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Overview of age constraints for gold mineralization in central and western Newfoundland and new 40Ar/39Ar ages for muscovite from selected auriferous zones

Survol des limites d'âge de la minéralisation aurifère dans le centre et l'ouest de Terre-Neuve et des nouvelles datations 40Ar/39Ar de la muscovite de certaines zones aurifères

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Article abstract

This contribution presents new 40Ar/39Ar laser step-heating data for muscovite associated with four significant orogenic gold-mineralized zones in central and western Newfoundland to build upon existing geochronological constraints for orogenic gold mineralization across much of the Newfoundland Appalachians. Additionally, we provide the first 40Ar/39Ar laser step-heating data for detrital muscovite from gold-mineralized sandstone of the Wigwam Formation (Botwood Group) at the Moosehead gold prospect. Most known gold zones on the isIand occur in proximity to reactivated crustal-scale faults and related structures, and are commonly localized within competent, rigid lithological units (e.g., granitoid rocks); although, some vein systems cut less competent, clastic sedimentary rock sequences. Host rocks range in age from Neoproterozoic to Devonian and may extend into the Carboniferous. Robust Pragian to Emsian (ca. 410–375 Ma) rutile, muscovite and zircon ages constrain the timing of gold mineralization in parts of the Exploits Subzone, whereas less precise age estimates for gold mineralization in the Notre Dame Subzone and Laurentian margin range from Wenlock to Emsian (ca. 433–375 Ma). Collectively, the geochronological data suggest that fluid-pressure cycling associated with gold mineralization in central and western Newfoundland occurred during progressive Siluro-Devonian tectonics associated with the waning stages of the Salinic orogenic cycle and spanning the Acadian and Neoacadian orogenic cycles. Multiple, polyphase, overlapping orogenic events allowed for repeated, gold mineralizing fluid flow events, particularly in proximity to long-lived, reactivated crustal-scale fault zones.

Overview of age constraints for gold mineralization in central and western Newfoundland and new $^{40}Ar/^{39}Ar$ ages for muscovite from selected auriferous zones

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ABSTRACT

This contribution presents new $^{40}Ar/^{39}Ar$ laser step-heating data for muscovite associated with four significant orogenic gold-mineralized zones in central and western Newfoundland to build upon existing geochronological constraints for orogenic gold mineralization across much of the Newfoundland Appalachians. Additionally, we provide the first $^{40}Ar/^{39}Ar$ laser step-heating data for detrital muscovite from gold-mineralized sandstone of the Wigwam Formation (Botwood Group) at the Moosehead gold prospect. Most known gold zones on the isIand occur in proximity to reactivated crustal-scale faults and related structures, and are commonly localized within competent, rigid lithological units (e.g., granitoid rocks); although, some vein systems cut less competent, clastic sedimentary rock sequences. Host rocks range in age from Neoproterozoic to Devonian and may extend into the Carboniferous. Robust Pragian to Emsian (ca. 410–375 Ma) rutile, muscovite and zircon ages constrain the timing of gold mineralization in parts of the Exploits Subzone, whereas less precise age estimates for gold mineralization in the Notre Dame Subzone and Laurentian margin range from Wenlock to Emsian (ca. 433–375 Ma). Collectively, the geochronological data suggest that fluid-pressure cycling associated with gold mineralization in central and western Newfoundland occurred during progressive Siluro-Devonian tectonics associated with the waning stages of the Salinic orogenic cycle and spanning the Acadian and Neoacadian orogenic cycles. Multiple, polyphase, overlapping orogenic events allowed for repeated, gold mineralizing fluid flow events, particularly in proximity to long-lived, reactivated crustal-scale fault zones.

RÉSUMÉ

La présente contribution fait état de nouvelles données obtenues par chauffage échelonné au laser $^{40}Ar/^{39}Ar$ de muscovite associée à quatre zones minéralisées aurifères orogéniques stratégiques dans le centre et l'ouest de Terre-Neuve permettant de mieux préciser les limites géochronologiques existantes de la minéralisation aurifère orogénique dans la majeure partie des Appalaches terre-neuviennes. Nous fournissons de plus les premières données par chauffage échelonné au laser $^{40}Ar/^{39}Ar$ de muscovite détritique provenant de grès minéralisé aurifère de la Formation de Wigwam (groupe de Botwood) dans la zone d'intérêt aurifère de Moosehead. La majorité des zones aurifères connues sur l'île se trouve à proximité de failles d'échelle crustale et de structures connexes, et elles se situent communément à l'intérieur d'unités lithologiques rigides parallèles (p. ex. des roches granitiques), bien que certains réseaux filoniens recoupent des séquences de roches sédimentaires clastiques moins parallèles. L'âge des roches hôtes varie du Néoprotérozoïque au Dévonien et peut s'étendre au Carbonifère. Des datations robustes du Praguien à l'Emsien (env. 410 à 375 Ma) de rutile, de muscovite et de zircon limitent le moment de la minéralisation de l'or dans des parties de la sous-zone Exploits, alors que des estimations moins précises de l'âge de la minéralisation aurifère dans la sous-zone Notre-Dame et de la marge laurentienne varient du Wenlock à l'Emsien (env. 433 à 375 Ma). Les données géochronologiques laissent collectivement supposer que les cycles de pression hydraulique associés à la minéralisation d'or dans le centre et l'ouest de Terre-Neuve se sont manifestés durant la progression tectonique siluro-dévonienne associée aux stades de ralentissement du cycle orogénique salinique et s'étendant aux cycles orogéniques acadien et néoacadien. Plusieurs phénomènes orogéniques polyphasés se chevauchant ont permis des écoulements de fluides minéralisateurs aurifères répétés, en particulier à proximité de zones de failles d'échelle crustale réactivées persistantes.

[*Traduit par la redaction*]

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INTRODUCTION

Prior to the late 1980s, the vast majority of gold produced in the Newfoundland Appalachians was derived as a by-product from auriferous volcanic massive sulphide deposits such as the Rambler, Ming and in particular, Buchans deposits of the central Newfoundland Dunnage Zone (see Piercey 2007; Galley *et al* 2007). Positive market conditions and the introduction of flow through shares stimulated an Island-wide gold exploration boom in the late 1980s that led to the discovery of many of the gold deposits that are past producers (Fig. 1) (e.g., Hope Brook Deposit, Big Ridge Resources; Hammerdown and Orion, Maritime Resources) and are currently in production (e.g., Stog'er Tight deposit, Anaconda Mining). In addition to these deposits, prospective gold deposits and occurrences seeing renewed exploration today include: (1) Valentine Lake Project, Marathon Gold Corporation; (2) Cape Ray Deposits, Matador Mining; (3) Appleton-JBP linears (now Queensway Project), New Found Gold; (4) Little River Prospects (now Golden Baie), Canstar Resources; and (5) Moosehead, Sokoman Minerals.

The geoscientific knowledge base related to gold mineralized zones in central and western Newfoundland is lean compared to other global gold producing districts. Early gold-related studies, subsequent to the explosion of exploration in the late 1980s, provided some of the first descriptive and comparative documentation of the gold occurrences on the Island (e.g., Tuach 1987; Tuach *et al* 1988; Evans 1991, 1993, 1999, 2004; Churchill *et al* 1993; Wilson and Evans 1994). Extant geochronological investigations on gold zones are limited to those from the Hope Brook (Dubé *et al* 1995) and Cape Ray deposits (Dubé *et al* 1996; Dubé and Lauzière 1997) and select geochronological studies at the Nugget Pond (Sangster *et al* 2008) and Hammerdown (Ritcey *et al* 1995) deposits. Subjects of more recent gold-related, paragenetic, lithogeochemical and geochronological studies include: the Rattling Brook (Kerr and van Breemen 2007) and Thor prospects (Minnett *et al* 2012) in western Newfoundland (White Bay); the Pine Cove (Ybarra 2020) and Ming (Au-rich VMS) deposits of Baie Verte Peninsula (Pilote *et al* 2020); and the central Newfoundland gold district (Valentine Lake deposit and Wilding Lake prospect; Honsberger *et al* 2022a).

Robust U–Pb geochronological constraints on gold mineralization are largely restricted to the Neoproterozoic (ca. 570–585 Ma) epithermal prospects of eastern Newfoundland (e.g., O'Brien *et al* 2001; Sparkes *et al* 2005; 2016; Sparkes and Dunning 2014), with fewer constraints on the timing of orogenic gold mineralization in central and western Newfoundland (e.g., ca. 374 Ma muscovite, Sandeman and Dunning 2016; ca. 410 Ma rutile, Honsberger *et al* 2022a). Kerr and Selby (2012) summarized many of the earlier geochronological data for gold mineralization, mostly on the Baie Verte Peninsula, and this contribution builds upon their compilation. We review existing age constraints on gold mineralization in the context of our new $^{40}Ar/^{39}Ar$ geochronological data for muscovite from four gold-mineralized zones across western and central Newfoundland and discuss the data with respect to Paleozoic orogenesis.

CRUSTAL-SCALE ARCHITECTURE OF NEWFOUNDLAND

Williams *et al* (1988) subdivided the Newfoundland Appalachians into four major pre-Silurian tectonic-stratigraphic domains including, from west to east, the Humber, Dunnage, (including the Notre Dame and Exploits subzones), Gander and Avalon zones. The Gander Zone was further divided into Meelpaeg, Mount Cormack and Gander Lake subzones. These zones broadly correspond to (also from west to east): the Laurentian margin (Humber); the Dashwoods terrane (extended Laurentian margin and Notre Dame Subzone); Ganderia (peri-Gondwana terranes including all Gander subzones and overthrust intraoceanic Exploits Subzone rocks); and Avalonia (e.g., van Staal *et al* 1996; van Staal and Barr 2012; Fig. 1). The Bras d'Or terrane of Cape Breton Island may extend to the Cinq-Cerf and Grey River areas in southern Newfoundland and its basement may underlie all the Exploits Subzone (Barr *et al* 2014).

The geographic/aerial extent of the Exploits Subzone and its boundaries in northeast-central Newfoundland is misrepresented on most extant compilation maps, particularly its interpreted southeastern termination at the former Gander River Ultrabasic Belt (GRUB Line), now known as the Gander River Complex (cf. O'Neill and Blackwood 1989). The Exploits Subzone includes Ordovician volcanic and sedimentary rocks of the Baie Du Nord Group that are structurally interleaved with Ganderian basement in the Meelpaeg Subzone (e.g., Valverde-Vaquero and van Staal 2002). The correlated Ordovician Baie D'Espoir and Davidsville groups in central Newfoundland stratigraphically overlie and are imbricated with Cambrian ophiolites and Gander zone basement (e.g., Blackwood and Green 1983; Colman-Sadd *et al* 1992). Moreover, brachiopod and trilobite-bearing strata of Late to Middle Ordovician (Darriwilian) age, comparable to other Exploits Subzone fauna, are exposed ~30 km east of the Gander River Complex at Indian Bay Big Pond (Fig. 1) in the Gander Lake Subzone (Wonderly and Neumann 1984). The latter are spatially accompanied by pillow basalt, siltstone, conglomerate, and minor gabbro along northeast-trending curvilinear magnetic highs that likely represent klippe of Exploits Subzone assemblages structurally above and interleaved with Ganderian margin sedimentary strata (Miller and Weir 1982; Wonderly and Neumann 1984; O'Neill and Colman-Sadd 1993). Exploits Subzone rocks occur sporadically across parts of the poorly exposed Gander Lake subzone and are likely tectonically intercalated with Gander Zone rocks. Emplacement of these klippe is constrained to Middle Ordovician (Colman-Sadd *et al* 1992; Sandeman and Dickson 2019); thus, the Exploits Subzone and Gander Zone were amalgamated by that time and were no longer independent terranes after the Middle

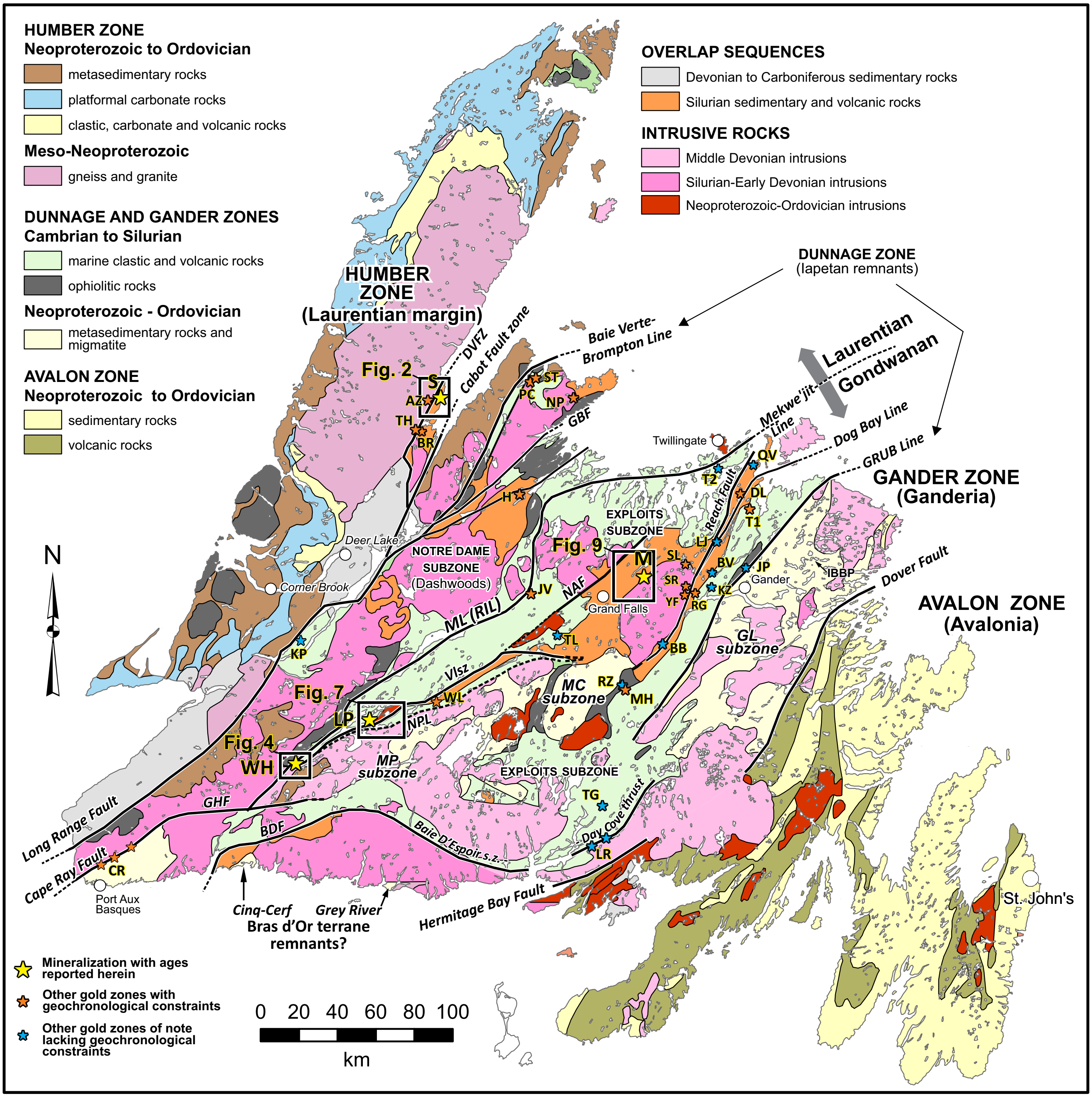


Figure 1. Simplified geological map of the Island of Newfoundland showing the major geological terranes, tectonic boundaries and faults (modified after Colman-Sadd *et al* 1990) and the locations of the gold mineralized zones discussed in this report. AZ–Apsy zone; BB–Beaverbrook; BR–Browning; BV–Big Vein; CR–Cape Ray; DL–Duder Lake; DVFZ–Doucers Valley Fault zone; GBF–Green Bay Fault; GHF–Gunflap Hills Fault; GL Subzone–Gander Lake Subzone; H–Hammerdown; IBBP–Indian Bay Big Pond; JP–Jonathons Pond; JV–Jaclyn Vein; KP–Kettle Pond; KZ–Keats Zone; LJ–Little Joanna; LP–Leprechaun Pond; LR–Little River; M–Moosehead; MC Subzone–Mount Cormack Subzone; MH–Mosquito Hill; MP Subzone–Meelpaeg Subzone; NAF–Northern Arm Fault; NP–Nugget Pond; NPL–Noel Paul's Line; PC–Pine Cove; QV–Quinlan Veins; RG–Road Gabbro; RZ–Reid Zone; S–Shrik; SL–The Slip; SR–Salmon River; ST–Stoger'tite; T1–Titan east; T2–Titan west; TG–True Grit; TH–Thor; TW–Twilite; VLsz–Victoria Lake shear zone; WH–Woods Lake and Hill Top; WL–Wilding Lake; YF–Yellow Fox.

Ordovician. Gander River Complex and other linear strongly magnetic anomalies in Gander Zone represent remnant overthrust Ordovician ophiolitic rocks, and Ordovician to Silurian cover rocks of Ganderia that were subsequently structurally modified during younger orogenic events.

The four major pre-Silurian terranes (Laurentian margin, Dashwoods terrane, composite Ganderian terranes, and Avalonia: van Staal and Barr 2014) are separated and transected by several major, long-lived polyphase fault zones. Progressing eastwards, the terrane-bounding fault zones include: the Baie Verte–Brompton Line separating the Laurentian margin from Dashwoods terrane; the Mekwe'jit Line (formerly Red Indian Line; RIL: see White and Waldron 2022) separating Dashwoods terrane from arcs and backarcs of the leading Ganderian margin; the Noel Paul's Line, Dog Bay Line, and Gander River Complex separating allochthonous blocks of composite Ganderia and; the Dover-Hermitage Bay Fault Zone separating Ganderia and Avalonia (e.g., Blackwood and Kennedy 1975; van Staal *et al* 2009; van Staal and Barr 2012; van Staal *et al* 2014, and references therein).

Despite the prevalence of terrane-bounding faults, orogenic gold mineralization in Newfoundland tends to be associated with crustal-scale fault zones that transect the pre-Silurian terranes. In the west, for example, the Silurian to Carboniferous Cabot–Doucers Valley fault system (Lock 1969; Tuach 1987) merges with the Baie Verte–Brompton Line (Fig. 1) to separate the Laurentian margin from Dashwoods terrane (Waldron and van Staal 2001). Furthermore, splays of the Baie Verte–Brompton Line must have been active post-Ordovician accretion to form Silurian vein-hosted gold mineralization (Dubé *et al* 1993; Poulsen *et al* 2000). In central Newfoundland, the approximately five-million-ounce gold deposit at Valentine Lake and numerous gold prospects along strike (e.g., Wilding Lake prospect) are hosted along an Early Devonian thrust-backthrust system (Honsberger *et al* 2022a) that imbricated rocks of the Exploits Subzone and Gander Zone and uplifted the Meelpaeg nappe along the Noel Paul's Line.

The new $^{40}Ar/^{39}Ar$ geochronology samples in the present study are from: (1) the White Bay area along the Doucer's Valley–Cabot Fault system of the Laurentian margin (Jacksons Arm, Shrik prospect); (2) the southwestern confluence of the Exploits and Meelpaeg subzones with Dashwoods terrane (Wood Lake South zone and Hill Top showing; Leprechaun Pond deposit, Valentine Lake); and (3) the northeastern Exploits Subzone of central Newfoundland (Moosehead prospect; Fig. 1). Existing geochronological constraints for additional auriferous zones are also illustrated in Figure 1.

AURIFEROUS ZONES INVESTIGATED WITH ^{40}AR/^{39}AR GEOCHRONOLOGY

Jacksons Arm trend (Shrik prospect)

The Jacksons Arm gold trend (Shrik, Boot n Hammer, and Stocker zones) occur ~ 4 km north of the community of Jacksons Arm on the Coney Head Peninsula in western White Bay (Fig. 1; Reid and Myllyaho 2012; Myllyaho 2013; English *et al* 2017). The showings occur in a curvilinear zone along the margin of the Ordovician Coney Head Complex (ca. 478 Ma; Dunning 1987; Fig. 2), an ophiolite-related tonalite and marginal basaltic and sedimentary units. The Coney Head Complex is unconformably overlain by syntectonic, clastic sedimentary and bimodal volcanic rocks of the orogenic gold-mineralized Silurian Sops Arm Group (e.g., Heyl 1937; Betz 1948; Kerr 2006a and b; Sandeman and Dunning 2016). The unconformity and the volcanic-sedimentary rocks of the Sops Arm Group are thrust imbricated with tonalite of the Coney Head Complex along broadly north-striking, east-dipping fault zones (this study; Magna Terra Minerals 2022). A sample of altered tonalite and adhering quartz vein (HS12-200C), weakly anomalous in Bi (3.9 ppm), As (24 ppm), Ag (0.1 ppm), and Au (4650 ppb), was collected from the Shrik trench where fine- to medium-grained, variably foliated, sericite-altered, pyritic and quartz-veined tonalite of the Coney Head Complex is exposed over a ~10 m × ~30 m area (Figs. 3a and b). The tonalite is locally cut by irregular, pinch and swell quartz veins with rare pyrite, but the relationships between deformation, veining, and gold mineralization remain unresolved. The tonalite wall rock contains quartz, sericitized plagioclase, mats of intergrown fine-grained muscovite and sparse pyrite and goethite (Fig. 3c).

Wood Lake South (Main) zone - Hill Top showing

The Wood Lake South (Main) gold zone and Hill Top showing occur in central-western Newfoundland near the confluence of the Exploits, Meelpaeg, and Notre Dame subzones (Figs 1 and 4). The Hill Top gold showing consists of two narrow (1–10 cm wide), southeast-northwest-trending, steeply dipping, pinch and swell pyrite + arsenopyrite-bearing quartz veins that cut Ordovician (ca. 467 Ma) Peter Strides monzogranite (e.g., van Egmond 2004; van Staal *et al* 2005a; Valverde-Vaquero *et al* 2006; Sandeman *et al* 2014; Sandeman 2014a) of the Meelpaeeg nappe and extend sporadically along strike for ~50 m. The quartz veins are hosted in an inferred northwest-trending mineralized fracture zone that cuts the monzogranite (Figs. 4 and 5). The host granite is strongly foliated, with a strong quartz mineral lineation, and is cut by translucent-white, foliated and lineated, barren quartz veins oriented sub-parallel to the foliation. The $^{40}Ar/^{39}Ar$ geochronology sample from Hill Top (HS10-59A) is a light grey to pink, fine- to medium-grained, quartz-veined, foliated and lineated monzogranite adjacent to the two quartz veins (Figs. 5a and 5b). In thin section, polyhedral and sutured quartz porphyroclasts (≤1.5 mm) are surrounded by fine-grained intergrown anhedral albite, quartz, and sericite (Fig. 5c). Rare euhedral monazite and subhedral rutile are intergrown with quartz and sericite in the groundmass (Fig. 5d).

Gold-mineralized quartz veins of the Wood Lake South (Main) zone are hosted by massive to brecciated and/or(?)

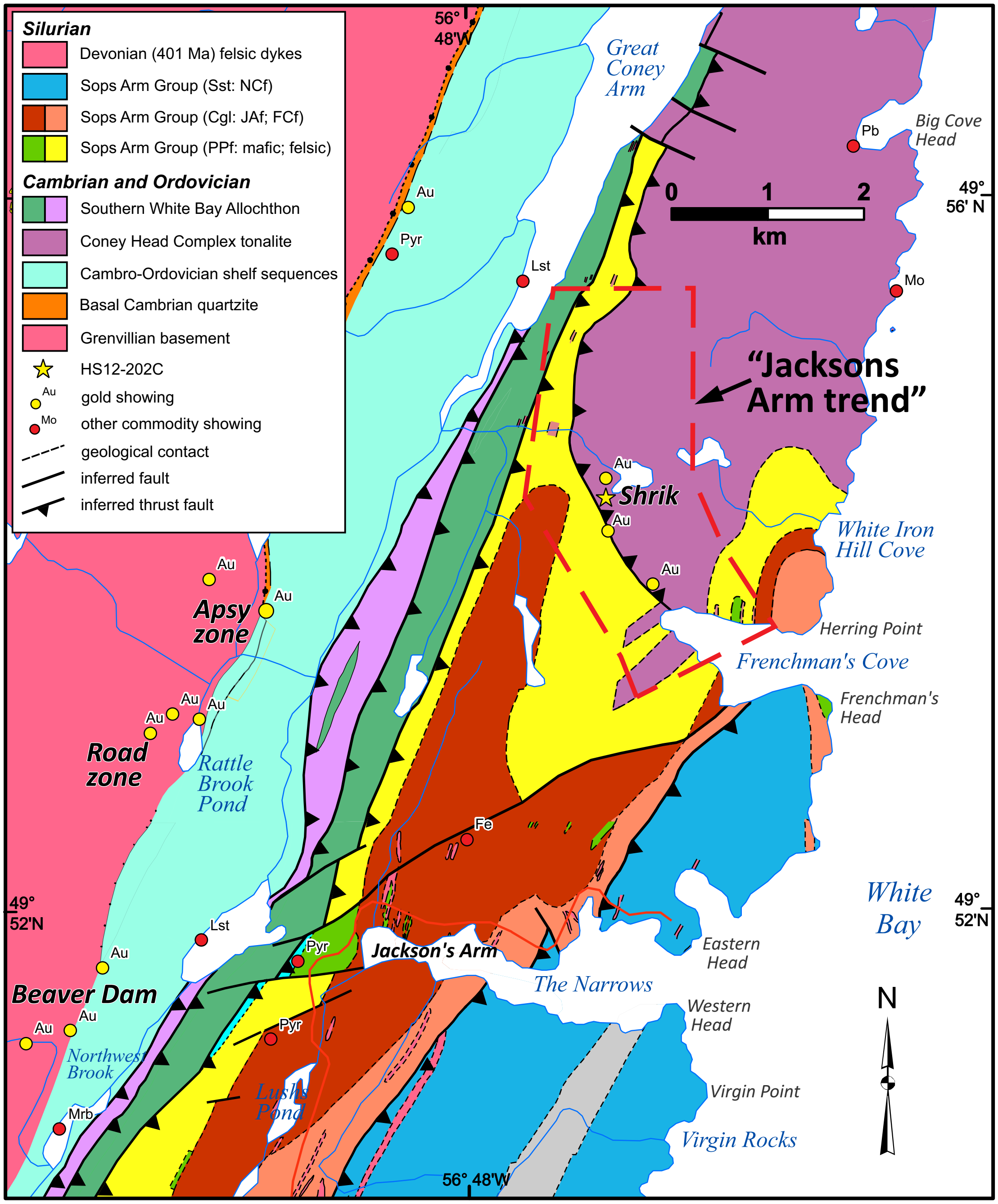


Figure 2. Simplified geology of part of the western White Bay area, northwestern Newfoundland (modified after Kerr 2006b; Sandeman and Dunning 2016), showing the approximate location of $^{40}Ar/^{39}Ar$ muscovite sample HS12-200C (yellow star), as well as the locations of precious- and base-metal showings of the region (Geoscience Atlas 2022)

mylonitic, orange-pink monzogranitic rocks of the Peter Strides Granite Suite. In the main trench (Fig. 6a), intensely deformed monzogranite is intruded by a less deformed, fine- to medium-grained, sericitic monzogranite. The less intensely deformed monzogranite is cut by an extensive array of steeply dipping irregular fractures and anastomosing, pinch and swell quartz veins (≤10 cm). Both the veins and fractures have minor pyrite + hematite ± arsenopyrite, accompanied by adjacent wall rock sericitization, albitization and silicification. Muscovite locally forms randomly oriented clumps and masses in the matrix of brecciated monzogranite, but occurs more typically as wispy platelets along fractures (Figs. 6b and 6c). Further details of the geology of the main trench and associated auriferous zones are provided by van Egmond and Cox (2005) and Sandeman *et al* (2014).

The $^{40}Ar/^{39}Ar$ geochronology sample (HS13-063A) from the Wood Lake South (Main) zone trench consists of an orange-pink, medium-grained, brecciated, and foliated monzogranite exposed below a strand of mylonitic monzogran-

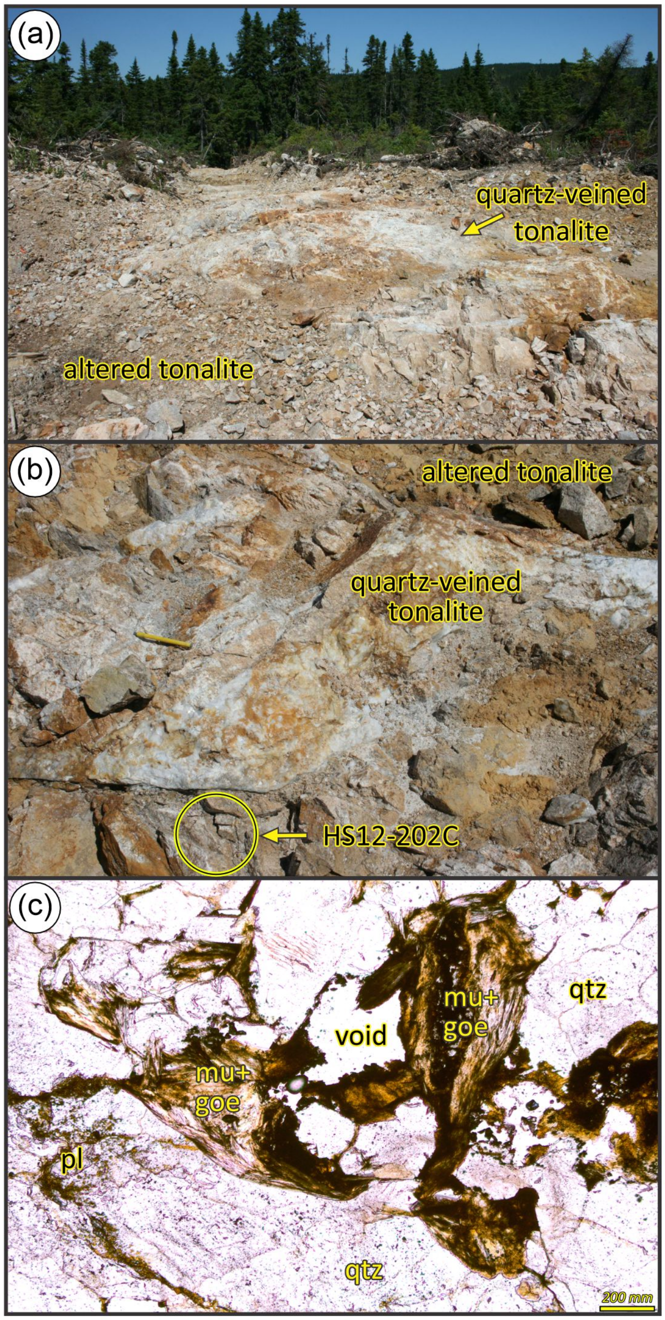


Figure 3. Photographs and photomicrographs of Shrik Showing sample HS12-200C. (a) Photograph of the Shrik discovery trench looking north with quartz-veined, altered tonalite in the centre, bounded to the north and south by sericite altered tonalite. The field of view is 10 m. (b) Close-up of the Shrik trench with quartz veined tonalite mantled by altered tonalite, and the location of sample HS12-200C. Field of view is 15 cm. (c) Photomicrograph in plane polarized light (PPL) showing the mineralogy of the altered tonalite and the random, mat-like nature of the muscovite in the sample. The brown tint of the muscovite is because of goethite staining. Mineral abbreviations after Whitney and Evans (2010).

ite (Figs. 4 and 6). In thin section, large (≤2 mm) polyhedral and sutured quartz grains are surrounded by fine-grained albite, sericite, and quartz. Subhedral pyrite and arsenopyrite are dispersed throughout and locally concentrated in vugs and fractures (Fig. 6b). Relatively large (≤1 mm), weakly to non-aligned muscovite grains are common (Figs. 6c and d).

Leprechaun Pond deposit (Valentine Lake)

The Leprechaun Pond deposit of the Valentine Lake gold property in central-western Newfoundland occurs within the Exploits Subzone near the boundary with the Meelpaeg Subzone (Figs. 1 and 7). The Neoproterozoic to Silurian rocks of the Valentine Lake area trend northeasterly and are bisected by the Victoria Lake shear zone (Valverde-Vaquero *et al* 2006; van Staal *et al* 2005b). This major northeast-trending, variably southeast-dipping, crustal-scale shear zone extends from the Gunflap Hills Fault in the southwest, through central Newfoundland along the northern margin of the Meelpaeg nappe (Figs. 1 and 7). The northeastern trace of the Victoria Lake shear zone is poorly constrained, and it may continue north-eastward to the Bay of Exploits, or alternatively, it may bifurcate and verge to the east along the northern margin of the Mount Cormack Subzone (Honsberger *et al* 2022a).

To the northwest, in the structural footwall of the Victoria Lake shear zone, Neoproterozoic (ca. 570 Ma) orogenic gold-mineralized basement granitoid rocks of the Valentine Lake Intrusive Suite (Evans and Kean 2002; Rogers and van Staal 2002; Rogers *et al* 2006), are uplifted and juxtaposed against the orogenic gold-mineralized Rogerson Lake Conglomerate (Kean and Jayasinge 1980) along the northwest-dipping Valentine Lake shear zone. The Valentine Lake shear zone hosts an approximately five-million-ounce orogenic gold resource, including the Leprechaun Pond deposit, where bleached and altered Neoproterozoic trondhjemite-tonalite and associated rocks contain a stacked array of fault-fill and extensional quartz-tourmaline-pyrite (QTP) vein sets (Lincoln *et al* 2018). The Rogerson Lake Conglomerate crops out southeast of the Valentine Lake shear zone, and is an aerially extensive latest Silurian, syntectonic, clastic sedimentary unit of central Newfoundland that delineates the southwest-northeast-trending fault system that is host to many of the gold occurrences in the central Newfoundland gold district (Honsberger *et al* 2022b; this volume).

At the Wilding Lake gold property, ~36 km northeast along strike of the Leprechaun Pond deposit, orogenic gold mineralization is hosted within both the Rogerson Lake Conglomerate and the associated ca. 422 Ma felsic subvolcanic and volcanic rocks in the footwall of the northeastern extension of the Valentine Lake shear zone (WL on Fig. 1; Honsberger *et al* 2019a; 2019b; 2020a; 2020b; 2022a). Overlapping ca. 410 Ma ID-TIMS U–Pb ages for hydrothermal rutile in quartz veins from both the Leprechaun Pond deposit and the Elm Prospect of the Wilding Lake property (Honsberger *et al* 2022a) indicate an Early Devonian (late

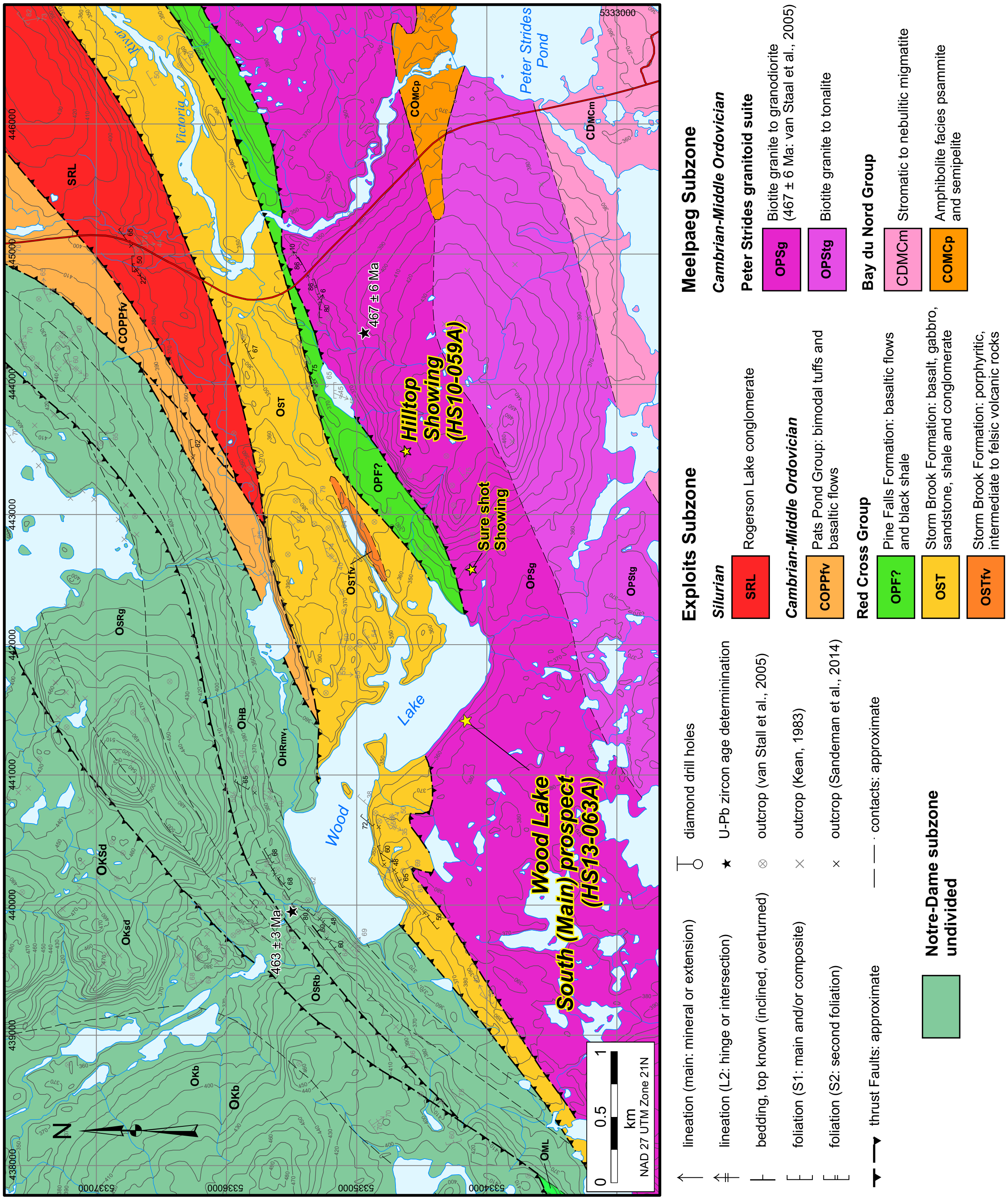


Figure 4. Simplified geology of the area around the Wood Lake South (Main) zone and Hill Top Showing in central western Newfoundland (modified after Sandeman *et al* 2014). Approximate locations of the $^{40}Ar/^{39}Ar$ muscovite samples HS13-063A (Woods Lake South) and HS10-059A (Hill Top Showing) are shown as well as the locations of precious- and base-metal showings (Geoscience Atlas 2022).

Lochkovian) age for quartz vein emplacement associated with orogenic gold mineralization.

The $^{40}Ar/^{39}Ar$ geochronology sample from the Leprechaun Pond deposit, VL-24-62.1m, is a weakly auriferous, bleached, fine-grained, foliated and quartz-veined tourmaline-muscovite-bearing trondhjemite from drillcore (62.1–63.0 metres depth: Figs. 8a, b, c). Large (≤6 mm) polyhedral sutured quartz grains and extensively altered plagioclase are surrounded by fine-grained albite, sericite and quartz. Subhedral pyrite is dispersed throughout the rock but concentrated near the margins of quartz veins (Fig. 8c). Tourmaline occurs as needles in or along vein margins. Relatively large (≤0.6 mm) muscovite grains are common and occur as plates in the groundmass and in primary feldspar grains

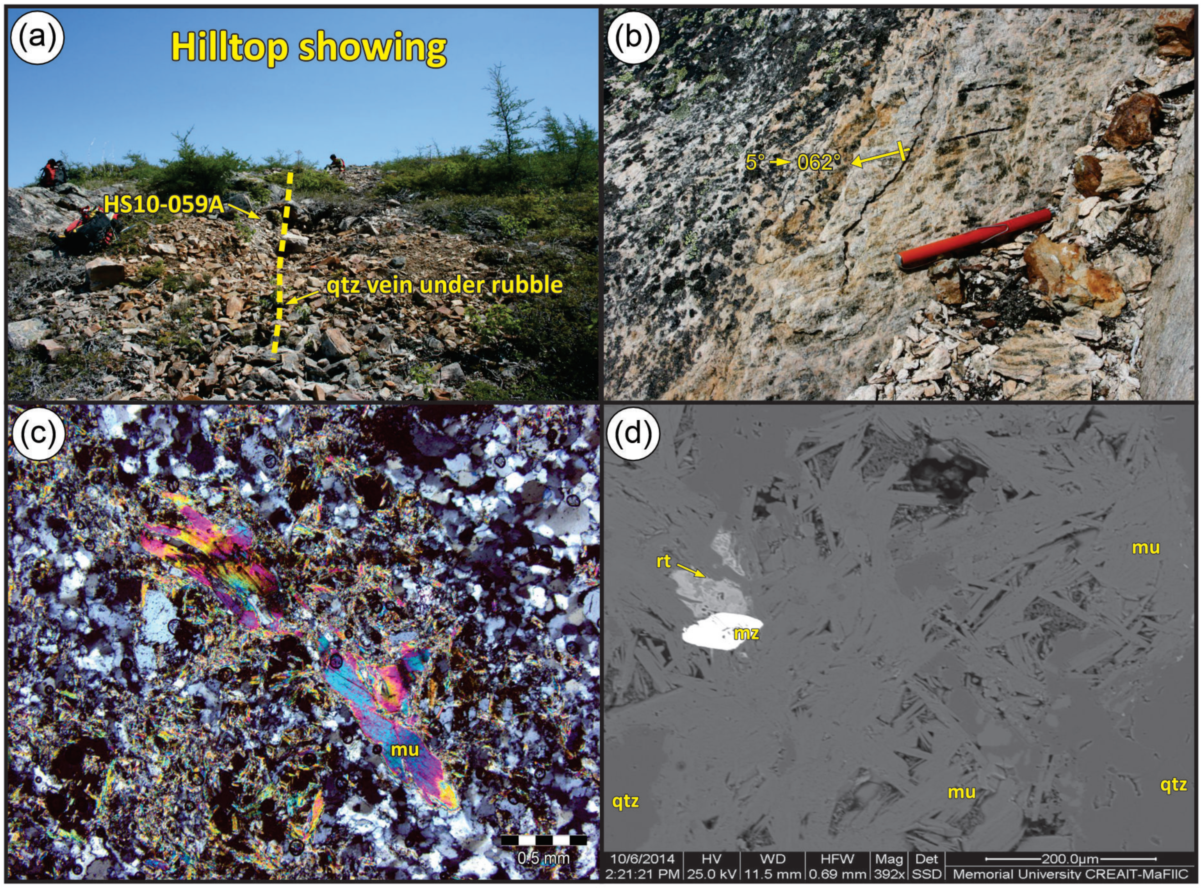


Figure 5. Photographs and photomicrographs of Hill Top Showing sample HS10-059A. (a) Photograph viewed southeast at the narrow Hill Top veins. Note person in background. (b) Photograph of a foliation surface on the wall rock adjacent to the Hill Top vein, illustrating the strong L-fabric in the Peter Strides monzogranite defined by aligned quartz and muscovite. (c) Photomicrograph in crossed polars of the monzogranite wall rock illustrating the disseminated subhedral pyrite, the altered sericitic groundmass and the large, secondary muscovite grains. (d) Backscattered electron image illustrating the minerals and their detailed relationships. Note the subhedral rutile and euhedral monazite, targets for future geochronology.

(Fig. 8c); a 250–450 μm fraction was extracted for $^{40}Ar/^{39}Ar$ geochronology.

Moosehead prospect (North Pond trench; TRMH15-3)

The Moosehead Prospect occurs southeast of the town of Bishops Falls in north-central Newfoundland (Figs. 1 and 9; Morgan 2016; Froude 2019, 2021). It lies within the latest Silurian–Early Devonian, intraorogenic Botwood Basin, ~4 km west of the ca. 425–418 Ma Mount Peyton Intrusive Suite (Sandeman *et al* 2017) in the north-central Exploits Subzone (Figs. 1 and 9). Mineralization consists of extensional, auriferous, sulphide-sulfosalt-bearing quartz veins and breccias that cut mainly muscovite-bearing sandstone and siltstone of the Wigwam Formation of the Botwood Group (i.e., Botwood basin; Williams 1969; Dickson *et al* 2000; O'Brien 2003; Morgan 2016). Mafic volcanic rocks of the lower Botwood Group (Laurenceton Formation) occur immediately south and southeast of the prospect. Gabbroic and fine-grained mafic dykes locally cut the sedimentary rocks and are themselves locally bleached, silicified and carbonate + pyrite ± sericite altered (e.g., Clark 1999; Morgan 2016). Trenching uncovered medium-bedded muscovite-bearing sandstone, southwest-dipping in the north, and south-dipping in the south, with weakly sulphidic, highly disrupted, quartz-veined, sandstone-quartz breccia in between (Figs. 9a, b and 10). The sandstone is variably mineralized, and quartz veins are more abundant in the northern part of the trench. Mineralization occurs in the hanging wall of a discrete east-west fault zone (Figs. 9b and 10). Bedding and crosscutting quartz veins are deflected into the fault zone, consistent with dextral rotation and reverse(?) slip. Further description and assay information for the Moosehead prospect are presented in Morgan (2016).

The $^{40}Ar/^{39}Ar$ geochronology sample from the Moosehead trench is a beige-grey, medium-grained, medium-bedded, quartz-veined muscovite-bearing sandstone of the Wigwam Formation from immediately north of the east-west fault near the centre of the trench (Figs. 9b and 10a). In thin section, large (≤0.4 mm) quartz and muscovite grains are surrounded by fine-grained matrix of albite, sericite, and quartz with subhedral pyrite dispersed throughout (Fig. 10b).

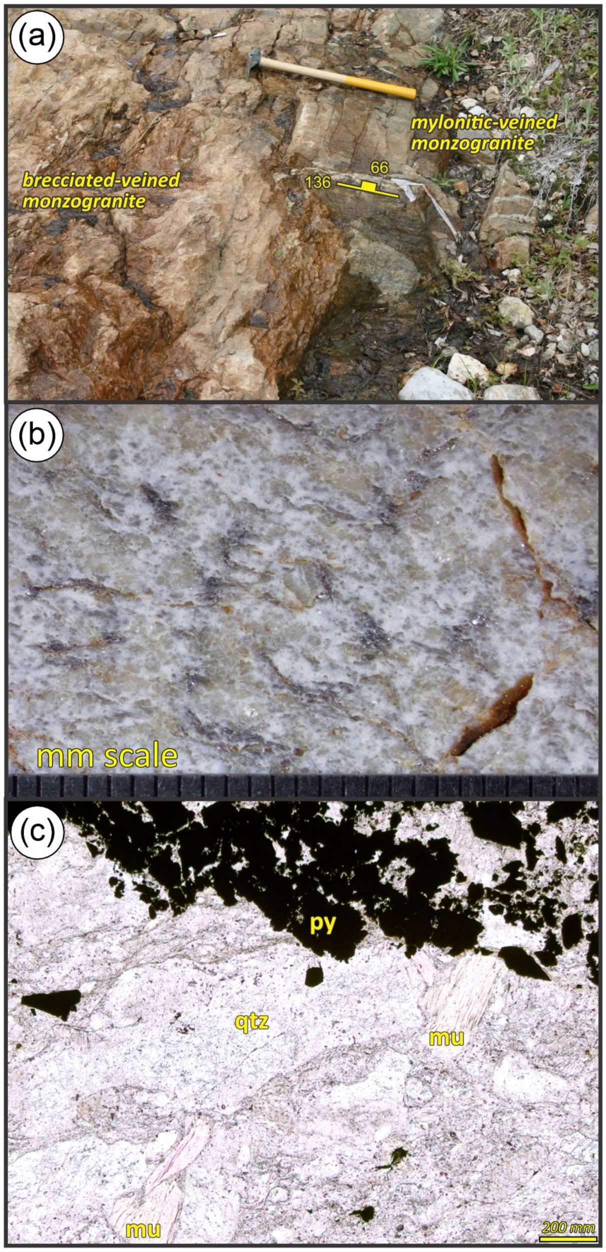


Figure 6. Photographs and photomicrographs of Wood Lake South Main zone sample HS13-063A. (a) Photograph from the main trench with massive and brecciated, quartz-veined and sericite + pyrite ± arsenopyrite mineralized monzogranite cutting mylonitic monzogranite having fabric-parallel, sulphide-poor, internally deformed quartz veins. The location of sample HS13-063A is shown and the Geotul is 54 cm in length. Mylonitic fabric trends 136° and dips 66° to the southwest. (b) Cut slab photograph of sample HS13-063A. White is altered feldspar, grey is quartz and reflective silver grains are muscovite. (c) Photomicrograph in PPL of the brecciated altered monzogranite illustrating the disseminated subhedral pyrite, the altered sericite groundmass and the large, secondary muscovite grains.

Relatively large (≤1 mm), bedding-parallel muscovite grains are common, and appear to be detrital in origin (Fig. 10c).

^{40}Ar/^{39}Ar GEOCHRONOLOGY

Methods

Geochronology samples were collected during 2010–2015 from selected gold-mineralized zones and drill core across central and western Newfoundland (e.g., Sandeman *et al* 2013; Sandeman 2014b; Sandeman and Dunning 2016). Kilogram-sized hand samples or ~ 40 cm long pieces of split drill core were cut and cleaned of all weathered surfaces and crushed to ~ 1 cm chips. About 100 grams of each sample was gently hand pulverised with pestle and mortar and sieved to two size fractions, 250–420 µm and 180–250 µm. The grain separates were washed repetitively in deionized water and the solute drained. Cleaned and dried samples were then gently cleaned in dilute (~0.5N) HNO_3 to remove adhering sulphides and carbonates from the grain separates. The cleaned separates were re-sieved and muscovite was hand-picked under a binocular microscope for laser step-heating analyses. Muscovite from the Shrik Showing (HS12-200C) was of poor quality, fine-grained, and only a single muscovite–rich (180–250 µm) grain separate was extracted.

The ^{40}Ar/^{39}Ar age data were obtained in the ^{40}Ar/^{39}Ar Thermochronology Laboratory at Queen's University. Mineral separates and flux-monitors (standards) are wrapped in Al-foil, stacked sequentially into an 8.5-cm-long and 2.0-cm-diameter Al irradiation capsule, and then irradiated with fast neutrons in position 8D of the McMaster Nuclear Reactor (Hamilton, Ontario) for a duration of 72 h (at 3 MWH). Packets of flux monitors are located at ~0.5 cm intervals along the irradiation container and the J-value for an individual sample is determined by least-squares, second-order polynomial interpolation using replicate analyses of splits for each monitor position in the capsule. The samples are loaded into flat-bottomed pits in a copper sample-holder and placed beneath the ZnS view-port of a small, bakeable, stainless-steel chamber connected to an ultra-high vacuum purification system. Following bake out at 100°C, a 30 watt New Wave Research MIR 10-30 CO_2 laser with a faceted lens is used to heat samples for ~3 minutes at increasing percent power settings (2 to 45%; beam diameter 3 mm). After purification using hot and cold SAESC50 getters (for ~5 minutes), the evolved gas is admitted to an MAP 216 mass spectrometer, with a Bäur Signer source and an analog electron multiplier (set to a gain of 100 over the Faraday detector). Measured argon-isotope peak heights are extrapolated to zero-time and corrected for discrimination using a ^{40}Ar/^{36}Ar atmospheric ratio of 295.5 and measured ratios of atmospheric argon. Blanks, measured routinely, are subtracted from the subsequent sample gas-fractions. The extraction blanks are typically <10 x 10–13, <0.5 x 10–13, <0.5 x 10–13, and <0.5 x 10–13 cm-3 STP for masses 40,

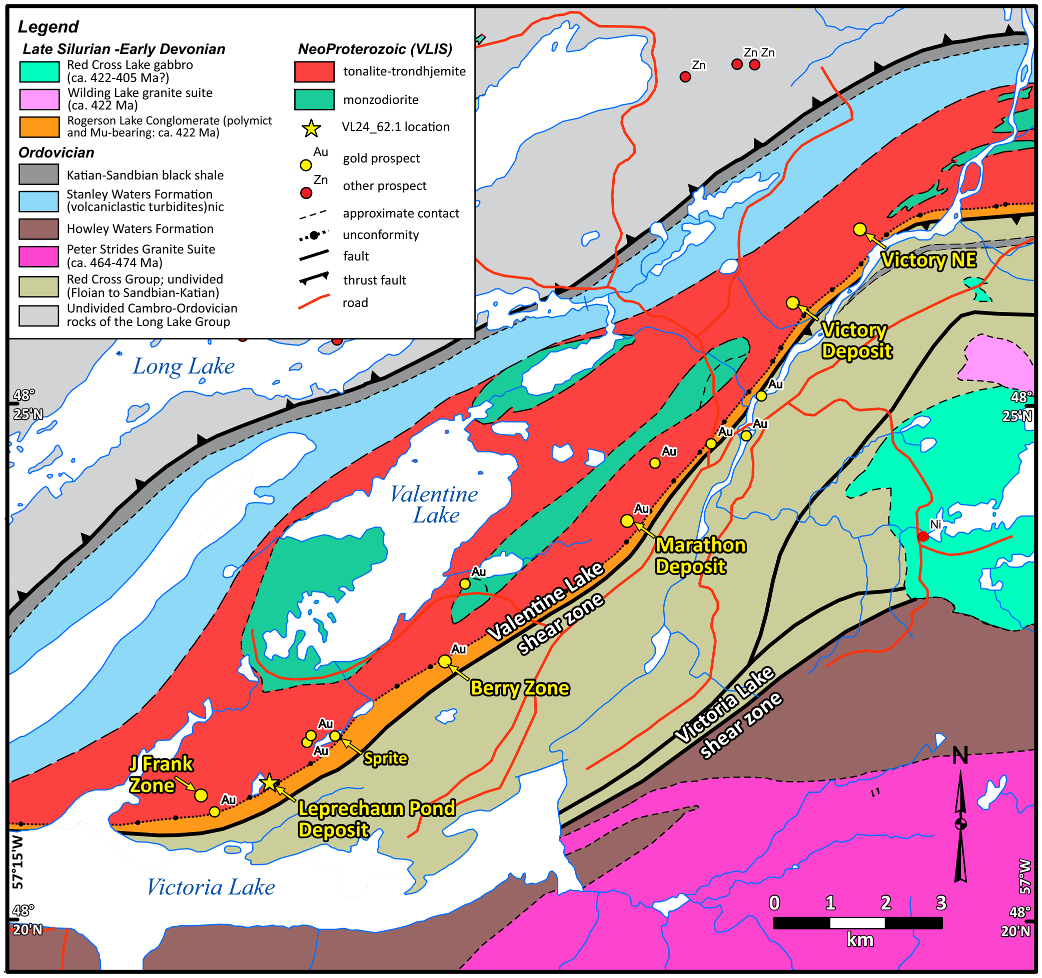


Figure 7. Simplified geology of the area around the Leprechaun Deposit (modified after van Staal *et al* 2005b) showing the approximate locations of the $^{40}Ar/^{39}Ar$ muscovite sample and the recently dated CA-TIMS U–Pb titanite sample (VL335-245; Honsberger *et al* 2022) at the Leprechaun Pond deposit. The locations of precious- and base-metal showings are from the Geoscience Atlas (2022).

39, 37, and 36, respectively. The ^{39}Ar and ^{37}Ar are corrected for radioactive decay during and after irradiation. Corrections are made for neutron-induced ^{40}Ar from potassium, ^{39}Ar and ^{36}Ar from calcium, and ^{36}Ar from chlorine (Roddick 1983; Onstott *et al* 1991). Dates and errors are calculated using the procedure of Dalrymple *et al* (1981) and the constants of Steiger and Jäger (1977). Plateau and inverse isotope correlation dates are calculated using ISOPLOT v. 3.60 (Ludwig 2012). A plateau is herein defined as 3 or more contiguous steps containing >50% of the ^{39}Ar released, with a probability of fit >0.01 and MSWD <2. Errors shown in Supplementary data Table S1 and in Figure 11 represent the analytical precision at 2σ, assuming that the errors in the ages of the flux monitors are zero. This is suitable for comparing within-spectrum variation and determining which steps form a plateau (e.g., McDougall and Harrison 1988, page 89). The dates and J-values are referenced to GA-1550biotite (98.5 Ma; Spell and McDougall 2003) and Hb-3Grhornblende (PP-20; 1073.6 Ma; Jourdan *et al* 2006). The complete $^{40}Ar/^{39}Ar$ dataset is in Supplementary data Table S1, whereas the laser step-heating results are illustrated in Figure 11. Sample coordinates are NAD27 datum, zone 21.

Results

Shrik Showing (HS12-200C: UTM Zone 21, 516037 E, 5527889 N: muscovite)

Altered tonalite wall rock from this sample was crushed, sieved, cleaned, and small (≤0.5 mm), weakly to non-aligned, goethite-dusted muscovite grains were concentrated into a 180–250 µm grain separate for $^{40}Ar/^{39}Ar$ dating. The muscovite separate yielded a complex age spectrum (Fig. 11a). The initial low-T (power) step (1.43% of ^{39}Ar released) yielded an anomalously young age (ca. 336 Ma) but the next 6 steps (30.3% of ^{39}Ar released) yielded anomalously old ages ranging from ca. 390 to 428 Ma and are attributed to the incorporation of excess argon. The higher temperature (power) steps, excluding the final young gas fraction, form a relatively flat segment representing 58.9 % of the ^{39}Ar%

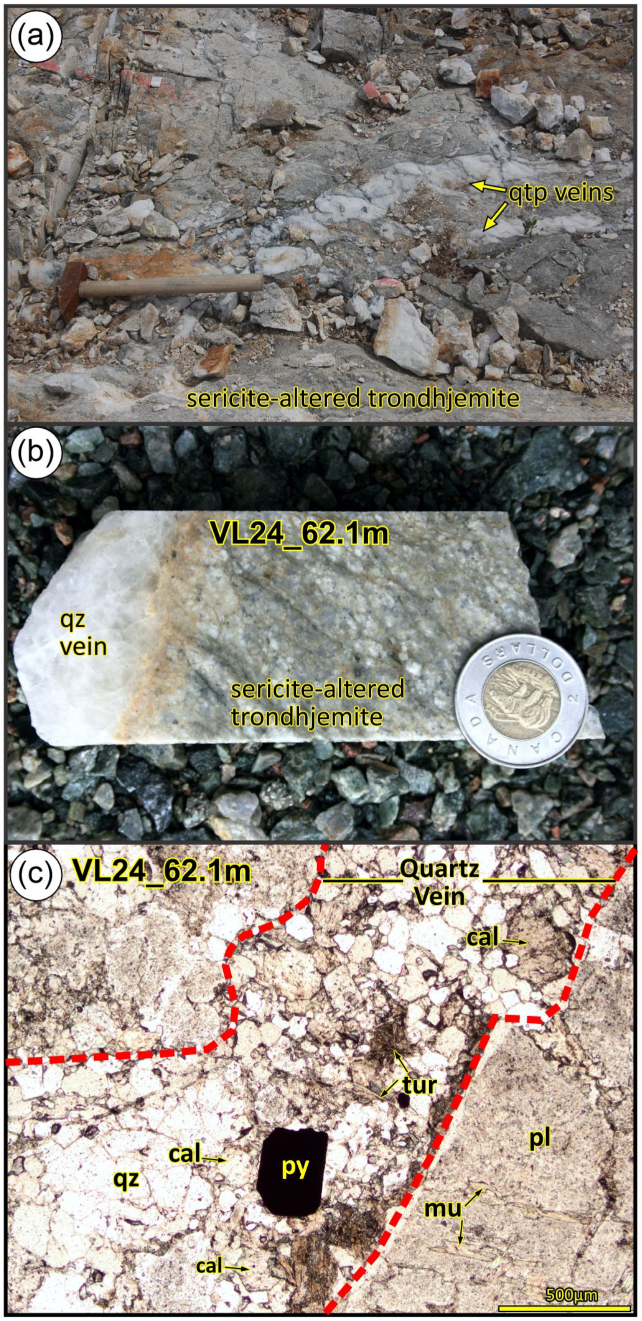


Figure 8. Photographs and photomicrograph of Leprechaun Pond deposit. (a) Photograph from the main trench to the northwest of Leprechaun Pond illustrating the sericite-altered trondhjemite-tonalite of the Valentine Lake Intrusive Suite cut by quartz-tourmaline-pyrite veins. (b) Cut core photograph of quartz-tourmaline vein cutting bleached trondhjemite (DDH VL-24-62.1m). (c) Photomicrograph in PPL of a quartz-tourmaline vein containing pyrite, calcite and muscovite cutting altered trondhjemite host rock composed of saussuritized plagioclase and quartz. Muscovite forms coarse plates along fractures in plagioclase and in vein margins.

released and yield an age of 379.7 ± 1.4 Ma (2σ; POF = 0.36; MSWD = 1.10). The volume of ^{39}Ar released is slightly less than the suggested convention of >60% volume for a plateau age (McDougall and Harrison 1988; Ludwig 2012; Schaen *et al* 2021), but the quasi-plateau appears to have geological significance.

Hill Top Showing (HS10-59A: UTM Zone 21, 443526 E, 5334700 N: muscovite)

Analyses of relatively large (250–425 μm) muscovite grains yielded a relatively simple ^{40}Ar/^{39}Ar age spectrum (Fig. 11b). The nine higher temperature (power) steps formed a relatively flat segment representing 91.4% of the ^{39}Ar released and gave a plateau age of 409.1 ± 1.3 Ma (2σ; POF = 0.77; MSWD = 0.42).

Wood Lake South (Main) zone (HS13-063A: UTM Zone 21, 500450 E, 5504824 N: muscovite)

Two fractions (250–425 μm and 180–250 μm) of muscovite were extracted for ^{40}Ar/^{39}Ar analysis. The nine highest (out of 15) temperature (power) steps of the 250–425 μm fraction, representing 91.4 % of the ^{39}Ar released gives a plateau age of 403.1 ± 1.2 Ma (2σ; POF = 0.91; MSWD = 0.42; Fig. 11c). The second 180–250 μm aliquot (Fig. 11d) yielded a quasi-plateau age of 398.4 ± 1.3 Ma, representing 56.9% of the ^{39}Ar released (2σ; MSWD = 0.74; POF = 0.65), due largely to an unfortunately large-volume last step. The plateau age of 403.1 ± 1.2 Ma is considered the best estimate of the age of the muscovite.

Leprechaun Pond Deposit (Valentine Lake: VL-24_62.1m: UTM Zone 21, 486400 E, 5355880 N: muscovite)

The muscovite at the Leprechaun Pond deposit yielded a somewhat jagged age spectrum (Fig. 11e), but five of the steps formed a flat segment, comprising 59.9% of the ^{39}Ar released, and yielded a quasi-plateau age of 384.2 ± 1.6 Ma (2σ; POF = 0.57; MSWD = 0.74) and is interpreted as the best estimate of the age of the muscovite.

Moosehead Prospect (HS15-137; 613561E, 5428182N: muscovite)

Two muscovite fractions (250–425 μm and 180–250 μm) were extracted for ^{40}Ar/^{39}Ar geochronology and yielded two similar age spectra (Figs. 11f, g). The coarse-grained (250–425 μm) aliquot yielded a well-defined ^{40}Ar/^{39}Ar plateau age of 457.3 ± 1.2 Ma (2σ; POF = 0.94; MSWD = 0.44), representing 91.4% of the ^{39}Ar released (Fig. 11f). The 180–250 μm grain-size fraction (Fig. 11g), similarly yielded a well-defined ^{40}Ar/^{39}Ar plateau age of 453.5 ± 1.1 Ma (2σ; POF = 0.48; MSWD = 0.97), representing 97.0% of the ^{39}Ar released. The older age of 457.3 ± 1.2 Ma for the coarser-grained 250–450 μm fraction is interpreted as the best estimate of the ^{40}Ar/^{39}Ar age of the muscovite.

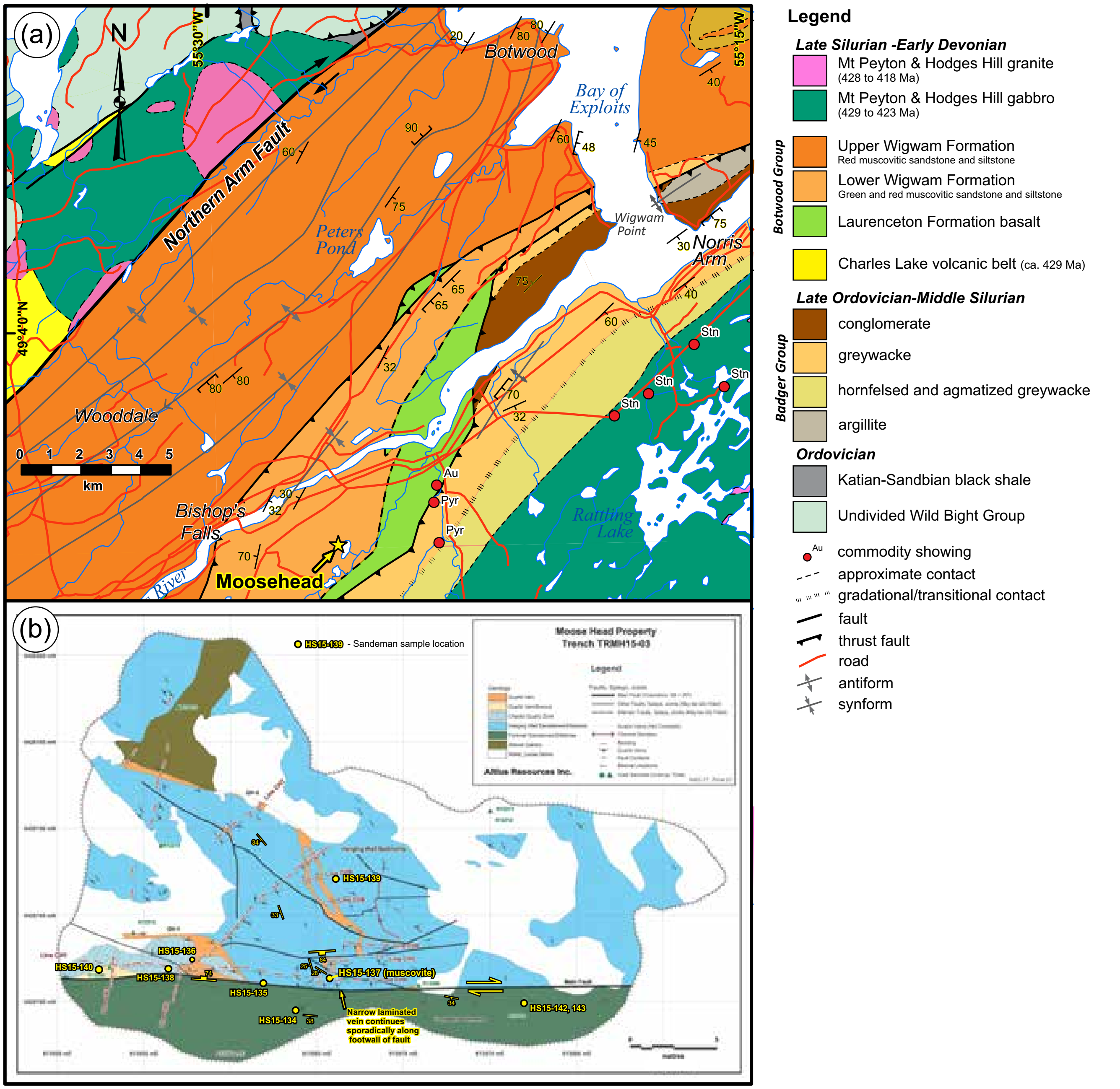


Figure 9. **(a) Simplified geology of the northeastern Botwood Basin and the location of the Moosehead Prospect and other local mineral occurrences (modified after the Geoscience Atlas (2022). (b) Geological map of trench TRMH15-3 at the Moosehead Prospect with the locations of the $^{40}Ar/^{39}Ar$ muscovite sample, other lithogeochemical samples and the location of DDH MH-02-15 (see Morgan 2016).**

DISCUSSION

Integration of these new $^{40}Ar/^{39}Ar$ geochronological data with existing regional geochronological constraints on gold mineralized zones and magmatic events elucidates deformational, metamorphic, and tectonic intervals that were favourable for gold-mineralization across Newfoundland (Fig. 12). The collective compiled data are diverse as they include age constraints determined via different radiometric methods on various phases/mineral species: some of which are more robust than others. These include studies applying $^{40}Ar/^{39}Ar$ cooling ages on dynamo-metamorphism and mineralization-associated potassic alteration; Re–Os ages on sulphide minerals; implied maximum ages based on U–Pb ages of host rocks and direct U–Pb CA-TIMS dating of the minerals coeval with quartz vein emplacement. For example, the interpreted age of the Hammerdown gold deposit (Springdale Peninsula) comes from U–Pb (zircon) thermal ionization mass spectrometry (TIMS), which yielded an age of 437 ± 4 Ma for a felsic dyke cut by an auriferous vein

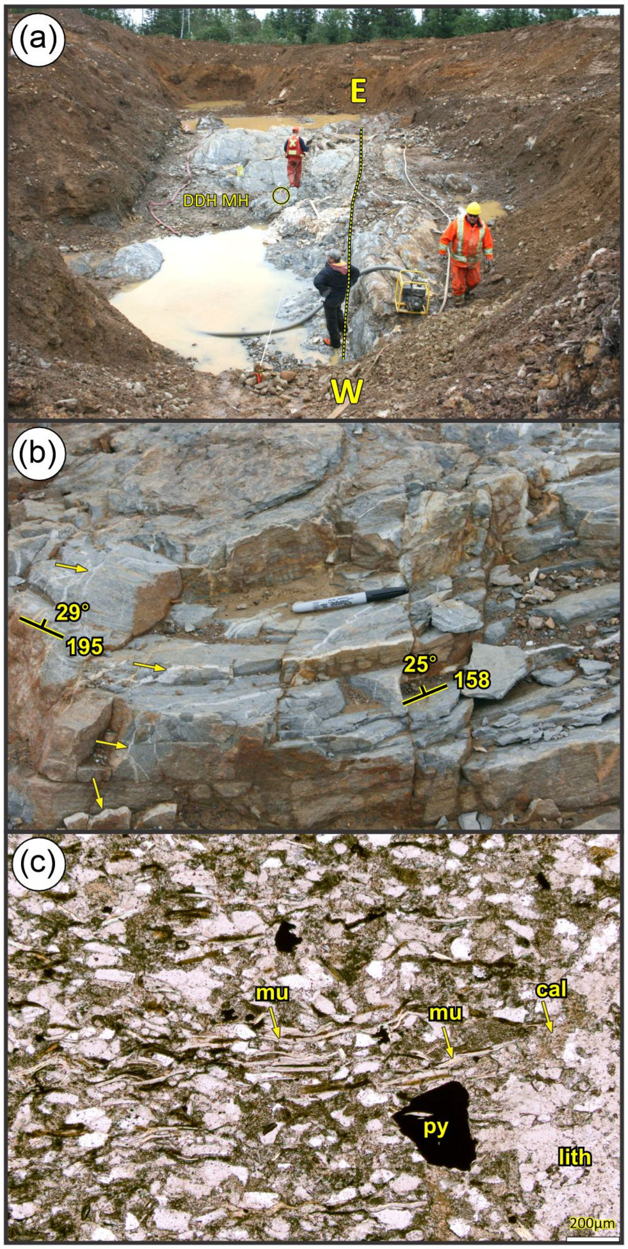


Figure 10. Photographs and photomicrographs of the Moosehead Prospect trench. (a) Photograph looking north from the east-west fault with decimetre-scale bedded muscovitic sandstone cut by an array of narrow, weakly sulphidic quartz veins. These veins largely trend northwest-southeast and are rotated into an east-west orientation near the main fault, indicating this is a dextral fault. (b) Close up of the warped bedding and crosscutting quartz veins at sample location HS15-137. Note the folding of bedding and the small yellow arrows pointing to quartz veins. (c) Photomicrograph in PPL of the sandstone showing disseminated subhedral pyrite, carbonate-sericite-altered groundmass and large, bedding-parallel muscovite grains.

(Ritcey *et al* 1995). This is therefore a maximum age constraint for gold mineralization. In contrast, the ca. 410 Ma chemical abrasion (CA) TIMS ages for rutile from auriferous quartz veins at the Wilding Lake gold prospect and Leprechaun Pond gold deposit (Honsberger *et al* 2022a) provide high-precision maximum constraints on the age of orogenic gold-mineralized quartz vein emplacement. Detailed investigations of vein and alteration mineral parageneses, their relationships to gold deposition and systematic geochronological study of different mineral species are required to better understand the timing of gold mineralization in Newfoundland.

The collective geochronological data outline two distinct, broad age-ranges for orogenic-style gold mineralization in the central and western Newfoundland Appalachians (Fig. 12). These include an older, Wenlock (middle Silurian) to Lochkovian (Lower Devonian) ca. 440 to ca. 405 Ma event, and a younger, Middle Devonian event at ca. 400–375 Ma. The former includes muscovite growth/resetting intervals for gold-bearing zones of the Laurentian margin, Dashwoods terrane, western Exploits subzone and along the Meelpaeg–Exploits subzones boundary; the latter includes muscovite from gold-bearing zones across the Laurentian Margin, Dashwoods terrane, Exploits Subzone, and Gander Zone (Fig. 12).

The muscovite from the Shrik showing occurs in an Ordovician, intraoceanic arc-related tonalite that has a strongly metaluminous composition (Sandeman, unpublished data 2022). The muscovite is spatially associated with quartz veining and bleaching of the tonalite resulting from hydrothermal fluid flow; therefore, it formed as a result of metasomatism, opposed to by igneous or dynamothermal metamorphic processes. Accordingly, the $^{40}Ar/^{39}Ar$ geochronological result of 379.7 ± 1.4 Ma is interpreted as a maximum age constraint for gold mineralization.

The host rocks of the Hill Top and Woods Lake South zones are muscovite-biotite-bearing, strongly peraluminous granitoid rocks of the Ordovician Peter Strides suite (part of the Meelpaeg Subzone) that comprise the hanging wall of the Victoria Lake-Valentine Lake fault system. The northern portion of the Meelpaeg Subzone records metamorphic U–Pb monazite and titanite ages and $^{40}Ar/^{39}Ar$ hornblende, muscovite and biotite cooling ages that range from ca. 418 to 400 Ma (Valverde-Vaquero *et al* 2003). Muscovite from the Hill Top (409.1 ± 1.3 Ma) and Woods Lake zones (403.1 ± 1.2 Ma) therefore likely represent Acadian metamorphic cooling temperatures in the immediate hanging wall of the Victoria Lake Shear Zone, which represent best approximations of maximum ages of gold mineralization.

Metaluminous tonalite and trondhjemite of the Valentine Lake Intrusive Suite host the Leprechaun Pond gold deposit. These rocks do not contain primary muscovite and the white mica is hydrothermal in origin. However, the relationship between the muscovite and deformation of the auriferous quartz-tourmaline-pyrite veins is ambiguous. The hydrothermal rutile age of ca. 410 Ma (see Honsberger *et al* 2022a) is significantly older than the muscovite plateau age of 384.2 ± 1.6 Ma (this study), suggesting either a single protracted alteration and mineralization event, or multiple discrete events.

In contrast to the other dated samples, muscovite from the sandstone of the Moosehead prospect (ca. 457.3 ± 1.2 Ma and 453.5 ± 1.1 Ma) is detrital in origin and oriented parallel to bedding. Therefore, these ages represent metamorphic cooling ages for the metasedimentary or granitoid sources for the sandstone. One proximal potential Ordovician (Darriwillian: Cohen *et al* 2013) source terrane for the detrital muscovite is the Mount Cormack Complex (Gander Zone) of central Newfoundland (Fig. 1; Williams *et al* 1988; Colman-Sadd *et al* 1992). The Mount Cormack Complex preserves a central core of foliated, upper amphibolite-grade migmatitic psammite and pelite that were metamorphosed and intruded by garnet-muscovite syenogranite (Through Hills granite) at ca. 465–464 Ma (Colman-Sadd *et al* 1992; Valverde-Vaquero *et al* 2006). Metamorphic ages from the complex include: a monazite age of 462 ± 1 Ma; a titanite age of 460 ± 3 Ma; a $^{40}Ar/^{39}Ar$ hornblende plateau age of 465.7 ± 6.4 Ma; and a $^{40}Ar/^{39}Ar$ biotite plateau age of 439.4 ±2.4 Ma (Valverde-Vaquero *et al* 2003, 2006). The hornblende and biotite ages bracket the interval defined by the Moosehead trench muscovite ages and support the suggestion of the Mount Cormack Complex as a possible detrital muscovite source. Muscovite from the Meelpaeg nappe yield younger, Devonian regional metamorphic cooling ages ranging from ca. 418 to 394 Ma (Valverde-Vaquero *et al* 2003), similar to those obtained in the Gander Lake Subzone (ca. 404 to 388 Ma: O'Neill and Lux 1989; O'Neill and Colman-Sadd 1993). The apparent absence of older, Ordovician muscovite in these areas does not entirely preclude them as possible sources, however, this appears to be the case. To the west of the Botwood Basin, an alternative Ordovician, muscovite-bearing source might be represented by the muscovite-biotite-psammite of the reworked Laurentian margin (e.g., Fleur de Lys Supergroup, Baie Verte Peninsula).

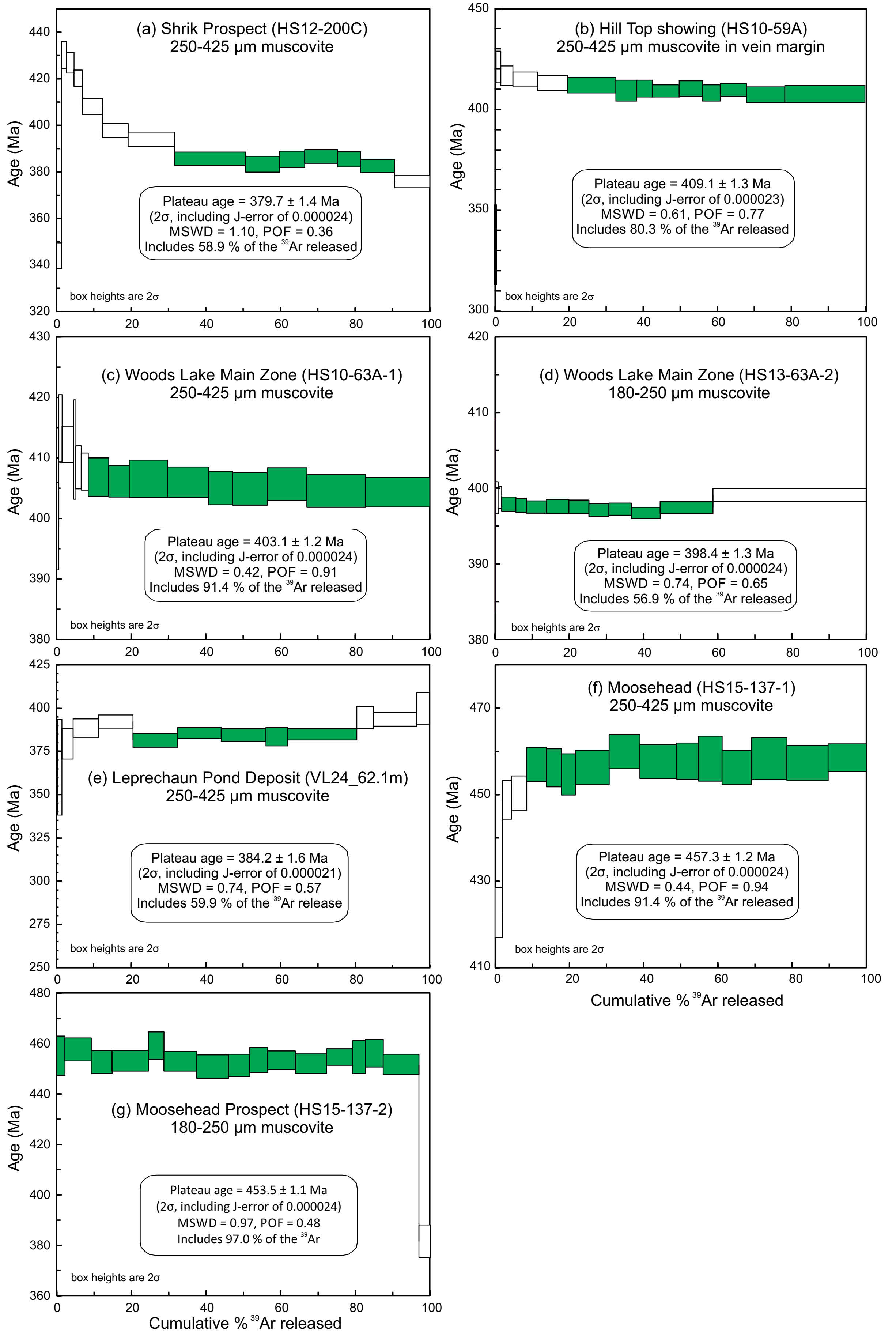
The Early Devonian muscovite ages from central Newfoundland (Hill Top showing and Wood Lake South zone) are similar to, but slightly younger than, the ca. 410 Ma ages determined along strike to the northeast for hydrothermal rutile in gold-mineralized veins from the Leprechaun Pond deposit (Valentine Lake) and Wilding Lake prospect (Honsberger *et al* 2022a). This may reflect a lower $^{40}Ar/^{39}Ar$ closure temperature for muscovite relative to the U–Pb closure temperature for rutile (ca. 600°C; Vry and Baker 2006). The ca. 410 Ma rutile ages are interpreted to provide the best minimum estimates for quartz vein emplacement and initial orogenic gold mineralization along the Victoria Lake-Valentine Lake fault corridor (Fig. 1), whereas the muscovite ages provide the best estimates for potassic alteration associated with quartz vein emplacement. Furthermore, the ca. 403 and 409 Ma muscovite ages are also in broad agreement with two identical 406 ± 2 Ma $^{40}Ar/^{39}Ar$ plateau ages for alteration-related muscovite from the Mosquito Hill gold prospect along the southeastern margin of the Mount Cormack Complex (Fig. 1; Sandeman *et al* 2013).

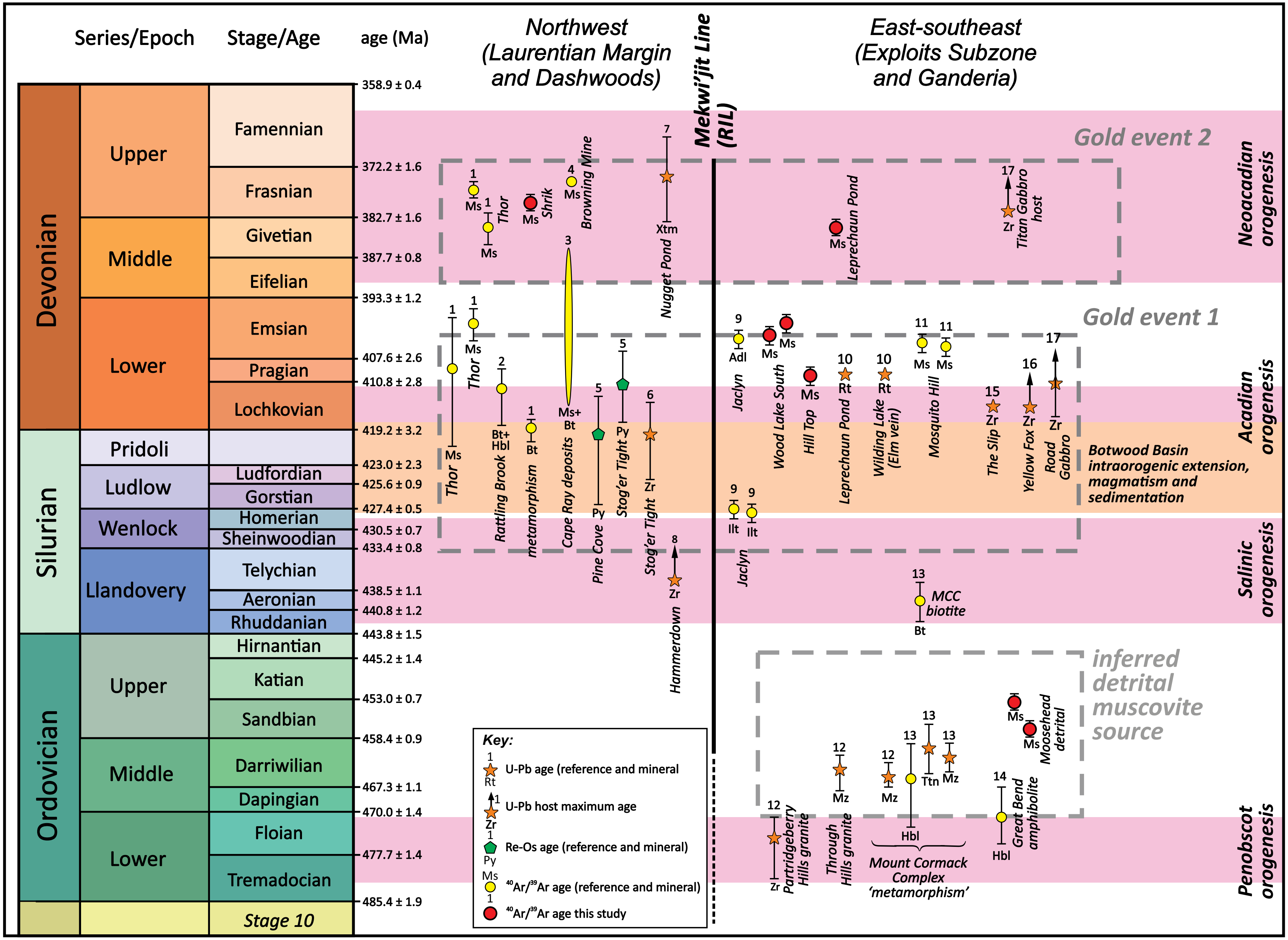
Early Devonian metamorphism, metasomatism and orogenic gold mineralization along the Victoria Lake–Valentine Lake fault corridor is compatible with the timing of initial Acadian thrusting after ca. 418 Ma in southcentral Newfoundland (Dunning *et al* 1990; Valverde-Vaquero and van Staal 2001; van der Velden *et al* 2004; Valverde-Vaquero *et al* 2006). Furthermore, Early Devonian mineralization coincides with ca. 415 to 410 Ma Acadian ductile deformation in north-central and southwestern Newfoundland (Dunning *et al* 1990; Dubé *et al* 1996; McNicoll *et al* 2006). In southwestern–central Newfoundland, $^{40}Ar/^{39}Ar$ geochronology of white mica provides evidence for low-*P* – low-*T* Acadian metamorphism between ca. 408 and 390 Ma (Willner *et al* 2018). On the Baie Verte Peninsula, orogenic gold mineralization may have been initiated earlier than in central Newfoundland as Re–Os pyrite geochronology yielded ages of 420 ± 7 Ma and 411 ± 7 Ma for the Stog'er Tight and Pine Cove deposits (Kerr and Selby 2012), respectively. Similarly, hydrothermal zircon from the Stog'er Tight deposit was dated at 420 ± 5 Ma (Fig. 1; Ramezani *et al* 2002).

The new Middle–Upper Devonian muscovite ages for the Leprechaun deposit (ca. 384 Ma) at Valentine Lake and Shrik showing at White Bay (ca. 380 Ma), contrast with Early Devonian orogenic gold-bearing vein formation documented in both locations (ca. 410 Ma rutile; Honsberger *et al* 2022a; ca. 419 to ca. 408 Ma; Kerr and van Breemen 2007; Minnett *et al* 2012). However, the new data are compatible with a previous age determination for secondary muscovite at White Bay (ca. 374 Ma, Sandeman and Dunning 2016), as well as with ca. 374 ± 8 Ma hydrothermal xenotime from a gold-mineralized vein at the Nugget Pond deposit on the Baie Verte Peninsula (Sangster *et al* 2008). Moreover, a gold-mineralized mafic sill/dyke that cuts the Late Silurian Indian Islands Group near Gander Bay at the Titan prospect (Fig. 1; McNicoll *et al* 2006) yielded a SHRIMP U–Pb zircon age of 381 ±5 Ma, providing a maximum, late Devonian age for the gold mineralization. All these data support the existence of a Middle–Upper Devonian gold mineralization event that is superimposed on Early Devonian quartz vein systems in western, west–central, and central Newfoundland.

All geochronologically constrained orogenic gold occurrences in central and western Newfoundland are Late

Figure 11. (next page) $^{40}Ar/^{39}Ar$ age spectra for muscovite grain separates from the samples under investigation. (a) Shrik Showing muscovite HS12-200C (250–425 µm). (b) Hill Top Showing muscovite HS10-059A (250–425 µm). (c) Wood Lake South (Main) zone muscovite HS13-063A-1 (250–425 µm). (d) Wood Lake South (Main) zone muscovite HS13-063A-2 (180-250µm). (e) Leprechaun Pond Deposit muscovite VL-24-62.1m (250–425 µm). (f) Moosehead Prospect detrital muscovite HS15-137-1 (250–425 µm). (g) Moosehead Prospect detrital muscovite HS15-137-2 (180–250 µm).


(a) Shrik Prospect (HS12-200C)
250-425 µm muscovite
Plateau age = 379.7 ± 1.4 Ma
(2σ, including J-error of 0.000024)
MSWD = 1.10, POF = 0.36
Includes 58.9 % of the 39Ar released
box heights are 2σ
Age (Ma)
(b) Hill Top showing (HS10-59A)
250-425 µm muscovite in vein margin
Plateau age = 409.1 ± 1.3 Ma
(2σ, including J-error of 0.000023)
MSWD = 0.61, POF = 0.77
Includes 80.3 % of the 39Ar released
box heights are 2σ
Age (Ma)
(c) Woods Lake Main Zone (HS10-63A-1)
250-425 µm muscovite
Plateau age = 403.1 ± 1.2 Ma
(2σ, including J-error of 0.000024)
MSWD = 0.42, POF = 0.91
Includes 91.4 % of the 39Ar released
box heights are 2σ
Age (Ma)
(d) Woods Lake Main Zone (HS13-63A-2)
180-250 µm muscovite
Plateau age = 398.4 ± 1.3 Ma
(2σ, including J-error of 0.000024)
MSWD = 0.74, POF = 0.65
Includes 56.9 % of the 39Ar released
box heights are 2σ
Age (Ma)
(e) Leprechaun Pond Deposit (VL24_62.1m)
250-425 µm muscovite
Plateau age = 384.2 ± 1.6 Ma
(2σ, including J-error of 0.000021)
MSWD = 0.74, POF = 0.57
Includes 59.9 % of the 39Ar release
box heights are 2σ
Age (Ma)
(f) Moosehead (HS15-137-1)
250-425 µm muscovite
Plateau age = 457.3 ± 1.2 Ma
(2σ, including J-error of 0.000024)
MSWD = 0.44, POF = 0.94
Includes 91.4 % of the 39Ar released
box heights are 2σ
Age (Ma)
Cumulative % 39Ar released
(g) Moosehead Prospect (HS15-137-2)
180-250 µm muscovite
Plateau age = 453.5 ± 1.1 Ma
(2σ, including J-error of 0.000024)
MSWD = 0.97, POF = 0.48
Includes 97.0 % of the 39Ar
box heights are 2σ
Age (Ma)
Cumulative % 39Ar released



Series/Epoch
Stage/Age
age (Ma)
Northwest (Laurentian Margin and Dashwoods)
Mekwi'jit Line (RIL)
East-southeast (Exploits Subzone and Ganderia)
Devonian
Upper
Middle
Lower
Famennian
Frasnian
Givetian
Eifelian
Emsian
Pragian
Lochkovian
Silurian
Pridoli
Ludlow
Wenlock
Llandovery
Ludfordian
Gorstian
Homerian
Sheinwoodian
Telychian
Aeronian
Rhuddanian
Ordovician
Upper
Middle
Lower
Hirnantian
Katian
Sandbian
Darriwilian
Dapingian
Floian
Tremadocian
Stage 10
358.9 ± 0.4
372.2 ± 1.6
382.7 ± 1.6
387.7 ± 0.8
393.3 ± 1.2
407.6 ± 2.6
410.8 ± 2.8
419.2 ± 3.2
423.0 ± 2.3
425.6 ± 0.9
427.4 ± 0.5
430.5 ± 0.7
433.4 ± 0.8
438.5 ± 1.1
440.8 ± 1.2
443.8 ± 1.5
445.2 ± 1.4
453.0 ± 0.7
458.4 ± 0.9
467.3 ± 1.1
470.0 ± 1.4
477.7 ± 1.4
485.4 ± 1.9
Gold event 2
Gold event 1
Neoacadian orogenesis
Acadian orogenesis
Salinic orogenesis
Penobscot orogenesis
Thor
Shrik
Browning Mine
Nugget Pond
Xtm
Leprechaun Pond
Titan Gabbro host
Rattling Brook
metamorphism
Cape Ray deposits
Ms+ Bt
Bt+ Hbl
Pine Cove
Stog'er Tight
Hammerdown
Jaclyn
Wood Lake South
Hill Top
Wilding Lake (Elm vein)
Mosquito Hill
The Slip
Yellow Fox
Road Gabbro
Botwood Basin intraorogenic extension, magmatism and sedimentation
MCC biotite
inferred detrital muscovite source
Moosehead detrital
Partridgeberry Hills granite
Through Hills granite
Mount Cormack Complex 'metamorphism'
Great Bend amphibolite
Key:
U-Pb age (reference and mineral
U-Pb host maximum age
Re-Os age (reference and mineral)
$^{40}Ar/^{39}Ar$ age (reference and mineral)
$^{40}Ar/^{39}Ar$ age this study

Figure 12. Diagram summarizing geochronological constraints on gold mineralized zones of central and western Newfoundland. Timescale from the International Commission on Stratigraphy stratigraphic chart (Cohen *et al* 2013: updated 2021). Also outlined are the approximate estimates for the orogenic events of the Newfoundland Appalachians (e.g., van Staal and Barr 2012). The orogenic-style mineralization occurs in two broad intervals, one in the latest Silurian to Early Devonian and a second in the Middle to Late Devonian. The latter may be synchronous with, and immediately postdate accretion of the Meguma terrane. Data sources: 1- Minnett et al (2012); 2- Kerr and van Breemen (2007); 3- Dubé *et al* (1996); 4- Sandeman and Dunning (2016); 5- Kerr and Selby (2012); 6- Ramezani *et al* (2002); 7- Sangster *et al* (2008); 8- Ritcey *et al* (1995); 9- Sandeman (2014d); 10- Honsberger *et al* (2022); 11- Sandeman *et al* (2013); 12- Colman-Sadd *et al* (1992); 13- Valverde-Vaquero *et al* (2003); 14- Sandeman and Dickson (2019); 15- Sandeman *et al* (2017); 16- Sandeman and Spurrell (2020); 17- McNicoll *et al* (2006).

Silurian to Middle–Upper Devonian and define two gold-forming intervals broadly between ca. 433 and 405 Ma and ca. 390 and 372 Ma. Spatiotemporal coincidence of orogenesis, metamorphism, magmatism and precious metal mineralization occurs across much of the Laurentian margin, Dashwoods terrane, the western Exploits Subzone and selected parts of the eastern Exploits Subzone. The oldest orogenic gold deposits occur in the west along the Laurentian margin and eastern Dashwoods terrane and are associated with the terminal stages of the Middle to Late Silurian Salinic orogenic cycle (ca. 435–427 Ma: e.g., van Staal and Barr 2012). Moreover, regional magmatic, sedimentary, metamorphic, and structural events indicate that although terrane accretion progressed oceanward (present-day east) throughout the Paleozoic (e.g., van Staal *et al* 2014), earlier accreted terranes were affected by mineralizing events related to subsequent accretion of outboard terranes (e.g., Honsberger *et al* 2022a). Thus, mineralized zones in central and western Newfoundland yield Middle–Late Silurian to Middle Devonian ages that post-date accretion of the encompassing terrane. For example, accretion of Dashwoods to the Laurentian margin took place in the Ordovician (Waldron and van Staal 2001), but gold mineralization at White Bay (Humber Zone, Fig. 1) is Late Silurian to Early or Middle Devonian (Fig. 12). Furthermore, ca. 410 Ma orogenic gold mineralization along the Victoria Lake–Valentine Lake fault corridor post-dates ca. 435 Ma accretion of the composite Gander Zone/Exploits Subzone (Ganderia) to the Dashwoods terrane and composite Laurentia (e.g., Honsberger *et al* 2022a). These relationships indicate that other tectonic processes in addition to accretion, such as oroclinal bends and orogen-parallel along strike temporal variations in the kinematics of orogenic accommodation, were critical to generating the orogenic gold-mineralized faults in central and western Newfoundland, as is presumed elsewhere along the Iapetan suture zone of the Appalachian mountain belt (Romer and Kroner 2018).

CONCLUSIONS

1. New $^{40}Ar/^{39}Ar$ geochronological constraints across central and western Newfoundland are consistent with two distinct intervals of orogenic gold mineralization between ca. 433 and 405 Ma and ca. 390 and 372 Ma.

2. The late Silurian–Early Devonian event includes muscovite growth/resetting intervals for gold-bearing zones of the Laurentian Margin, Dashwoods terrane, western Exploits subzone and along the Meelpaeg–Exploits subzones boundary, whereas the younger Devonian interval includes muscovite from gold-bearing zones across the Laurentian Margin, Dashwoods terrane, Exploits Subzone, and Gander Zone.

3. $^{40}Ar/^{39}Ar$ plateau ages for detrital muscovite from Wigwam Formation sandstone at the Moosehead prospect (ca. 457.3 ± 1.2 to 453.5 ± 1.1 Ma) suggest the Mount Cormack Complex is an erosional source for the sedimentary units of

the Botwood Basin.

4. Detailed investigations of quartz vein and alteration mineral parageneses, their relationships to gold deposition and systematic geochronological investigations of a number of different mineral species at select auriferous zones is necessary to better constrain the timing of gold mineralization in central and western Newfoundland.

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