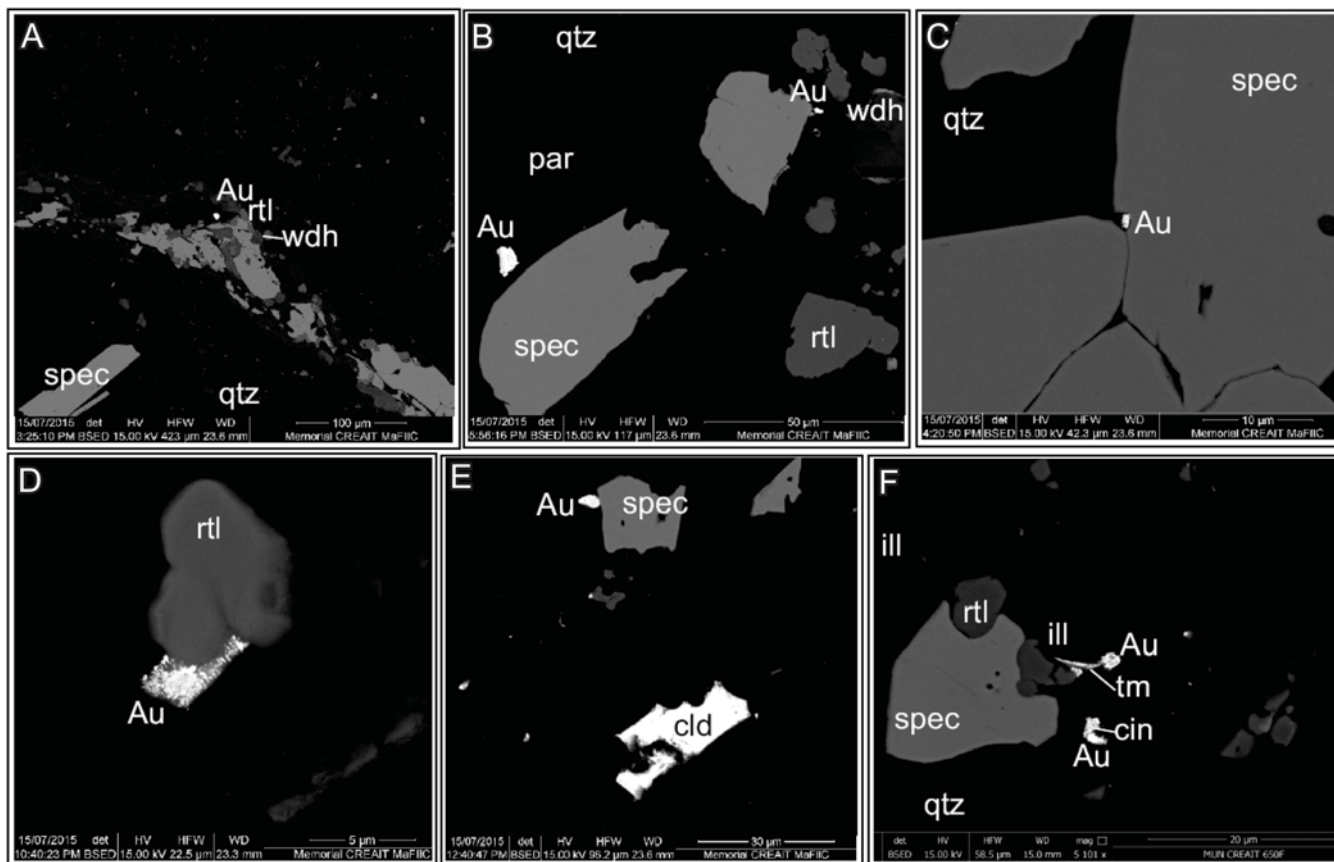


Plate 12. Representative BSE SEM photomicrographs of the occurrence of gold in the specularite–quartz–white mica zone (DDH HP-90-02; ~117 m); A) native gold (Au) occurring in association with a coarse seam of specularite (spec), white mica, rutile (rtl), and woodhouseite (wdh); B) native gold (Au) associated with specularite (spec) within a seam as described above, including paragonite (par); C) native gold (Au) occurring within cluster of coarse specularite; D) native gold (Au) partially intergrown with rutile within a coarse specularite seam; E) close-up of Plate 11A, showing native gold (Au) occurring with specularite (spec) and coloradoite (cld) within the quartz-rich matrix; F) native gold (Au) occurring in a seam with specularite (spec), rutile (rtl), quartz (qtz), and possible fine illite (ill). Gold (Au) is rimmed by later cinnabar (cin) and tiemannite (tm).

The second sample consisted of a weakly altered fragmental unit; inferred to be located within the hanging wall of the Hickey's Brook Fault. This sample (GS-13-23) was collected from archived drillcore to test the age of the volcanic rock outside of the main zone of advanced argillic alteration. All zircon from sample GS-13-23 (Plate 14) was chemically abraded to remove altered domains prior to analysis, following the procedures given in Mattinson (2005). Small fractions of 2 to 7 grains were analyzed and all overlap the concordia curve. However, the age determinations from the fractions are variable (Figure 5B) with one giving an age of 653 ± 3 Ma (Z3), one at 605 Ma (Z1), and two are at 594–595 Ma (Z2, Z4). Two analyses of 2 to 3 tiny low-uranium prisms (Z5, Z6, *ca.* 40 ppm U, Table 3) give ages of 586.4 ± 3 and 585.5 ± 2 Ma and these yield a weighted average $^{206}\text{Pb}/^{238}\text{U}$ age of 585.8 ± 1.7 Ma (Figure 5). The age from the tiniest zircon prisms give a maximum age for

the volcanic rock. The rest are interpreted to represent xenocrystic and/or pyroclastic inclusions of older zircon.

SUMMARY AND DISCUSSION

Detailed mineralogical investigations into the style and nature of gold mineralization at the Hickey's Pond prospect confirm the predominantly high-sulphidation nature of the mineralization as indicated by the accompanying advanced argillic mineral assemblages determined through VIRS analyses. Within the main mineralized portion of the prospect, detailed examination of both surface grab samples and subsurface samples collected from drillcore has identified four discrete zones or associations of anomalous gold mineralization within the prospect: namely, vuggy massive silica; quartz–alunite–pyrite; hydrothermal specularite breccia;

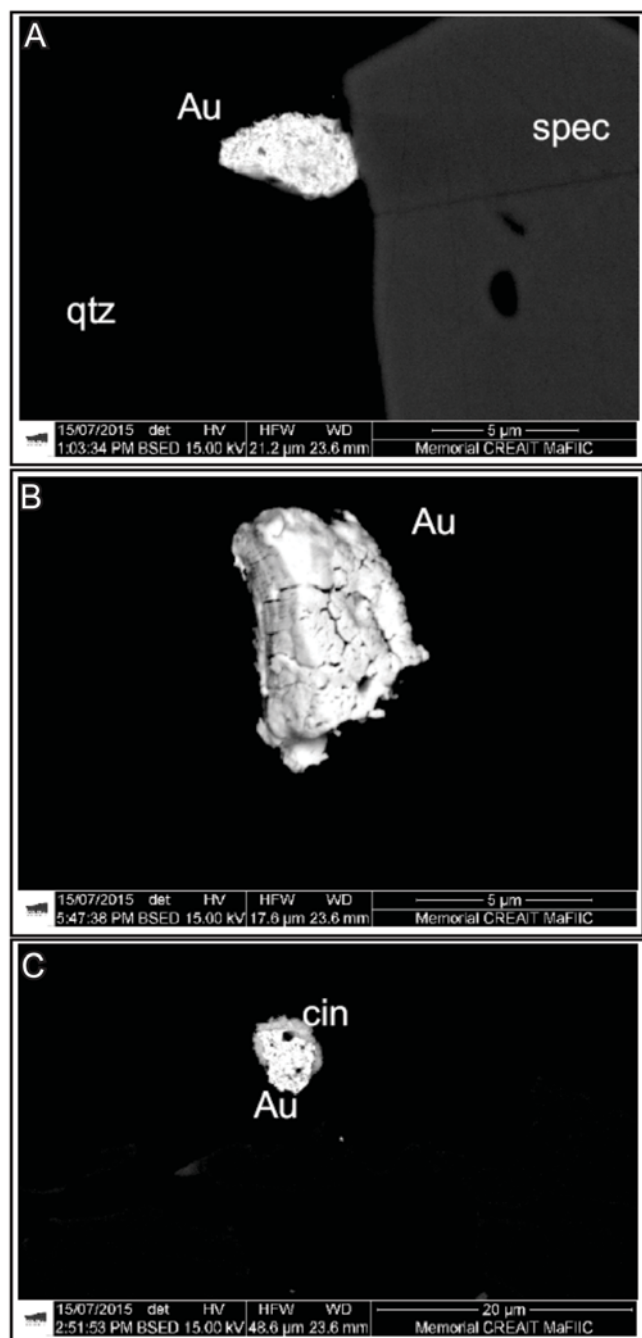


Plate 13. Representative BSE-SEM photomicrographs displaying the detailed textures of native gold grains identified in the specularite-quartz-white mica zone (DDH HP-90-02; ~117 m); A) close-up of Plates 11A and 12E with native gold (Au) displaying a microcrystalline texture; B) close-up of gold (Au) in Plate 12B, showing the detailed texture of the gold grain; C) close-up of gold (Au) in Plate 12A, showing a more microcrystalline texture in the gold, which is rimmed by later cinnabar (cin).

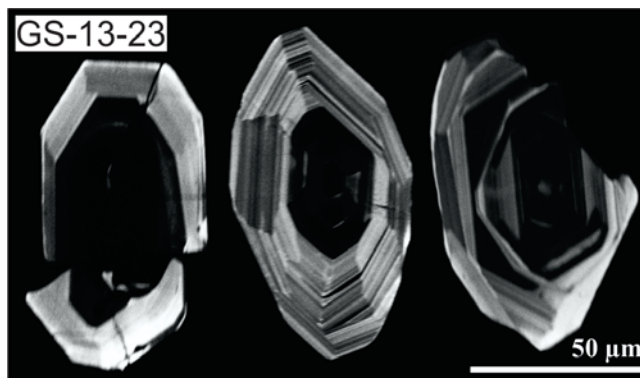


Plate 14. Cathode luminescence images for select grains outlining the typical textures observed within zircon grains obtained from sample GS-13-23.

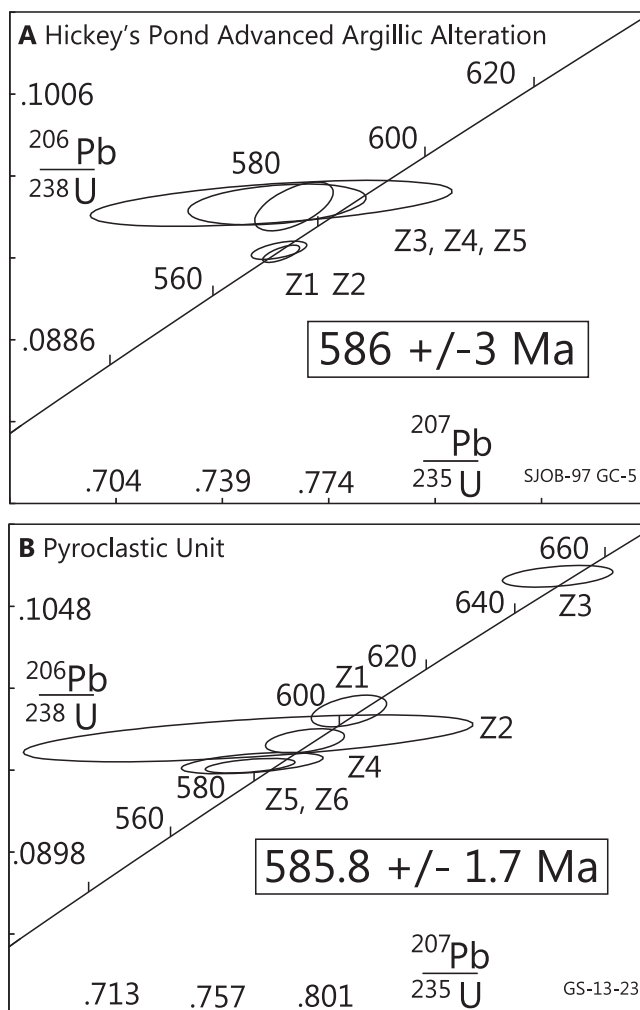


Figure 5. Concordia diagrams of U-Pb results from zircon analyses for samples discussed in the text. Error ellipses are at the 2σ level. Refer to Table 3 for sample location and description.

Table 3. U–Pb zircon data from volcanic rocks at the Hickey's Pond prospect; UTM's are in NAD 27, Zone 21 coordinates

Fraction	Concentration		Measured		Corrected Atomic Ratios *				Age [Ma]	
	Weight [mg]	U [ppm]	Pb rad	total common Pb [pg]	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$
SJOB-97 GC-5 – Alunite-specularite alteration (699314m E, 5295001m N)										
Z1 sml clr euh prm	0.066	103	11.5	192	224	0.3378	0.09280	34	0.7583	50
Z2 sml clr euh prm	0.035	103	11.6	172	140	0.3483	0.09297	36	0.7576	74
Z3 3 clr euh prm abr	0.003	40	4.6	11	86	0.3417	0.09526	92	0.7551	486
Z4 4 clr euh prm	0.004	53	6.0	2.5	516	0.3331	0.09511	98	0.7625	106
Z5 3 clr euh prm	0.003	26	2.9	2.7	190	0.3252	0.09521	82	0.7570	240
GS13-23 – Pyroclastic unit (699276m E, 5295145m N)										
Z1 7 sml euh prm	0.007	52	5.9	4.7	490	0.2765	0.09841	78	0.8096	128
Z2 2 sml clr euh prm	0.002	23	2.5	6.4	61	0.2827	0.09674	116	0.7680	760
Z3 3 sml euh prm	0.003	113	14.0	4.1	579	0.2851	0.10663	54	0.8959	186
Z4 4 sml clr euh prm	0.004	85	9.2	6.4	341	0.2316	0.09659	60	0.7914	134
Z5 2 tiny prm	0.002	44	5.0	3.4	173	0.3361	0.09523	54	0.7696	240
Z6 3 tiny prm	0.003	41	4.3	2.9	264	0.2516	0.09507	36	0.7688	152

Notes: Z=zircon, 2,3,4 =number of grains, sml=small, clr=clear, prm =prism, euh=euhedral.

In sample 1, Z3,4,5 and in sample 2 all zircon was chemically abraded (Mattinson, 2005).

Except for sample 1, fractions Z1 and Z2, weights were estimated so U and Pb concentrations are approximate.

* Atomic ratios corrected for fractionation, spike, laboratory blank of 2 picograms of common lead, and initial common lead at the age of the sample calculated from the model of Stacey and Kramers (1975), and 0.3 picogram U blank. Two sigma uncertainties are reported after the ratios and refer to the final digits.

cia; and specularite–quartz–white mica. Within these zones, gold is primarily hypogene, occurring in close association with, or as inclusions in, characteristic high-sulphidation minerals (*e.g.*, pyrite, tennantite, alunite, specularite, tellurides).

Within the Hickey's Pond prospect, evidence exists for multiple generations of hydrothermal activity; the most notable is the local development of hydrothermal specularite-bearing breccia that crosscuts the advanced argillic alteration. Smaller scale examples include replacement-style sulphide mineralization occurring as both vug filling material and as disseminations within the silica alteration, which is crosscut by later quartz–sulphide veins.

There is also evidence that the fluid chemistry has evolved over time. Pyrite commonly displays cores and rims of different composition, illustrating this phenomenon. The presence of both pyrite-dominant and specularite-dominant assemblages may also reflect temporally different fluids, or alternatively, changing redox conditions affecting a single fluid over time. These overprinting assemblages also occur at the nearby Tower prospect (Figure 2), where alunite–specularite alteration is overprinted by a pyrite-rich assemblage; the latter being accompanied by anomalous concentrations of Au, Cu, Mo and Se (Sparkes and Dunning, 2014).

There has been local secondary or supergene enrichment of both gold and selenium at Hickey's Pond. Evidence of this enrichment has been identified in drillcore at vertical depths as great as 80 m below surface. Examples include the presence of coarse native gold within colloform hematite occurring as a replacement of pyrite, formed *via* dissolution and re-precipitation of gold during later weathering or supergene processes of original epithermal (hypogene) mineralization. Likewise, the presence of fischerite in oxidized breccias indicates supergene gold enrichment. In this instance, the dissolution of primary, hypogene ore containing Au–Ag–Se, leads to the formation of solution collapse breccias and subsequent re-precipitation of the precious-metal-bearing selenide. In addition, selenium-rich assemblages ($\pm$ Hg, Ag, Au) occur throughout the four different gold associations, where they occur with late stage iron-oxides, and as late cavity and fracture filling material. Such examples are taken to represent evidence for the remobilization of selenides from the epithermal-related mineralization within the prospect.

VIRS analysis of archived drillcore suggests that rocks occurring within the hanging wall of the Hickey's Brook Fault are less altered and contain propylitic mineral assemblages (phengite, iron-magnesium chlorite and epidote) related to regional metamorphism. The advanced argillic

alteration is separated from the marginal less-altered units by a zone of muscovite–pyrite dominated alteration, which is inferred to have an overriding structural control related to the presence of the Hickey's Brook Fault. The development of this alteration is inferred to postdate the development of the advanced argillic alteration and is potentially linked with younger deformational events in the region. The main core of the alteration system is dominated by sodic-rich alunite, but also contains a minor zone of potassic-rich alunite. As noted by Chang *et al.* (2011), sodic-rich alunite is generally indicative of higher temperatures of formation in comparison to the potassic-rich endmember. The predominantly alunite-rich alteration transitions to pyrophyllite-dominated assemblages at depth. These advanced argillic assemblages are commonly enveloped by a paragonite-dominated alteration assemblage, which is inferred to be related to the development of the overall high-sulphidation system and is itself locally host to anomalous gold mineralization.

The new geochronology data confirm that the host to the advanced argillic alteration is part of the *ca.* 590–575 Ma Marystown Group. The *ca.* 585 Ma age of the volcanic host rock at Hickey's Pond is similar to that reported for other rocks hosting high-sulphidation related alteration elsewhere within the Avalon Zone of Newfoundland such as the Hope Brook deposit (Dubé *et al.*, 1998) and the Oval Pit Mine (Sparkes *et al.*, 2005). The refined age of 585.8 ± 1.7 Ma for the volcanic host rock at Hickey's Pond provides a better fit with regional interpretations of the area, whereby the 577 ± 3 Ma Swift Current Granite intrudes the volcanic sequence and is inferred to be related to the development of the spatially associated advanced argillic alteration.

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