THE TIMING OF MINERALIZATION AT THE JACLYN ZONE GOLD DEPOSIT, CENTRAL NEWFOUNDLAND: CONSTRAINTS FROM 
$^{40}\text{Ar}/^{39}\text{Ar}$ STUDIES OF WHITE MICA ALTERATION ADJACENT TO AURIFEROUS QUARTZ VEINS

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ABSTRACT

The Jaclyn Zone gold deposit (the Golden Promise deposit), is located in the western Exploits Subzone of the central mobile belt of the Newfoundland Appalachian Orogen. The gold resource at the deposit is based upon a ~1-m-wide, north-east-trending and steeply southeast-dipping quartz-vein network termed the Jaclyn Main vein; this is only one of several such veins exposed in the deposit area. Vein textures are varied, including laminated- and comb-textured material and these are hosted by interlayered, mafic volcaniclastic arenite, siltstone and wacke of the Noel Paul’s Brook Group of the Middle–Late Ordovician Victoria Lake supergroup. Regional metamorphic grade is low (sub-greenschist facies). The veins are developed in the uppermost strata of the supergroup, directly below the conformable transition to Sandbian (Caradocian) black shale. Native gold occurs as blebs in the comb-textured quartz and in the margins of laminated veins. Alteration in the footwall of the veins is dominated by illite+ankerite+Fe-chlorite+albite, whereas alteration in the immediate hanging wall is dominated by ankerite+albite+Fe-chlorite+illite+barian-potassium feldspar (adularia). The $^{40}\text{Ar}/^{39}\text{Ar}$ thermochronology on 2 samples from the immediate structural footwall of 2 major veins (Jaclyn Main and Christopher) indicate that the illite-dominated assemblage formed at ca. 428 Ma. The ankerite+Fe-chlorite+albite+illite+adularia-bearing assemblage in the hanging wall yielded a less robust age of ca. 400 Ma. Because the latter sample contains two distinct potassium-bearing phases, its younger age may be derived from a mixture of argon from sparse, ca. 428 Ma illite and from fine-grained and disseminated, younger (ca. 400–380 Ma?) adularia. Presently, the ca. 428 Ma age is interpreted to be the best estimate for the time of gold mineralization.

INTRODUCTION

The Jaclyn Zone gold deposit (Golden Promise deposit) occurs about 10 km southwest of the community of Badger in central Newfoundland (Figures 1 and 2). Discovered in 2002 by prospector William Mercer, the showing consisted of coarse-grained, comb-textured and stylolitic quartz boulders that were derived from underlying outcrops. A composite sample from ~10 of these boulders assayed ~30 g/t Au. The project was optioned by Rubicon Minerals Corporation and has since been explored under a number of joint-venture projects. Since 2002, the mineralization has been intensely explored (e.g., Copeland and Newport, 2004a, b, 2005; Pilgrim and Giroux, 2008; T. Tettelaar, personal communication, 2013). That work included, a regional airborne magnetic and electromagnetic survey, a regional soil-sampling program (6000 B-horizon samples), intensive prospecting and mapping, and 136 shallow (<314 m depth) NQ drill-holes totalling 22 529 m. A NI-43-101F1-compliant resource calculation on the Jaclyn Main zone (Pilgrim and Giroux, 2008) outlined a total of 921 000 tonnes averaging 3.02 g Au/t (2.5 million contained grams of gold), with a cut-off grade of 1 g/t Au. In 2010, bulk sampling of 2174 metric tonnes to test the veracity of the diamond-drill hole-defined resource, yielded 8780.52 grams of gold (and 645.4 grams of Ag) for an average recovered ore gold grade of 5.59g/t Au (Jet Metal Corporation, Press Release, April 20th, 2011; Sedar website). In addition, two detailed research-oriented investigations focussed on the nature and setting of the quartz veins (Newport, 2003; Sandeman et al., 2010), and a third study examined the petrochemistry of the mafic dykes associated with the auriferous quartz veins (Sandeman and Copeland, 2010).

This contribution builds on the earlier work of Sandeman et al. (2010) and presents petrographic and mineral chemical information (confirmed by electron microprobe; H. Sandeman, unpublished data, 2013) on alteration immediately adjacent to the Jaclyn Main vein, constituting the resource calculation, as well as the Christopher vein,
exposed 500 m to the southwest. Two 40Ar/39Ar ages are pre-
sented for illite from the immediate structural footwall of the
two different veins and a third 40Ar/39Ar age is from the
structural hanging wall of the Jaclyn Main vein. These data
provide new insights into the mineral assemblages and age
of the alteration associated with the auriferous quartz veins,
which in turn provides constraints on the timing of gold
mineralization.

REGIONAL SETTING

The Jaclyn gold deposit and several nearby auriferous
quartz veins were collectively termed the Golden Promise
Property (Mullen, 2003). The area lies within the Exploits
Subzone of the Newfoundland Appalachians (Figure 1). The Dunnage Zone consists of
accreted-arc, back-arc and intra-oceanic island terranes
formed in the Iapetus Ocean during the Cambrian and
Ordovician. A fundamental feature of the Dunnage Zone is
the Red Indian Line, a major lithospheric-scale fault zone
that juxtaposes rocks of the peri-Gondwanan Exploits Sub-
zone, to the southeast, against peri-Laurentian oceanic rocks
of the Notre Dame Subzone to the northwest (Williams
et al., 1988; Williams, 1995). The trace of the Red Indian Line
is located approximately 8 km to the west of the Jaclyn gold
deposit (Figure 2).

The Exploits Subzone is underlain by a structurally
imbricated series of lithologically diverse, arc-back-arc vol-
cano-sedimentary assemblages that include the Tulks Hill,
Long Lake and Tally Pond belts as well as the sedimentary-
dominated Harpoon Brook belt (Evans and Kean, 2002;
Rogers and van Staal, 2002). These are collectively known
as the Victoria Lake supergroup (VLS; Evans and Kean,
2002; Rogers and van Staal, 2002). The immediate study
area is underlain by marine volcanoclastic sedimentary rocks
initially termed the Harpoon Brook belt (Evans and Kean,
2002) but have recently been assigned to the Noel Paul’s
Brook Group (Rogers et al., 2005). The oldest rocks of
the Noel Paul’s Brook Group are green-grey shale and mud-
stone, volcanoclastic sandstone and wacke collectively con-
sidered to represent turbidites (Kean and Jayasinge, 1982).
These form a megascopic, north- and west-facing sequence that
finches upward away from the major volcanic centres of
the Tulks Hill, Long Lake and Tally Pond belts. These tur-
biditic sedimentary rocks were assigned to the Stanley
Waters formation (Rogers et al., 2005).

The Stanley Waters formation is described as being
conformably overlain by pyritic and graphitic black shale
that, on the basis of graptolite fauna (e.g., Williams and
O’Brien, 1991), are Sandbian (Caradocian). Contacts
between the Sandbian shale and the Stanley Waters forma-
tion are typically sheared and structurally complex, but have
locally been reported as conformable (e.g., Kean and
Jayasinge, 1982; Williams, 1991). The Sandbian graphitic
shales are assigned to the Lawrence Harbour Formation, the
uppermost strata of the Victoria Lake supergroup (Rogers
et al., 2005). The Lawrence Harbour Formation is inferred to
be conformably overlain by the continentally derived, fore-
arc overlap-sequence rocks of the Ordovician–Silurian
Badger Group (Williams, 1995; van Staal, 2007), however,
most of the exposed contacts are structurally complex and
highly strained and primary relationships are uncertain (cf.,
Williams, 1991 versus McNeill, 2005, in Copeland and
Newport, 2005). Rocks of the Badger Group comprise grey-
blue sandstone with less common, grey-black shale
interbeds and rip-ups that are overlain by polymictic con-
glomerate. These rocks are considered to be dominantly
derived from the topographically uplifted rocks of the Notre
Dame Subzone to the west (Waldron et al., 2012) and
deposited in a restricted fore-arc oceanic basin immediately
prior to final closure of Iapetus Ocean in the Silurian Salin-
ic orogeny (Dunning et al., 1990; van Staal, 2007; van Staal
et al., in press). All units are cut by an array of northeast- to
southeast-trending fine-grained diabase dykes termed the
Exploits dykes (McNeill, 2005 in Copeland and Newport,
2005; Sandeman and Copeland, 2010).

The rocks of the region exhibit four generations of
structures. The oldest are cryptic, early thrust faults having
a strong, locally developed cleavage. Second-generation

Figure 1. Location of the Jaclyn deposit in the western
Exploits Subzone of the central Newfoundland Appalachi-
ans. Also shown are the locations of other gold deposits dis-
cussed in the text.
Figure 2. Simplified geological map of the region (adapted from McNeill, 2005 in Copeland and Newport, 2005, and Rogers et al., 2005) showing the location of the Jaclyn veins at the inferred top of the Stanley Waters formation of the Victoria Lake supergroup. Units of the Badger Group are largely defined using detailed airborne magnetic and resistivity data.
structures fold the Badger Group and Victoria Lake supergroup into km-wavelength-scale, upright to inclined, doubly plunging (primarily to the northeast; McNeill, 2005 in Copeland and Newport, 2005) folds. These are southeast-verging, tight, chevron-style antiform–synform pairs that commonly exhibit broken limbs that are cut by, and likely locally transposed into, small-scale, limb-parallel reverse faults. These dominate the regional map pattern (Figure 2).

The third-generation structures are less conspicuous, large wavelength (~6 km), open folds that variably plunge to the southeast and have steeply dipping southeast-trending axial planes. Both regional-scale fold sets exhibit uncommon, outcrop-scale, macroscopic equivalents (McNeill, 2005 in Copeland and Newport, 2005). The area is transected by several northwest- and northeast-trending late brittle faults that crosscut older structures.

**JACLYN DEPOSIT GEOLOGY AND MINERALIZATION**

The gold resource estimate at the Jaclyn deposit is based upon the most extensive of four auriferous quartz veins recognized in the area. From south to north these comprise: the Jaclyn South, the Christopher, the Jaclyn Main and, the Jaclyn North veins (Figure 3); the resource is contained within the Jaclyn Main vein. Bedrock in the area was only encountered via trenching or through diamond drilling, although boulder-train analysis greatly assisted in delimiting the extent and location of the veins.

These vein systems are collectively hosted by the uppermost stratigraphic levels of the Stanley Waters formation, consisting of wacke, sandstone and siltstone that are dominated by plagioclase-rich, intermediate to mafic volcanic and fine-grained pelagic sedimentary detritus. The beds are upright and typically fine upward to the northeast. These rocks form the core of a 2- to 3-km wavelength, tight, moderately northeast-plunging and southeast-verging F1 anticline that folds the Stanley Waters formation, black, pyritic Sandbian shale of the Lawrence Harbour Formation and the turbiditic sedimentary rocks of the Badger Group (MacNeill, 2005 in Copeland and Newport, 2005; Rogers et al., 2005).

**CHRISTOPHER ZONE**

The Christopher vein is located approximately 500 m to the southwest of the Jaclyn zones (Figure 3). The vein trends
085°/75°S and ranges in width from <1 to 3 m. It has stylolitic margins, locally with a coarse-grained, comb-textured interior and contains abundant country-rock inclusions (Figure 4). Visible gold has been found in outcrop, but the best outcrop assay returned a value of only 1.96 g/t Au with strongly elevated arsenic. Limited drilling (2 holes) returned a maximum of 0.3 g/t Au over 0.7 m, accompanied by anomalous arsenic (Copeland and Newport, 2004a, b, 2005) that was interpreted to indicate that the grades are generally lower than at the Jaclyn Main zone. At surface, the wallrocks to the Christopher vein are dominated by epiclastic(?) sandstone and wackes containing minor siltstone and mud-

Figure 4. A) Sketch map of the Christopher zone trench showing the orientation, width and inclusion-rich character of the auriferous quartz vein (up to 3.6 g/t Au) and the location of 40Ar/39Ar thermochronological sample HS08-15A; B) Photograph illustrating the pinch and swell character of the Christopher vein.
stone intervals. Alteration of the coarse-grained clastic sedimentary rocks in the structural footwall of the vein is subtle, but comprises bleaching of the rocks’ matrix accompanied by an increase in sulphides (typically pyrite) along with illite, ankerite, chlorite and local hematite. Petrographic study confirms that in the structural footwall, the matrix is extensively altered, whereas spotting is locally developed in thin mudstone intervals. The matrix of the medium-grained sandstone in the structural hanging wall of the vein is extensively altered to an ankerite+albite+hematite-bearing assemblage.

The matrix of the plagioclase-rich wacke (sample HS08-15A) from the immediate footwall of Christopher vein is intensely altered (Plate 1). The alteration has resulted in extensive replacement of the wacke matrix by intimately intergrown illite+ankerite+calcite+chlorite+pyrite. This sample was dated using the $^{40}$Ar/$^{39}$Ar method.

**JACLYN MAIN ZONE**

The Jaclyn Main zone contains several major, east-northeast-trending (~080°) quartz veins that contain minor sulphides and visible gold. The widest and most significant is the Jaclyn Main vein (Figure 3). Wallrocks are dominated by medium- to coarse-grained feldspathic sandstone and mudstone-clast-bearing feldspathic wacke, and metre-scale intercalated beds of varicoloured siltstone and mudstone. Bleaching and spotting of the fine-grained host rocks is common, particularly near the veins. The quartz veins have laminated chlorite-rich stylolitic margins and coarse-grained, comb-textured interiors (Mullen, 2003; Sandeman et al., 2010). The stylolitic margins of the veins contain foliated, chlorite-altered siltstone septae or bands that locally terminate quartz and quartz carbonate veins in the wallrocks. The stylolitic vein margins also locally contain soft, gouge-like material or breccia-like zones of illite+ankerite+calcite+chlorite+albite-altered, fine-grained siltstone fragments. Within 2 m of the Jaclyn Main vein, host siltstones typically exhibit strong bleaching, which occurs in irregular patches and anastomosing channel-like zones (Sandeman et al., 2010). In siltstones, up to 15 m from the vein, a spotted, bleached texture is very common but is not definitively genetically related to the Au-bearing quartz veins (Sandeman and Copeland, 2010). The veins and host rocks are locally cut by at least two distinct suites of mafic dykes, one set of which is contemporaneous with the auriferous quartz veins (Sandeman and Copeland, 2010).

In drillhole GP07-86, a 60-cm-wide, auriferous quartz vein occurs at a depth of 94.85–95.45 m and contains 2.84 g/t Au over that 60 cm interval (Plate 2A). Intense alteration and bleaching, forming channel-like conduits (Plate 2B) and spotted zones occur in the immediate hanging wall of the vein (sample GP07-86 94.7: Plate 2C). These bleached zones and spots in the structural hanging wall are characterized by intergrown ankerite, albite, calcite, illite, chlorite and potassium feldspar (adularia?). The intensely bleached portion of this sample was dated using the $^{40}$Ar/$^{39}$Ar method. Immediately below the vein is a 5-cm-wide zone of breccia consisting of angular altered fragments of siltstone enclosed in an anastomosing network of similarly altered siltstone flour (sample GP07-86 95.45: see Plate 2B). The breccia fragments and their matrix contain intergrown illite, ankerite, albite, calcite and chlorite with abundant anhedral grains of galena, sphalerite and intergrown pyrite and chalcopyrite. This altered breccia material was also dated using $^{40}$Ar/$^{39}$Ar thermochronology.
At Jaclyn North (Figure 3), west-southwest-trending, moderately northwest-dipping, fine- to very-fine-grained, green to black cherty mudstone and siltstone predominate in trench exposures. In drillholes, these pass gradationally downward into grey, mudstone-clast-bearing wacke and plagioclase-rich and feldspathic air fall tuff (Copeland and Newport, 2004a, b, 2005; Sandeman et al., 2010; T. Tettelalaar, personal communication, 2013). The proportion of coarse-grained sedimentary rocks increases downhole, and local graded beds indicate younging to the northwest and east (Figure 3). Three irregular, stylolitic and inclusion-rich, bedding-parallel quartz veins and veined zones up to 9.6 m wide have been intersected in drillcore at Jaclyn North.

**40Ar/39Ar AGE DATA**

The **40Ar/39Ar** age determinations were obtained at the Queen’s University **40Ar/39Ar** Thermochronology Laboratory using the methods outlined by Minnett et al. (2012). The gas steps used in the calculation of the plateau ages are marked by bold type in Table 1 and by shaded boxes in Figure 5. All
Table 1. The $^{40}$Ar/$^{39}$Ar thermochronological data for hydrothermal illite grain concentrates from three samples of altered host rocks immediately adjacent to the Jaclyn Main and Christopher veins

<table>
<thead>
<tr>
<th>Lab #</th>
<th>Sample</th>
<th>J Value</th>
<th>Integrated age</th>
<th>Power</th>
<th>$^{40}$Ar/$^{39}$Ar</th>
<th>$r$</th>
<th>K/Ca</th>
<th>%40Atm</th>
<th>$^{40}$Ar*/$^{39}$K</th>
<th>%39Ar</th>
<th>Age (Ma)</th>
<th>+/-</th>
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<tr>
<td>D-672</td>
<td>HS08-15A illite</td>
<td>0.016899</td>
<td>429.2 ± 1.1 Ma</td>
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<td></td>
<td>D-668</td>
<td>0.016901</td>
<td>429.8 ± 1.2 Ma</td>
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<td></td>
<td>D-685</td>
<td>0.016904</td>
<td>400 ± 8 Ma</td>
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H.A. SANDEMAN

Age calculations used the \(^{40}\text{Ar}/^{39}\text{Ar}\) age spectrum module of Ludwig (2003). \(^{40}\text{Ar}/^{39}\text{Ar}\) plateau ages are typically defined by at least 3 contiguous gas release steps (consisting of >60% of released \(^{39}\text{Ar}\)), with \(^{40}\text{Ar}/^{39}\text{Ar}\) ages overlapping within 2\(\sigma\) error (McDougall and Harrison, 1988 and references therein; Snee et al., 1988; Singer and Pringle, 1996). A plateau must also be defined by \(^{40}\text{Ar}/^{39}\text{Ar}\) steps with reasonably low excess scatter (MSWD < 2.2). These criteria were not fully satisfied by two of the three gas-release spectra for the samples under investigation. These two analyses yielded quasi-plateaux that do not fully satisfy the above criteria (Table 1; Figure 5), however, their internal consistency, high K/Ca ratios for concurrent steps and, small volumes of contained atmospheric argon indicate that these quasi-plateaux are likely representative of the cooling ages of the dominant potassium-bearing phases in the grain separates. The approximate argon closure temperatures for muscovite (~300°C) and potassium feldspar (~150°C) aid the interpretation of the cooling history of the host rocks (McDougall and Harrison, 1988; Reynolds, 1992). Preliminary fluid inclusion analysis (H. Sandeman, unpublished data, 2013) indicates that the fluids associated with deposition of the quartz veins were low salinity (4–10 wt% equivalent NaCl) and on the order of ~275°C. This is below the closure temperature for muscovite, but above that for low-temperature potassium feldspar (adularia). The illite grain concentrate ages presented below are therefore inferred to represent the time of argon closure in the micas. Age uncertainties for all results are quoted at the 2\(\sigma\) uncertainty level.

The \(^{40}\text{Ar}/^{39}\text{Ar}\) laser step-heating ages were determined for grain separates (175–250 \(\mu\)m), dominated by very fine-grained, randomly oriented white mica, extracted from three samples of altered and mineralized siltstone and sandstone adjacent to the Jaclyn Main and Christopher veins. The white mica is typically ≤50 \(\mu\)m long, too small to ensure pure mineral separates. These grain separates, therefore, represent white mica concentrates and contain other fine-grained mineral phases. HS08-15A is an altered sandstone obtained from the immediate structural footwall of the Christopher vein (see above). Sample GP07-86_95.45m is an altered mudstone from the immediate structural footwall, and GP07-86_94.7m is an altered mudstone from the hanging wall of the Jaclyn Main vein. Both samples were described in the preceding section.

An illite concentrate from sample HS08-15A (Christopher vein) yields a well-defined argon release spectrum characterized by an abrupt rise in the ages of the lowest temperature gas release steps, and the remainder of the spectrum consisting of a relatively flat segment having consistently younger ages for each successively higher temperature gas fraction (Figure 5A). Six consecutive steps (steps 9–14) overlap, within error, comprising 49.9% of the total \(^{39}\text{Ar}\) released, and yield a quasi-plateau age of 427.8 ± 1.4 Ma.

**Figure 5.** The \(^{40}\text{Ar}/^{39}\text{Ar}\) age spectra for white mica grain separates from three specimens of altered wall rock adjacent to veins from the Jaclyn deposit area. A) HS08-15A; structural footwall to the Christopher vein; B) GP07-86_95.45; structural footwall to the Jaclyn Main vein; C) GP07-86_94.7; structural hanging wall to the Jaclyn Main vein.
The quasi-plateau age overlaps, within error, with the integrated age of 429.2 ± 1.1 Ma. The age of 427.8 ± 1.4 Ma is therefore interpreted to represent the time of formation of the illite alteration and hence the age of the hydrothermal event responsible for deposition of the mica.

Illite from GP07-86_95.45m, in the immediate structural footwall of the Jaclyn Main vein, yields a well-defined argon release spectrum characterized by a rapid rise in the ages of the lowest temperature gas release steps, to the remainder of the spectrum consisting of a relatively flat segment with progressively younger ages for each successively higher temperature gas fraction (Figure 5B). The final two gas fractions yield slightly older ages. Four of the high temperature steps (fractions 9–12 of 14), represent 39.1% of the total $^{39}$Ar released, and yield a quasi-plateau age of 427.9 ± 1.7 Ma (MSWD=0.36; POP= 0.78). Although this result is a quasi-plateau age, it is identical, within error, to the integrated age of 429.8 ± 1.2 Ma. Moreover, this age is also identical, within error, to that of HS08-15A, and is therefore also interpreted to represent the age of the hydrothermal event responsible for deposition of the mica.

An illite grain separate from the immediate structural hanging wall of the Jaclyn Main vein (GP07-86_94.7m) yielded a significantly different, mildly humped, argon release spectrum (Figure 5C). The ages of the gas fractions abruptly rise to a rough, humped plateau at ca. 400 Ma, and then rise again to significantly older ages for each successively higher temperature gas fractions. Each individual gas fraction is characterized by large errors, relative to those of the other two spectra, and the plateau age has a corresponding large error. Gas release steps 3 through 10 yield a plateau age of 400 ± 7 Ma, representing 74.1% of the $^{39}$Ar released (MSWD = 1.8; POE = 0.091). This overlaps, within error, with the total gas integrated age of 400 ± 8 Ma, but is significantly younger than the age determination for the illite alteration in the vein footwall, only 0.75 m downhole. It is important to note that the sample from the hanging wall (GP07-86_94.7m) yielded much lower K/Ca ratios and correspondingly higher atmospheric argon for each individual gas step (Table 1). Furthermore, this sample contains two distinct potassium-bearing minerals (illite and adularia) but these are far less abundant than in samples obtained from the footwall alteration zones of the Jaclyn and Christopher veins.

**DISCUSSION**

The extensive field, drillhole and regional geophysical investigations completed over the past decade, along with new petrographic, mineral, chemical and argon thermochronological data, provide important constraints on the setting and origin of the vein systems exposed at the Jaclyn Zone gold deposit. Collectively, the data are interpreted to suggest that the mineralized systems at the Jaclyn deposit are comparable to turbidite-hosted gold deposits of the Meguma Zone in Nova Scotia (e.g., Moosehead, Ovens; Sangster and Smith, 2007) and those of the prolific Bendigo-Ballarat region of southeastern Australia (e.g., Bendigo, Ballarat; Bierlein et al., 2000). These represent orogenic quartz-vein-hosted gold systems that are developed in volcano-sedimentary fold and thrust belts during orogenesis (Groves et al., 1998, 2003).

These turbidite-hosted, orogenic vein gold deposits are typically formed in association with greenschist-facies metamorphism during crustal thickening and regional folding and thrusting. Emplacement of the veins results from the close interrelationship between progressive tectonism and the episodic upward flow of orogenic fluids. Sandeman and Copeland (2010) discussed the complex inter-relationships between the auraliferous quartz veins and the Type-1 Exploits mafic dykes (Sandeman and Copeland, 2010). These dykes are commonly saussuritized and carbonatized, crosscut the veins, exhibit chilled margins and locally contain entrained xenocrysts and polycrystalline xenoliths of coarse-grained, euhedral, comb-textured quartz. They also exhibit elevated As, Sb, K$_2$O and CO$_2$ along with weakly anomalous gold (<1 to 12 ppb Au). The dykes are themselves, however, cut by quartz veins. The second set of dykes (Type-2) preserves primary clinopyroxene and plagioclase but relationships with the quartz veins were not seen. Because of their fresh character, these Type-2 dykes are inferred to postdate gold mineralization and alteration. The age of the dyke sets are not known, but Sandeman and Copeland (2010) note that one of the Type-1 dykes cuts quartz sandstones of the Badger Group (Himantian, Upper Ordovician: Williams, 1991), indicating that they must be younger than ca. 445 Ma (IUGS timescale, 2012). The new $^{39}$Ar/$^{39}$Ar data for illite in the structural footwall of the vein indicates that some of the alteration linked to auraliferous quartz veins developed at ca. 428 ± 2 Ma. Because the Type-1 dykes are contemporaneous with the veins, as demonstrated on the basis of cross-cutting relationships, the ages from vein-related alteration also constrain the age of these dykes to be ca. 428 Ma. This age is significantly older than an unpublished U/Pb zircon age of 415 ± 2 Ma for the Skull Hill Syenite, the most proximal Siluro–Devonian igneous intrusion, exposed 9 km to the west (personal communication to B. Greene by A. Halliday, 1980).

The varied orientations of the quartz veins and their tectural variability (including cocks-comb and laminated veins), the contemporaneity of vein and Type-1 mafic dykes, and the abundant evidence for associated brecciation of the country rocks, attest to the recurring, episodic nature of regional deformation and accompanying crack–conduit
propagation, mafic dyke injection and the infiltration of mineralizing fluids. Sandeman et al. (2010) proposed that the diverse field, structural, petrographic and drillhole data could be explained by a model in which the major north-east–southwest-trending regional folds are inferred to be Salinic D1 (ca. 435 Ma) structures (McNeill, 2005 in Copeland and Newport, 2005; Zagorevski et al., 2007; van Staal et al., in press). During progressive deformation, the folds lock up episodically as a result of fluctuation between ductile and brittle behaviour of the host rocks. Failure results in largely brittle deformation, despite substantial rheological contrast. This sporadic crack propagation and faulting is roughly axial planar to the regional D1 folds. Theological contrast. This sporadic crack propagation and faulting results in largely brittle deformation, despite substantial rheological contrast. This sporadic crack propagation and faulting is roughly axial planar to the regional D1 folds. The cracks or faults are infiltrated by early stage hydrothermal fluid that results in the deposition of quartz veins. Continued variation in the regional stress field during progressive deformation resulted in episodic faulting along pre-existing fractures and veins, commonly accompanied by further quartz veining, alteration, gold deposition and mafic magma emplacement (fault valve behaviour; Cox, 1995).

The ca. 428 Ma alteration, veining and mineralization are synchronous with or postdate regional F1 folding and aid in bracketing the timing of the Salinic event between 435 and 428 Ma (van Staal, 2007; van Staal et al., in press). Although the age of alteration and presumably mineralization is constrained to ca. 428 Ma on the basis of the two identical 40Ar/39Ar cooling ages for illite developed in the immediate footwall of the quartz veins, interpretation of the date from the hanging wall of the Jaclyn Main vein is much more difficult. The presence of two distinct potassium-bearing phases means that there are 2 distinct radiogenic argon sources in the alteration assemblage. Each mineral will release its argon at differing temperatures during incremental heating, thereby resulting in a mixed age. A possible explanation for the young, ca. 400 Ma age for the hanging wall specimen is that the sparse illite may have grown at the same time as the illite in the footwall samples; however the adularia records a distinct, younger (Middle Devonian?) later hydrothermal event. Mixing of ca. 428 Ma argon with ca 380 Ma argon might produce an 40Ar/39Ar gas release pattern that results in a mixed age of ca. 400 Ma.

Previous geochronological investigations have outlined two distinct ages of Siluro-Devonian gold deposition in the Newfoundland Appalachians (e.g., Dube et al., 1995; Ritey et al., 1995; McNicoll et al., 2006; Kerr and van Bremen, 2007; Kerr and Selby, 2012; Minnett et al., 2012). The earlier Siluro-Devonian event appears to range from ca. 420–405 Ma, whereas the second Middle to Late Devonian event ranges from ca. 385–370 Ma (Figure 6). The 40Ar/39Ar data presented herein for the Jaclyn and Christopher zones indicate that the illite alteration in the structural footwalls of two auriferous veins formed during the interval 430–426 Ma. These are the oldest ages for gold mineralization yet determined in the Newfoundland Appalachians and may suggest a previously unrecognized, early Salinic episode of orogenic gold mineralization. The adularia in the structural hanging wall of the Jaclyn Main vein may have formed during a later hydrothermal or heating event during the interval 407–393 Ma. Alternatively, the adularia may have formed at the same time as the ca. 428 Ma illite, but because of its lower closure temperature, was completely reset during subsequent hydrothermal fluid flow (>150°C) along the propagating vein. If this scenario is valid, then the 40Ar/39Ar data for the adularia-bearing assemblage provide a probable minimum age on the gold mineralization. Such a history of several or multiple pulses of hydrothermal fluid flow and gold mineralization is comparable to that recently presented for the orogenic Thor vein system at the Viking property in White Bay (Minett et al., 2012).

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Figure 6. Summary of geochronological constraints on gold mineralizing events in the Newfoundland Appalachians (adapted after Kerr and Selby, 2012). Data sources: 1) Kerr and van Breemen (2007); 2) Minnett et al. (2012); 3) Kerr and Selby (2012); 4) Ramezani et al. (2002); 5) Ricey et al. (1995); 6) Sangster et al. (2008); 7) McNicoll et al. (2006); 8) Sandeman et al. (2013); 9) this study.

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