U–Pb geochronology of Late Silurian (Wenlock to Pridoli) volcanic and sedimentary rocks, central Newfoundland Appalachians: targeting the timing of transient extension as a prelude to Devonian orogenic gold mineralization

Ian W. Honsberger[1*], Wouter Bleeker[1], Sandra L. Kamo[2], Chelsea N. Sutcliffe[2], and Hamish A.I. Sandeman[3]

1. Geological Survey of Canada, Ottawa, Ontario K1A 0E8, Canada
2. Jack Satterly Geochronology Laboratory, Department of Earth Sciences, University of Toronto, Toronto, Ontario M5S 3B1, Canada
3. Geological Survey Division, Department of Industry, Energy and Technology, Government of Newfoundland and Labrador, St. John's, Newfoundland A1B 4J6, Canada
*Corresponding author: ian.honsberger@nrcan-rncan.gc.ca

Date received:14 March 2022 ¶ Date accepted 10 June 2022

ABSTRACT

Bimodal igneous suites and associated immature clastic sedimentary rocks are characteristic of many orogenic gold-mineralized, crustal-scale fault zones globally. In the central Newfoundland Appalachian orogen, the Rogerson Lake Conglomerate belt and Botwood basin are Late Silurian (Wenlock to Pridoli), fault-controlled sedimentary rock sequences and magmatic suites closely associated with orogenic gold mineralization; however, the spatio-temporal evolution of faulting and associated sedimentation and magmatism are not fully resolved.

U–Pb zircon geochronological results were obtained by using an integrated approach employing LA-ICPMS (laser ablation-inductively coupled plasma mass spectrometry) followed by CA-ID-TIMS (chemical abrasion-isotope dilution-thermal ionization mass spectrometry) on the same detrital samples. Using this approach, a maximum depositional age for sedimentary rocks of the Rogerson Lake Conglomerate sequence is 421.9 ± 1.0 Ma (Pridoli), which confirms that they are younger than, and stratigraphically overlie, ca. 422–420 Ma igneous rocks exposed along the central Newfoundland gold belt. Towards the stratigraphic middle of the Botwood basin in north-central Newfoundland, a tuffite layer intercalated with graded siltstone produced a maximum depositional age of 427.9 ± 3.1 Ma (Wenlock; Homerian). The age of emplacement of an autobrecciated, flow-banded rhyolite dome of the Charles Lake volcanic belt along the northwestern Botwood basin is 429.3 ± 0.7 Ma (Wenlock; Homerian). The high-precision CA-ID-TIMS zircon data establish a clear link between Wenlock to Pridoli magmatism and sedimentation throughout central Newfoundland. Furthermore, these geochronological results are consistent with a structural model involving the southeastward (present-day coordinates) advancement of a transient extensional fault system across strike of the Exploits Subzone between ca. 429 and 418 Ma, with propagation along strike to the southwest (Rogerson Lake Conglomerate belt) between ca. 422 and 418 Ma. Extensional faulting may have contributed to basin formation, subsidence, and exhumation of pre-Late Silurian rocks of the Exploits Subzone.

Time-transgressive, extension-related magmatism and clastic sedimentation appear to mark the transition between the Salinic and Acadian orogenic cycles along the central Newfoundland gold belt. Transient Wenlock to Pridoli lithospheric extension may have been important for increasing heat and fluid flow in the crust as a prelude to Devonian crustal thickening, fluid focussing, and orogenic gold mineralization.

RÉSUMÉ

Les suites ignées bimodales et les roches sédimentaires clastiques immatures connexes sont caractéristiques de nombreuses zones faillées d'échelle crustale à minéralisation aurifère orogénique à l'échelle planétaire. Dans l'orogenèse appalachienne du centre de Terre-Neuve, la ceinture du conglomérat du lac Rogerson et le bassin de Botwood sont des suites magmatiques contrôlées par des failles et des séquences de roches sédimentaires du Silurien tardif (du Wenlock au Pridoli), étroitement associées à une minéralisation aurifère orogénique; l'évolution spatio-temporelle de la déformation par failles et le magmatisme ainsi que la sédimentation connexe n'ont toutefois pas été tout à fait résolus.

2564-2987|22|0215–0237$4.45|0
doi:10.4138/atlgeo.2022.009

On a obtenu des résultats géochronologiques U–Pb sur zircon au moyen d'une approche intégrée employant l'ablation par laser et la spectrométrie de masse avec plasma à couplage inductif (LA-ICPMS), suivies d'une analyse par abrasion chimique, par dilution isotopique et par spectrométrie de masse à thermoionisation (CA-ID-TIMS) des mêmes échantillons détritiques. Selon cette approche, l'âge maximal de sédimentation de la séquence de conglomérat du lac Rogerson est de 421,9 ± 1,0 Ma (Pridoli), ce qui confirme qu'elle est plus récente et qu'elle recouvre stratigraphiquement les roches ignées d'environ 422 à 420 Ma affleurant le long de la ceinture aurifère du centre de Terre-Neuve. Vers le milieu stratigraphique du bassin de Botwood dans le centre-nord de Terre-Neuve, une couche de tuffite interlitée de siltite granoclassée a produit un âge de sédimentation maximal de 427,9 ± 3,1 Ma (Wenlock, Homérien). L'âge de mise en place d'un dôme de rhyolite à rubanement de coulée, autobréchifié, de la ceinture volcanique du lac Charles le long du nord-ouest du bassin de Botwood est de 429,3 ± 0,7 Ma (Wenlock, Homérien). Les données de datation sur zircon par CA-ID-TIMS haute précision établissent un lien clair entre le magmatisme du Wenlock au Pridoli et la sédimentation partout dans le centre de Terre-Neuve. De plus, ces résultats chronologiques correspondent à un modèle structural présumant un avancement vers le sud-est (coordonnées actuelles) d'un système de failles d'extension transitoire en travers de l'orientation longitudinale de la sous-zone Exploits entre environ 429 et 418 Ma, avec une propagation le long de l'axe longitudinal vers le sud-ouest (ceinture du conglomérat du lac Rogerson) entre 422 et 418 Ma. La déformation par failles d'extension pourrait avoir contribué à la formation du bassin, à l'affaissement et à l'exhumation des roches préalables au Silurien tardif de la sous-zone Exploits.

Le magmatisme apparenté à l'extension, transgressif au fil du temps, et la sédimentation clastique semblent marquer la transition entre les cycles orogénique, salinique et acadien le long de la ceinture aurifère du centre de Terre-Neuve. L'extension lithosphérique transitoire du Wenlock au Pridoli pourrait s'être avérée importante pour accroître la chaleur et la circulation des fluides dans la croûte en guise de prélude à l'épaississement de la croûte, à la concentration des fluides et à la minéralisation aurifère orogénique du Dévonien.

[*Traduit par la redaction*]

INTRODUCTION

Fault-controlled magmatic suites and upper-crustal, immature clastic sedimentary rock sequences containing panels of polymict conglomerate are characteristic of many orogenic gold-mineralized fault systems globally (e.g., Hodgson 1993; Evans 1996; Poulsen *et al.* 2000; Bleeker 2002). Such rock sequences are not only key targets for gold exploration, but also provide records of fault zone dynamics that drive gold mineralization events (e.g., Bleeker 2012, 2015). Accordingly, constraining the setting, age, and process evolution of igneous and clastic sedimentary rocks associated with orogenic gold mineralization is essential for understanding the controls on mineralization.

In the central Newfoundland Appalachians, an approximately 400 km-long system of crustal-scale, northeast-southwest trending fault zones of the Exploits Subzone (Dunnage Zone) are delineated by post-Ordovician magmatic suites and immature clastic sedimentary rock sequences and closely associated orogenic gold mineralization (Figs. 1 and 2; Tuach *et al.* 1988; Tuach 1992; Evans 1996; Wardle 2005). The setting, timing, and associated faulting processes in this mineralized terrane are not fully understood because outcrop is sparse and gold-focussed exploration in areas of little outcrop has a relatively short history (~35 years, see Sandeman *et al.* this volume). The processes of polyphase fault reactivation that control orogenic gold mineralization, for example, are only beginning to be constrained (Figs. 1 and 2; Willner *et al.* 2018, 2022; Honsberger *et al.* 2022). Additionally, the occurrence of extension-related Silurian basins in central and western Newfoundland with strongly bimodal magmatic suites and clastic sedimentary rock sequences (Fig. 1; Colman-Sadd *et al.* 1990; Kusky and Kidd 1996; O'Brien 2003; Whalen *et al.* 2006) is in contrast to compressional deformational structures documented throughout the Dunnage Zone (e.g., Karlstrom *et al.* 1982; Valverde-Vaquero *et al.* 2006; van Staal and Barr 2012). Accordingly, some workers have interpreted these Silurian basin rocks to have formed during thrusting (e.g., Karlstrom *et al.* 1982; van Staal *et al.* 2014), whereas others considered such sequences to represent pull-apart basins related to protracted strike-slip motion (Kusky *et al.* 1987; Buchan and Hodych 1992; Kusky and Kidd 1996; O'Brien 2003). To resolve such discrepancies related to the Silurian tectonic evolution of central Newfoundland, stratigraphic, structural, geochemical, and geochronological data must be integrated. High-precision geochronological data are particularly useful in the Exploits Subzone because of rapid transitions (<5 million years) between deformational events and tectonic environments spanning the Salinic (Late Silurian) and Acadian (Early Devonian) orogenic cycles (e.g., van Staal *et al.* 2014).

In the present investigation, regional field observations, targeted geochronology sampling, and integrated LA-ICPMS and CA-ID-TIMS U–Pb zircon geochronological analyses of volcanic and sedimentary rocks establish the spatio-temporal dynamics of Wenlock to Pridoli extensional faulting in central Newfoundland, which may have been the operative process marking the transition between the Salinic and Acadian orogenic cycles. Silurian clastic sedimentary rocks in central Newfoundland were the subjects of a previous U–Pb LA-ICPMS geochronological study (Pollock *et al.* 2007) and, as well, one sample of these rocks was analyzed as part of a combined U–Pb-Hf isotopic study (Henderson *et al.* 2018). These previous investigations focussed on detrital zircon provenance but maximum depositional and

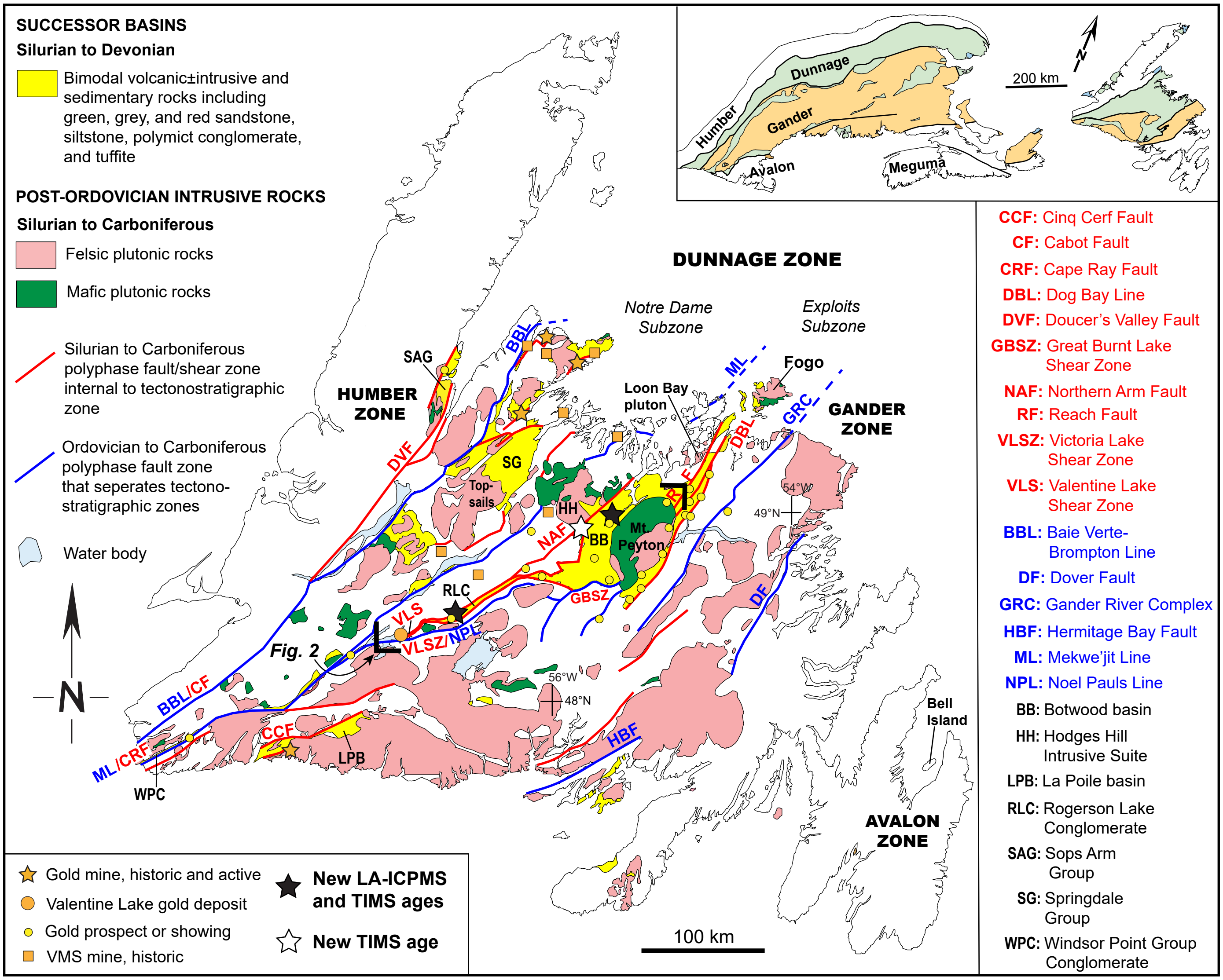


Figure 1. Simplified geologic map of the island of Newfoundland showing major fault zones, post-Ordovician magmatic and sedimentary rocks, and select gold-mineralized zones and historic volcanogenic massive sulfide (VMS) mines (modified from Colman-Sadd *et al.* 1990). Blue lines delineate polyphase fault zones that separate the tectonostratigraphic zones defined by Williams (1978), Williams *et al.* (1988), and Hibbard *et al.* (2006). The names of the boundary fault zones (blue lines) are labelled with blue text. The red lines with red text are fault/shear zones that occur internal to the tectonostratigraphic zones. Red text along blue lines is the name of the fault/shear zone that reactivates and overprints the boundary fault zone. The black text is used for notable geological units. Two bold, black, L-shaped lines mark the southwest and northeast corners of the rectangular area enlarged in Figure 2. Geochronology sample locations are marked by black (LA-ICPMS and TIMS) and white (TIMS) stars. Gold occurrences are from the Geological Survey of Newfoundland and Labrador, Department of Industry, Energy and Technology's Mineral Occurrence Database. Inset is a simplified tectonic lithofacies map of the northern Appalachian orogen based on Williams (1978) and Hibbard *et al.* (2006).

crystallization ages for the sedimentary and igneous rocks were not determined more precisely by CA-ID-TIMS. Absolute minimum ages of deposition for clastic sedimentary rocks in central Newfoundland have been estimated from U–Pb rutile and $^{40}Ar/^{39}Ar$ white mica ages of ca. 410 Ma (Honsberger *et al.* 2022) and ca. 390 Ma (Willner *et al.* 2018), respectively, in quartz veins that cut polymict conglomerate (Rogerson Lake Conglomerate).

GEOLOGICAL SETTING

The island of Newfoundland exposes Mesoproterozoic to Ordovician accretionary terranes from four fault-bounded tectonostratigraphic zones of the northern Appalachian orogen: Humber, Dunnage (Notre Dame and Exploits subzones), Gander, and Avalon zones (Fig. 1; Williams 1978; Williams *et al.* 1988). Orogenic gold mineralization in central Newfoundland, however, is not structurally controlled

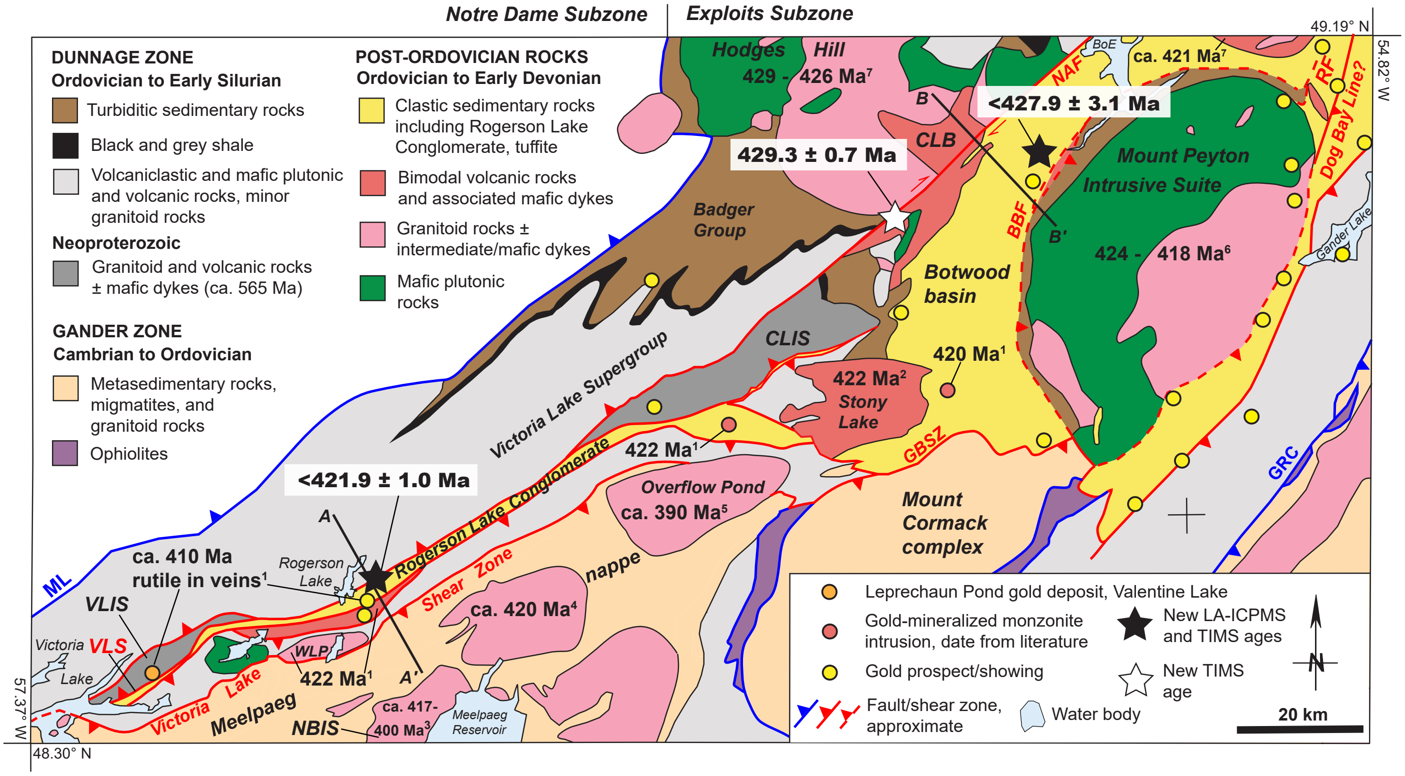


Figure 2. **Simplified geologic map of the central Newfoundland orogenic gold belt (modified from Colman-Sadd et al. 1990; O'Brien 2003; Rogers and van Staal 2005; Rogers *et al.* 2005; van Staal *et al.* 2005). Red lines and text mark major Early Devonian fault/shear zones related to emplacement of orogenic gold-bearing veins (Honsberger et al. 2022). A local boundary between the Dunnage and Gander zones in this area has been referred to as Noel Paul's Line (Fig. 1; Williams *et al.* 1988), which is the same age as the regionally extensive Early Devonian Victoria Lake Shear Zone that overprints and imbricates the Dunnage-Gander boundary across central Newfoundland (Valverde-Vaquero and van Staal 2002). Accordingly, the Victoria Lake Shear Zone is coloured red, unlike in Figure 1, to demonstrate that it does not represent sensu stricto the original boundary between the Dunnage and Gander zones. Blue lines and text are fault zones that separate the tectonostratigraphic zones. Faults within the Victoria Lake Supergroup are not illustrated. Geochronology sample locations are marked by black (LA-ICPMS and TIMS) and white (TIMS) stars, with absolute ages indicated. References to ages from the literature are as follows: 1, Honsberger *et al.* (2022); 2, Dunning *et al.* (1990) and McNicoll *et al.* (2006); 3, Kerr (1997); 4, Valverde-Vaquero *et al.* (2006); 5, Dallmeyer *et al.* (1983); 6, Sandeman *et al.* (2017); 7, Dickson (2000), van Staal et al. (2014), and G. Dunning, personal communication 2021. Cross-section lines A-A′ and B-B′ are illustrated in Figures 3 and 4, respectively. Gold occurrences are from the Geological Survey of Newfoundland and Labrador, Department of Industry, Energy and Technology's Mineral Occurrence Database. Abbreviations: BBF – Botwood Basin Fault Zone; BoE – Bay of Exploits; CLB – Charles Lake volcanic belt; CLIS – Crippleback Lake Intrusive Suite; GBSZ – Great Burnt Lake Shear Zone; GRC – Gander River Complex; ML – Mekwe'jit Line; NAF – Northern Arm Fault; NBIS – North Bay Intrusive Suite; RF – Reach Fault; VLIS – Valentine Lake Intrusive Suite; VLS – Valentine Lake Shear Zone; WLP – Wilding Lake pluton.**

sensu stricto by the fault zones that separate the tectonostratigraphic zones. Instead, gold mineralization is hosted along younger fault/shear zones that overprint, reactivate, and crosscut older stratigraphy and tectonostratigraphic zone boundaries (Figs. 1 and 2; e.g., Honsberger *et al.* 2022). In the Exploits Subzone (Fig. 2), for example, gold mineralization occurs along a Devonian crustal-scale thrust fault system that imbricates Gander Zone basement of the Meelpaeg Subzone and Ordovician Exploits Subzone rocks (Kean and Jayasinghe 1980; Colman-Sadd *et al.* 1990; Honsberger *et al.* 2022). This fault system corresponds to the Acadian deformation front and includes the regionally extensive, southeast-dipping Victoria Lake Shear Zone (Valverde-Vaquero *et al.* 2006), which correlates with Noel Paul's Line (Williams *et al.* 1988; Valverde-Vaquero and van Staal 2002), a local boundary in central Newfoundland that separates rocks of the Dunnage and Gander zones. Accordingly, a northwest-dipping Salinic suture zone representing the Dunnage-Gander boundary (e.g., van Staal *et al.* 2014) is not preserved in central Newfoundland because it was overprinted by Devonian thrusts during far-field compression associated with the Acadian orogenic cycle (e.g., Valverde-Vaquero *et al.* 2006). Northwest-dipping structures along the central Newfoundland gold belt are associated with

Devonian deformation and include the Valentine Lake Shear Zone, which hosts an approximately five-million-ounce orogenic gold deposit at Valentine Lake (Dunsworth and Walford 2018; Lincoln *et al.* 2018; Figs. 1 and 2).

The pre-Silurian terranes of the Exploits Subzone (Fig. 2) consist of Neoproterozoic magmatic suites (ca. 565 Ma Valentine Lake and Crippleback Lake intrusive suites) and overlying Cambrian to Ordovician, volcano-sedimentary assemblages of the Penobscot and Popelogan-Victoria arc and backarc systems including the Victoria Lake Supergroup and correlatives (Kean and Evans 1988; Evans *et al.* 1990; O'Brien 2003; Rogers *et al.* 2006). Accretion of pre-Silurian rocks in the Exploits Subzone to composite Laurentia along the Laurentia-Gondwana suture zone or "Mekwe'jit Line" (see White and Waldron 2022; Sandeman *et al.* this volume) began in the Late Ordovician during the third and final phase of the Taconic orogenic cycle (Zagorevski *et al.* 2007; van Staal and Barr 2012). The subsequent initiation of subduction of the Tetagouche-Exploits backarc basin beneath composite Laurentia (Salinic orogenic cycle) was then accompanied by deposition of overlying Late Ordovician—Early Silurian black and grey shale and turbiditic forearc sequences of the Badger Group (Fig. 2; Colman-Sadd *et al.* 1990; O'Brien 2003; van Staal and Barr 2012; Waldron *et al.* 2012). The terminal Salinic suture zone (ca. 435 Ma, van Staal *et al.* 2014) is interpreted to correspond to the Dog Bay Line in north-central Newfoundland (Figs. 1 and 2; Williams 1993; Williams *et al.* 1993; Pollock *et al.* 2007). However, detailed local and regional field-based observations indicate that the Dog Bay Line sensu stricto is a post-Salinic, southeast-dipping zone of strong deformation associated with the Acadian orogenic cycle (Dickson 2006; Dickson *et al.* 2007; Sandeman 2021). This implies that the precise trace of the northwest-dipping Salinic suture is not well defined in the field because it was overprinted by Devonian deformation along the southeast-dipping Dog Bay Line (i.e., Dog Bay fault, Sandeman 2021), which is the preferred interpretation herein.

In central Newfoundland, Wenlock to Pridoli bimodal igneous rocks and associated polymict conglomerate and arenitic sandstone of the Rogerson Lake Conglomerate sequence (Kean and Jayasinghe 1980) are juxtaposed against, and nonconformably overlie, Neoproterozoic tonalite, trondhjemite, and granodiorite basement (±mafic dykes) of the Valentine Lake and Crippleback Lake intrusive suites (Colman-Sadd *et al.* 1990; van Staal *et al.* 2005; Figs. 2–4). The gold-mineralized Rogerson Lake Conglomerate is the diagnostic immature clastic sedimentary rock that delineates the structurally controlled central Newfoundland gold belt (Fig. 2; Evans 1996; Wardle 2005). This polymict conglomerate (±intercalated grey to pinkish sandstone) ranges from unmetamorphosed to lower greenschist facies and is purplish-grey to grey, poorly sorted and clast supported, and contains locally-sourced, deformed to undeformed, pebble to cobble-sized clasts of felsic and mafic igneous rocks, sandstone, siltstone, shale, and jasper, within a matrix of sand, silt, and clay (Kean and Jayasinghe 1980; Valverde-Vaquero and van Staal 2002; Rogers *et al.* 2005; Pollock *et al.* 2007; Honsberger *et al.* 2019). The purplish-red jasper clasts are distinctive and suggestive of an Early Ordovician ironstone source similar to that now exposed on Bell Island offshore the Avalon Peninsula (Fig. 1; Todd *et al.* 2018). The Rogerson Lake Conglomerate is imbricated with ca. 422 Ma felsic volcanic and volcaniclastic rocks, granitoid and gabbro bodies, and is locally cut by lower greenschist facies mafic dykes (Honsberger *et al.* 2019, 2020). The Neoproterozoic to Late Silurian rocks in central Newfoundland are cut by orogenic gold-bearing quartz vein systems that define the main mineral resource of the central Newfoundland gold belt (Evans 1996; Honsberger *et al.* 2022).

Northeast along strike of the Rogerson Lake Conglomerate belt, related clastic sedimentary rocks of the Botwood Group (Williams 1962) occur in the Botwood basin (Figs. 1 and 2; Kusky *et al.* 1987; O'Brien 2003). Sedimentary rocks of the Botwood Group include gold-mineralized, grey, green, and red sandstone and siltstone intercalated with felsic tuff (Wigwam Formation; O'Brien 1993; Colman-Sadd 1994; Williams *et al.* 1995; Dickson *et al.* 2000). Magmatic rocks associated with the Botwood Group include: the ca. 424–418 Ma bimodal Mount Peyton Intrusive Suite (Strong 1979; Blackwood 1982; Strong and Dupuy 1982; Dickson 1993; Sandeman *et al.* 2017); the ca. 422 Ma Laurenceton and Stony Lake volcanic rocks and equivalents (Williams 1972; Colman-Sadd *et al.* 1990; Dunning *et al.* 1990; McNicoll *et al.* 2006; van Staal *et al.* 2014; Honsberger *et al.* 2022); the ca. 422 volcanic rocks and dykes of the composite Fogo Island Intrusive Suite (Elliot *et al.* 1991; Sandeman and Malpas 1995; Kerr 2013; Donaldson *et al.* 2015), and ca. 420 monzonite intrusions (Fig. 2; Honsberger *et al.* 2020). Carbonate-bearing and fossiliferous sandstone and siltstone sequences of the Indian Islands Group (Boyce and Dickson 2006; Dickson 2006; Dickson *et al.* 2007) comprise the rocks of the easternmost Botwood basin. Some workers interpret these sedimentary rocks to represent peri-Gondwanan detrital sediments deposited exclusively on the Ganderian side of the Salinic suture zone (Williams 1993; Williams *et al.* 1993; Currie 1995; Pollock *et al.* 2007), whereas others have questioned their lithologic distinction from similar but fossil-poor clastic sedimentary rocks of the adjacent Botwood Group (Dickson 2006; Dickson *et al.* 2007).

Northwest of the Botwood Group, the Hodges Hill Intrusive Suite, which represents a slightly older pulse of Late Silurian magmatism (ca. 429 to 426 Ma; Whalen *et al.* 1997, 2006; Dickson 1999, 2000; van Staal *et al.* 2014; G. Dunning, personal communication 2021), crosscuts the Mekwe'jit Line (Figs. 1 and 2; Colman-Sadd *et al.* 1990). The Hodges Hill Intrusive Suite comprises granitic to gabbroic units that are cut by intermediate and mafic dykes and intrudes, in the east, contemporaneous bimodal volcanic rocks of the Charles Lake volcanic belt (Figs. 1 and 2; Dickson 1999, 2000). Slightly older, Late Silurian (ca. 429–426 Ma) magmatic and clastic sedimentary rocks of the Topsails Intrusive Suite and Springdale Group (Chandler *et al.* 1987; Whalen *et al.* 1997, 2006), respectively, occur farther northwest and are

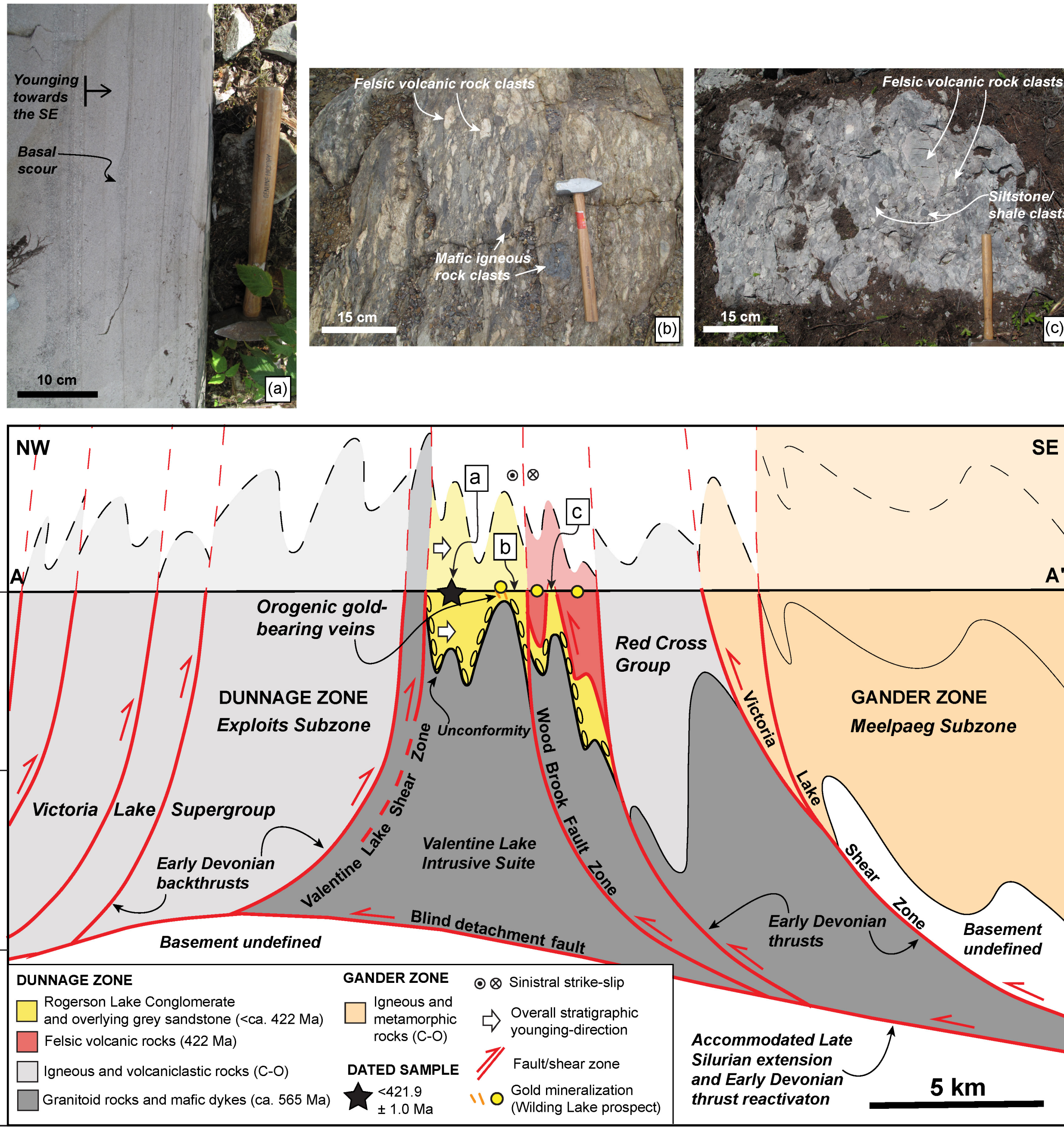


Figure 3. Cross-section interpretation along A-A′ (see Fig. 2). The black star marks the location of the Rogerson Lake Conglomerate sandstone (BNB18-IHNL-072) that was sampled for LA-ICPMS and CA-ID-TIMS U–Pb detrital zircon geochronology. Gold mineralization (yellow circles and orange lines on section) represent the Wilding Lake prospect. Pictures are as follows: A) Rogerson Lake Conglomerate sandstone geochronology sample BNB18-IHNL-072; B) Strongly deformed and gold-mineralized Rogerson Lake Conglomerate; C) Relatively undeformed Rogerson Lake Conglomerate.

associated with Latest Silurian to Devonian gold mineralization along fault splays of the Baie Verte – Brompton Line (Fig. 1; Evans 2004). Southeast of the central Newfoundland gold belt, Cambrian to Ordovician metamorphic terranes of the Gander Zone are uplifted along Early Devonian, Acadian thrust faults and intruded by Early to Middle Devonian granitoid rocks (Fig. 2; Colman-Sadd *et al.* 1990; Kerr 1997; Valverde-Vaquero *et al.* 2006).

STRUCTURAL CONTEXT

The central Newfoundland gold belt is hosted within a cross-sectional triangle zone-like structural domain that is bounded by southeast- and northwest-dipping imbricated fault/shear zones and an inferred, relatively flat-lying, blind detachment fault at depth (Figs. 2–4; van der Velden *et al.* 2004; van Staal and Barr 2012; Honsberger *et al.* 2020, 2022;

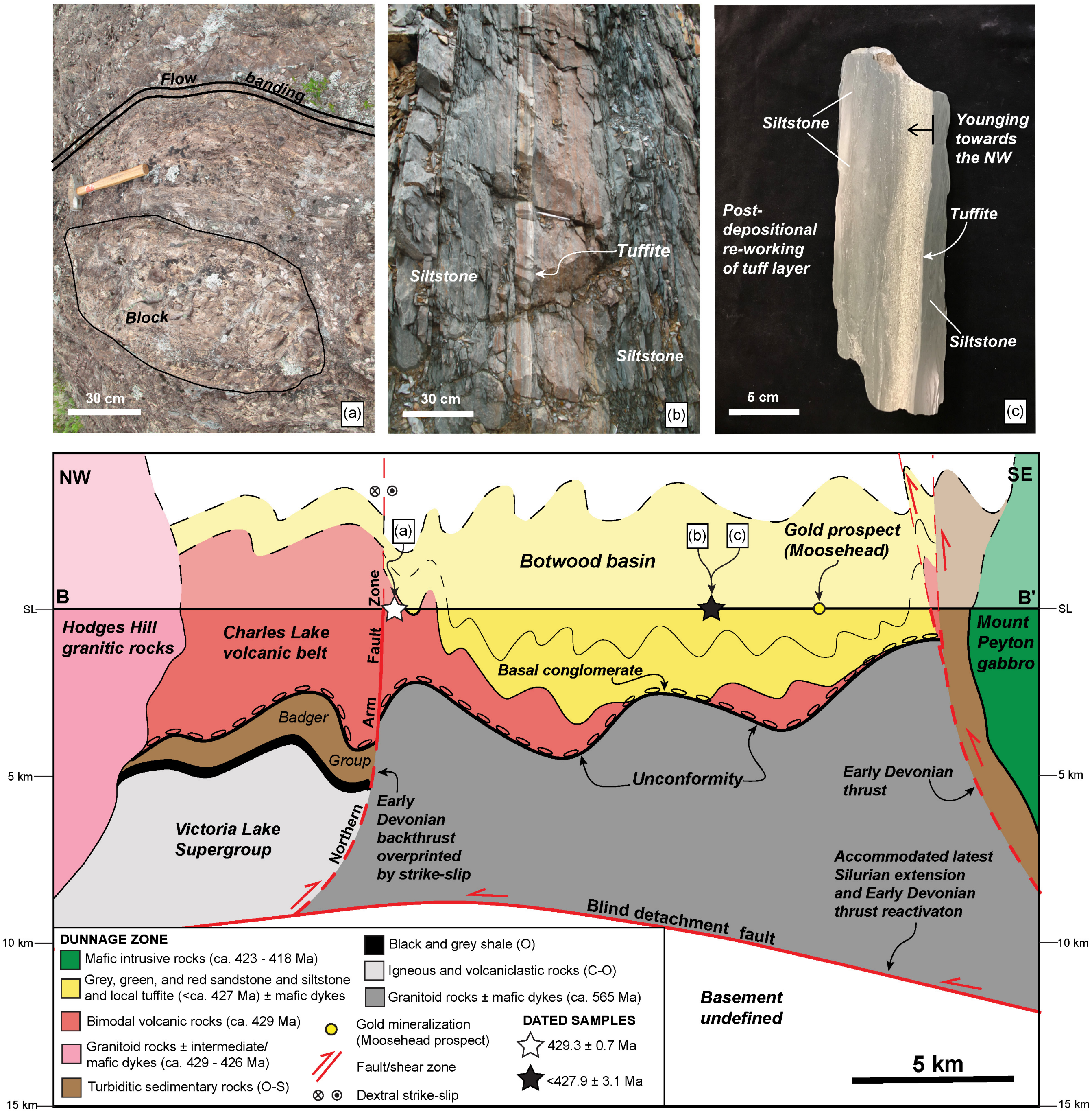


Figure 4. Cross-section interpretation along B-B′ (see Fig. 2). Geochronology sample locations are projected horizontally onto the line of section and are marked by black and white stars. The black star marks the location of the felsic tuffite sample (BNB19-IHNL-291) analyzed by both LA-ICPMS and CA-ID-TIMS U–Pb zircon geochronology, whereas the white star marks the location of the flow-banded rhyolite sample (BNB18-IHNL-092) analyzed only for CA-ID-TIMS U–Pb geochronology. Gold mineralization (yellow circle on section) represents the Moosehead prospect. Pictures are as follows: A) Flow-banded rhyolite geochronology sample BNB18-IHNL-092; B) Felsic tuffite outcrop sampled for geochronology; C) Felsic tuffite geochronology sample BNB19-IHNL-291.

Bleeker and Honsberger 2022). The southeast-dipping fault/shear zones include the Victoria Lake Shear Zone and Wood Brook Fault Zone (Valverde-Vaquero *et al.* 2006), whereas the northwest-dipping structures include the orogenic gold-mineralized Valentine Lake Shear Zone (Figs. 2 and 3; Dunsworth and Walford 2018; Lincoln *et al.* 2018). These fault/shear zones were active from at least the Late Silurian to the Early Devonian as the Meelpaeg nappe (Ganderian deformation front) advanced to the northwest as a result of far-field collision of Avalonia with composite Laurentia during the Acadian orogenic cycle (Valverde-Vaquero *et al.* 2006; van Staal and Barr 2012).

At Valentine Lake, the Valentine Lake Shear Zone crosscuts, uplifts, and juxtaposes the Valentine Lake Intrusive Suite against the Rogerson Lake Conglomerate in the overall footwall of the Victoria Lake Shear Zone (Figs. 2 and 3; Honsberger *et al.* 2020). The Valentine Lake gold deposit is hosted within structurally controlled, fault-fill and extensional quartz vein systems that emanate from the Valentine Lake Shear Zone and crosscut the Valentine Lake Intrusive Suite (Lincoln *et al.* 2018). Approximately 30 km northeast of the Valentine Lake deposit, gold-mineralized quartz veins of the Wilding Lake gold prospect form offshoots of the Wood Brook Fault Zone and cut southeast-younging stratigraphy of the Rogerson Lake Conglomerate sequence (Fig. 3; Honsberger *et al.* 2019). The Valentine Lake Shear Zone structure extends farther to the northeast along the northwestern boundary of the Crippleback Lake Intrusive Suite before merging with the Northern Arm Fault (Figs. 1 and 2), a zone of protracted, oblique dextral strike-slip faulting that marks the northwestern margin of the Botwood basin (Kusky *et al.* 1987; Colman-Sadd *et al.* 1990; O'Brien 2003).

The northeastern extension of the Victoria Lake Shear Zone system is the Great Burnt Lake Shear Zone, which uplifts Ganderian rocks of the Mount Cormack Complex and buries sandstone-siltstone sequences and monzonite intrusions of the southern Botwood basin (Fig. 2; Colman-Sadd 1980, 1985; Dec and Colman-Sadd 1990; Valverde-Vaquero *et al.* 2006; Honsberger *et al.* 2020, 2022). Farther northeast in the Botwood basin, the gold-mineralized Mount Peyton Intrusive Suite is bounded by southeast-dipping fault zones; a thrust fault system to the northwest, which we hereby name the "Botwood Basin Fault Zone", and a thrust structure to the southeast that may correlate with the Dog Bay Line in north-central Newfoundland (Figs. 2 and 4; Dickson *et al.* 2000; O'Brien 2003). In the overall footwall of the "Botwood Basin Fault Zone", orogenic gold mineralization of the Moosehead prospect is hosted within sandstones and siltstones (±mafic dykes) of the Wigwam Formation (Fig. 4; Froude 2021; Sandeman *et al.* this volume). A southeast-dipping fault zone bounds the southeastern-most contact of the Botwood Group, in contrast to the presumably northwest- to west-dipping fault trace of the Gander River Complex (Blackwood 1982; Miller 1988; O'Neill and Blackwood 1989), which delineates a peri-Ganderian, Cambro-Ordovician ophiolite tract that separates rocks of the Dunnage and Gander zones (Figs. 1–4; Colman-Sadd *et al.* 1990; van Staal and Barr 2012).

U–PB GEOCHRONOLOGY SAMPLING

In order to constrain the spatio-temporal history of faulting, magmatism, and sedimentation along the central Newfoundland gold belt, sampling for geochronological analysis was undertaken in the Rogerson Lake Conglomerate belt and Botwood basin (Figs. 1–4). In the Rogerson Lake Conglomerate belt, a sample of fresh, pink-grey, medium-grained, muscovitic sandstone containing local heavy mineral laminae and conformably overlying polymict conglomerate was processed for detrital zircon to be analyzed by LA-ICPMS and follow-up CA-ID-TIMS U–Pb dating methods. The same analytical approach was applied to a reworked felsic tuff (i.e., tuffite) intercalated with graded, muscovitic siltstone beds of the Wigwam Formation along the limb of a local anticline in the Botwood basin. The tuffite is a distinctive ~5 to 10 cm, yellowish-beige coloured layer in the field that contains medium-grained and angular epiclastic quartz and feldspar fragments (Fig. 4). An autobrecciated, flow-banded rhyolite dome of the Charles Lake volcanic belt adjacent to the Northern Arm Fault near Grand Falls, and along the northwestern margin of the Botwood basin, was sampled for direct CA-ID-TIMS dating of zircon to examine magmatic linkages with the felsic tuffite sample. UTM coordinates for geochronology samples are given in Supplementary data Tables S1 and S2 (see footnote 1).

ANALYTICAL METHODS

Laser ablation-inductively coupled plasma mass spectrometry

Following crushing and pulverization, initial separation of heavy minerals occurred on a Wilfley table, with subsequent paramagnetic and density separations performed, respectively, with a Frantz isodynamic separator and using methylene iodide. The freshest, least cracked zircon grains were hand picked under a binocular microscope with incident light (Fig. 5). Zircon grains from the sandstone sample (BNB18-IHNL-072) were annealed prior to analysis (Mattinson 2005), whereas zircon grains from the tuffite sample (BNB19-IHNL-291) were not pre-treated.

Grains were mounted on sticky tape and partially ablated using a 193 nm New Wave excimer laser and an Agilent 7900 inductively coupled plasma mass spectrometer. Depending on the sample, the laser generally operated at 5 Hz and about 5 J/cm^2 fluence with typical beam diame-ter of 20–30 microns. Data were collected on ^{88}Sr (10 ms) ^{206}Pb (30 ms) 207Pb (70 ms) 232Th (10 ms) and 238U (20 ms). Prior to analysis, spots were pre-ablated with a larger beam diameter for 2 s (10 pulses) to clean the surface. Following a 10 s period of baseline accumulation, the laser sampling beam was turned on and data were collected for 25 s before a washout period that preceded the next spot analysis. About 150 measurement cycles per sample were accumulated and resulting ablation pits are about 15 microns deep.

[1]Supplemental Data. Table S1 and S2. Please visit https://journals.lib.unb.ca/index.php/ag/article/view/32815/1882528251 and https://journals.lib.unb.ca/index.php/ag/article/view/32815/1882528252 to access the supplementary material

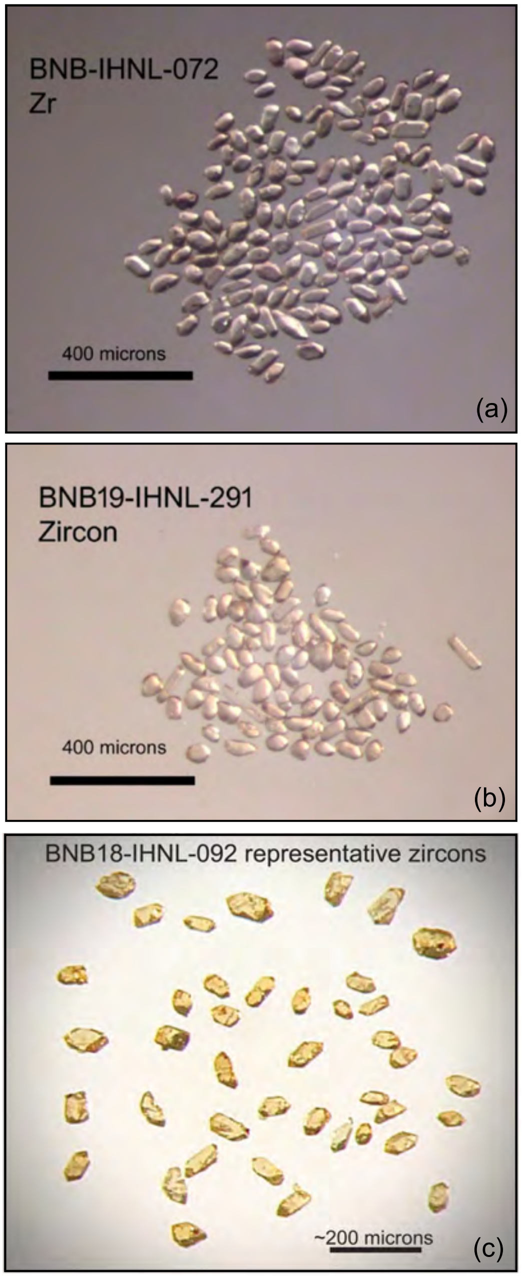


Figure 5. Images of representative zircon crystals analyzed for LA-ICPMS and CA-ID-TIMS U–Pb geochronology. (a) BNB18-IHNL-072, whole grains; (b) BNB19-IHNL-291, whole grains; (c) BNB18-IHNL-092, polished grains (CA-ID-TIMS only). Images were taken with a binocular microscope with incident light.

Data were edited and reduced using custom VBA software (UtilLAZ program) written by D. W. Davis, University of Toronto. ^{206}Pb/^{238}U ratios showed increasing fractionation throughout zircon runs caused by loss of refractory U with increasing penetration depth. No corrections were made for common Pb because the ^{204}Pb peak is too small to be measured precisely. If present, common Pb would have the effect of pushing data to the right of the concordia curve along a shallow mixing line with the slope determined by the isotopic composition of the common Pb contaminant. ^{88}Sr in zircon was monitored in order to detect intersection of the beam with zones of alteration or inclusions, and data showing high Sr or irregular time resolved profiles were either averaged over restricted Sr-free time windows or rejected. The Th/U ratio of zircon was calculated using the ^{208}Pb/^{206}Pb ratio and the ^{207}Pb/^{206}Pb age. This is more accuate than measuring the Th/U ratio directly because Th^{+} yield is strongly biased by oxidation in the plasma and, as well, the Th/U ratio in the standard available to correct the bias is not constant. Low Th/U (<0.1) is characteristic of metamorphic and hydrothermal zircon, whereas most zircon crystallized from felsic melts has Th/U in the range 0.1–1.0.

Two zircon standards were analysed: one from a quartz diorite from the Marmion batholith in northwest Ontario (DD85-17), which is dated at 3002 ± 2 Ma by ID-TIMS (Tomlinson *et al.* 2003); and one from a monzodiorite from the Pontiac province of Quebec (DD91-1) dated at 2682 ± 1 Ma (Davis 2002). Sets of four sample measurements are bracketed by measurements of DD85-17. DD91-1 was used as a secondary standard. Differences between standards were time interpolated when correcting sample measurements. Average age errors noted in the text, and error ellipses in Figures 6 and 7, are expressed at 2σ (twice the 1σ errors in Supplementary data Table S1 (see footnote 1). Ages and errors were calculated and plotted using the Isoplot program of Ludwig (1998, 2003). MSWD (mean square of weighted deviations) are expected to be around 1 or slightly higher with correctly chosen analytical errors for ^{207}Pb/^{206}Pb ages if the age population is unimodal. Pb/U errors do not include possible biases from compositional differences between samples and standard, therefore scatter above and below concordia may be pronounced. Uranium decay constantsare takenfrom Jaffey *et al.* (1971).

Chemical abrasion-isotope dilution-thermal ionization mass spectrometry

Prior to analyses, zircon crystals were thermally annealed and chemically etched ('chemically abraded'), which provides penetrative removal of alteration zones where Pb loss has occurred and generally improves concordance (Mattinson 2005). These zones correlate with high U zones that have suffered radiation damage prior to alteration. The pre-treatment involved placing zircon grains in a muffle furnace at ~900°C for ~24–60 hours to repair radiation damage and anneal the crystal lattice, followed by a modified single-step partial dissolution procedure in ~0.10 ml of ~50% HF and 0.020 ml 7N HNO_3 in Teflon dissolution vessels at 200°C for 3–8 hours. Zircon grains were rinsed with 8N HNO_3 at room temperature prior to dissolution. A ^{205}Pb-$^{233-235}$U spike or $^{202-205}$Pb-$^{233-235}$U spike (EARTHTIME community tracers) was added to the Teflon dissolution capsules during sample loading. The zircon grains were dissolved using ~0.10 ml of concentrated HF acid and ~0.02 ml of 7N HNO_3 at 200°C for 3–5 days, then dried to a precipitate and re-dissolved in ~0.15 ml of 3N HCl overnight

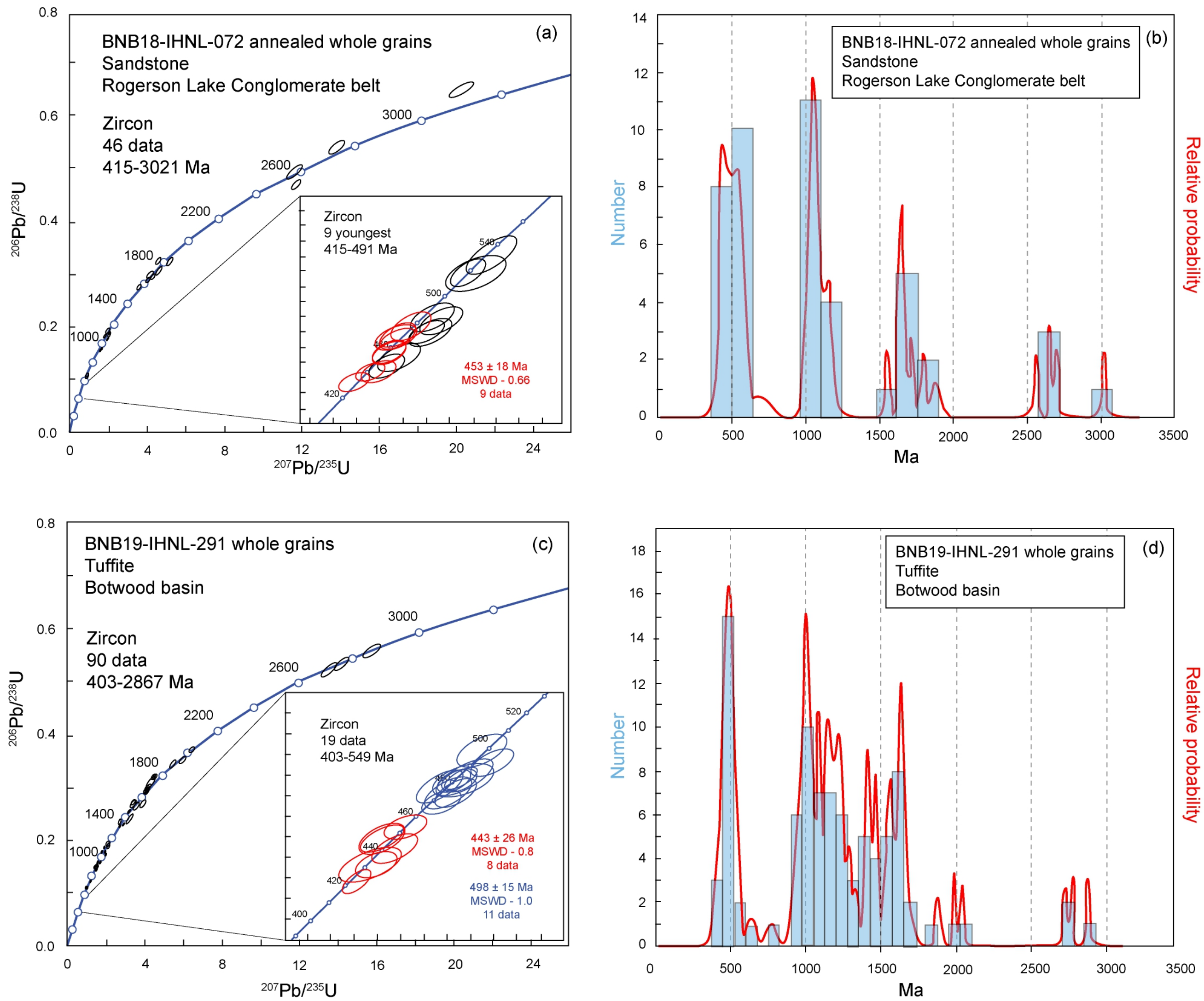


Figure 6. U–Pb LA-ICPMS geochronological results for zircon. (a) Concordia plot showing U–Pb LA-ICPMS isotopic data on annealed whole-grain zircon (N=46) from Rogerson Lake Conglomerate sandstone sample BNB18-IHNL-072. The inset shows the youngest grains (red ellipses) that give a mean $^{207}Pb/^{206}Pb$ age of 453 ± 18 (MSWD=0.66, N=9). Black ellipses represent data that are not included in the age estimates; (b) Relative probability density plot of $^{207}Pb/^{208}Pb$ ages on annealed whole-grain zircon from Rogerson Lake Conglomerate sandstone sample BNB18-IHNL-072; (c) Concordia plot showing all U–Pb LA-ICPMS isotopic data (N=90) and, as well, data for the 19 youngest whole-grain zircons (inset) from felsic tuffite sample BNB19-IHNL-291. The red ellipses represent data for the younger population and give a mean $^{207}Pb/^{206}Pb$ age of 443 ± 26 (MSWD=0.8, N=6). The blue ellipses represent data for the older population and give a mean $^{207}Pb/^{206}Pb$ age of 499 ± 15 (MSWD=1.0, N=14). The black ellipses represent data that are not included in the age estimates; (d) Relative probability density plot of $^{207}Pb/^{206}Pb$ ages on whole-grain zircons from felsic tuffite BNB19-IHNL-291. Note: all error ellipses are 2σ.

(Krogh 1973). U and Pb were isolated from zircon using 50 µl anion exchange columns with HCl, dried to a small droplet in H_3PO_4, deposited onto outgassed rhenium filaments with silica gel (Gerstenberger and Haase 1997), and analyzed with a VG354 mass spectrometer at the University of Toronto (Jack Satterly Geochronology Laboratory) using a Daly detector in pulse counting mode. Corrections to the ^{206}Pb-^{238}U ages for initial ^{203}Th disequilibrium in the zircon have been made assuming a Th/U ratio in the magma of 4.2. All common Pb was assigned to procedural Pb blank. Overall dead time of the measuring system for Pb and U was 16 and 14 ns, respectively. The mass discrimination correction for the Daly detector is constant at 0.05% per atomic mass unit. Amplifier gains and Daly characteristics were moni-tored using the SRM 982 Pb standard. Thermal mass discrimination corrections are 0.10% per atomic mass unit. Decay constants are those of Jaffey *et al.* (1971). All age errors quoted in the text and table, and error ellipses in the concordia diagrams, are expressed at the 95% confidence interval. Plotting and age calculations used Isoplot 3.00 (Ludwig 2003).

GEOCHRONOLOGICAL DATA

U–Pb LA-ICPMS isotopic data for zircon are given in Supplementary data Table S1 (see footnote 1) and geochronological results are plotted in Figure 6. In order to more closely constrain the precise time of deposition of the Rogerson Lake Conglomerate sequence and Botwood basin, the youngest, freshest zircon grains detected by LA-ICPMS in the sandstone (BNB18-IHNL-072) and tuffite (BNB19-IHNL-291) samples were removed from the sticky tape mounts and analyzed by CA-ID-TIMS (Supplementary data Table S2 - see footnote 1) (Fig. 7). The pre-screening of detrital zircon grains by LA-ICPMS helps minimize the number of analyses required by TIMS. The flow-banded rhyolite sample was analyzed by CA-ID-TIMS only (Fig. 7e).

BNB18-IHNL-072: Sandstone, Rogerson Lake Conglomerate sequence

Abundant zircon crystals consist of mixed populations of fresh and rounded, clear to beige grains (Fig. 5a), with some larger, cracked grains displaying visible reddish alteration. Fifty-two annealed whole grains were analyzed, six of which were discarded due to alteration and discordance over 15% (Supplementary data Table S1 - see footnote 1). The LA-ICPMS $^{207}Pb/^{206}Pb$ ages range from 415 to 3021 Ma (Supplementary data Table S1 - see footnote 1) (Figs. 6a and b). The nine youngest grains have a mean $^{207}Pb/^{206}Pb$ age of 453 ± 18 Ma (MSWD=0.66, N=9) and a mean $^{206}Pb/^{238}U$ age of 455 ± 12 Ma (MSWD=16, N=9; Supplementary data Table S1 - see footnote 1) (Fig. 6a). The LA-ICPMS U–Pb anal-yses show two additional age peaks of detrital grains at ca. 1100 and 1660 Ma, and scattered ages from 1886 to 3021 Ma (Figs. 6a and b).

Four of the youngest, least altered zircon grains dated by LA-ICPMS were removed from the sticky tape mount and individually chemically abraded. Grains numbered 43, 45, 48, and 51 yield concordant CA-ID-TIMS $^{206}Pb/^{238}U$ dates of 435.8 ± 0.8 Ma (grain 43), 435.2 ± 0.5 Ma (grain 51), 431.1 ± 0.8 Ma (grain 48), and 421.9 ± 1.0 Ma (grain 45) (Supplementary data Table S2 - see footnote 1) (Figs. 7a and b). The youngest grain at 421.9 ± 1.0 Ma provides a maximum age for the time of deposition of the sandstone sample.

BNB19-IHNL-291: Felsic tuffite, Botwood basin

Zircon crystals consist of small rounded subhedral grains and euhedral laths yellow to clear in color (Fig. 5b). Grains are fresh with few inclusions and cracks. Of one-hundred and twelve whole-grain analyses, twenty-two were discarded due to alteration and discordance over 15% (Supplementary data Table S1 - see footnote 1). The LA-ICPMS $^{207}Pb/^{206}Pb$ dates range in age from 403 to 2867 Ma and show a complicated age profile with a significant detrital component (Supplementary data Table S1 - see footnote 1) (Figs. 6c and d)). The analyses peak at ca. 480 Ma and the majority of grains form a continuous age distribution from 820 to 1695 Ma (Figs. 6c and d). The six oldest detrital zircon grains range from 1873 to 2867 Ma. The nineteen youngest grains show a bimodal age distribution (Supplementary data Table S1 - see footnote 1) (Figs. 6c and d). Applying the Unmix Ages utility in Isoplot (Sambridge and Compston 1994), gives LA-ICPMS $^{207}Pb/^{206}Pb$ age estimates of 443 ± 26 Ma (30%) and 498 ± 15 Ma (70%) under the assumption that there are just two age populations, whereas the $^{206}Pb/^{238}U$ ages of the nineteen youngest grains range from 422 to 498 Ma and correspond to Unmix ages of 439 ± 3 Ma (37%) and 480 ± 2 Ma (63%) (Supplementary data Table S1 - see footnote 1) (Fig. 6c).

Four of the youngest, fresh zircon grains numbered 22, 46, 71, and 72 give concordant CA-ID-TIMS $^{206}Pb/^{238}U$ dates of 470.8 ± 1.7 Ma (grain 46), 443.7 ± 6.0 Ma (grain 72), 438.0 ± 0.9 Ma (grain 22), and 427.9 ± 3.1 Ma (grain 71) (Supplementary data Table S2 - see footnote 1) (Figs. 7c and d). The youngest grain at 427.9 ± 3.1 Ma provides a maximum age for the time of deposition of the felsic tuff, with minor physical reworking (and mixing) into tuffite soon thereafter.

BNB18-IHNL-092: Rhyolite dome, Charles Lake volcanic belt

A range in concordant $^{206}Pb–^{238}U$ dates from 458 Ma to 429 Ma was determined from ten CA-ID-TIMS zircon grain analyses (Supplementary data Table S2 - see footnote 1) (Fig. 7e). A single result is 458.2 ± 2.7 Ma (Z1), data for three zircon analyses cluster at 438–437 Ma (Z2-4), three cluster at 434–433 Ma (Z5-7), and the youngest three data overlap with a weighted mean age of 429.3 ± 0.7 Ma (Z8-10). This latter date is interpreted as a maximum age for emplacement of the rhyolite. It is apparent from the results that there was a significant xenocrystic and/or antecrystic zircon component acquired at the magma source or during emplacement.

DISCUSSION

One of the biggest challenges to interpreting Silurian fault zone histories in central Newfoundland is that compression and strike-slip associated with Devonian to Carboniferous orogenesis overprint Silurian structures (e.g., van Staal and Barr 2012; Willner *et al.* 2018). Integrated LA-ICPMS and CA-ID-TIMS geochronology of sandstone of the Rogerson Lake Conglomerate sequence (BNB18-IHNL-072), felsic tuffite intercalated with graded siltstone of the Botwood basin (BNB19-IHNL-291), and a flow-banded rhyolite dome of the Charles Lake volcanic belt (BNB18-IHNL-092) provides new insights into the precise timing of Wenlock to Pridoli tectonics leading to Devonian orogenic gold mineralization in central Newfoundland. In order to place constraints on the time of deposition of the Rogerson Lake Conglomerate and Botwood basin sequences, the youngest detrital zircon grains were identified first by LA-ICPMS and then subjected to high-precision CA-ID-TIMS dating. For such samples,

Figure 7. (next page) U–Pb CA-ID-TIMS geochronological results for youngest zircon grains, as well as images taken with a binocular microscope with incident light. (a) Images of the youngest and best preserved detrital zircon grains identi-fied by LA-ICPMS and dated with follow-up CA-ID-TIMS for BNB18-IHNL-072; (b) U–Pb concordia diagram displaying the CA-ID-TIMS dates of the youngest detrital zircon grains from BNB18-IHNL-072 (youngest grain, 421.9 ± 1.0 Ma); (c) Images of the youngest and best preserved detrital zircon grains identified by LA-ICPMS and dated by follow-up CA-ID-TIMS for BNB19-IHNL-291; (d) U–Pb concordia diagram displaying the CA-ID-TIMS dates of the youngest detrital zircon grains from BNB19-IHNL-291 (youngest grain, 427.9 ± 3.1 Ma); (e) U–Pb concordia diagram displaying the CA-ID-TIMS date for zircon from the flow-banded rhyolite sample BNB18-IHNL-092 (429.29 ± 0.7 Ma). Note: all error ellipses are 2σ.

the mean U–Pb ages determined by LA-ICPMS range from Late Cambrian to latest Ordovician and have large statistical errors (Supplementary data Table S1 - see footnote 1) (Fig. 6); therefore, they are not sufficient alone to resolve depositional ages.

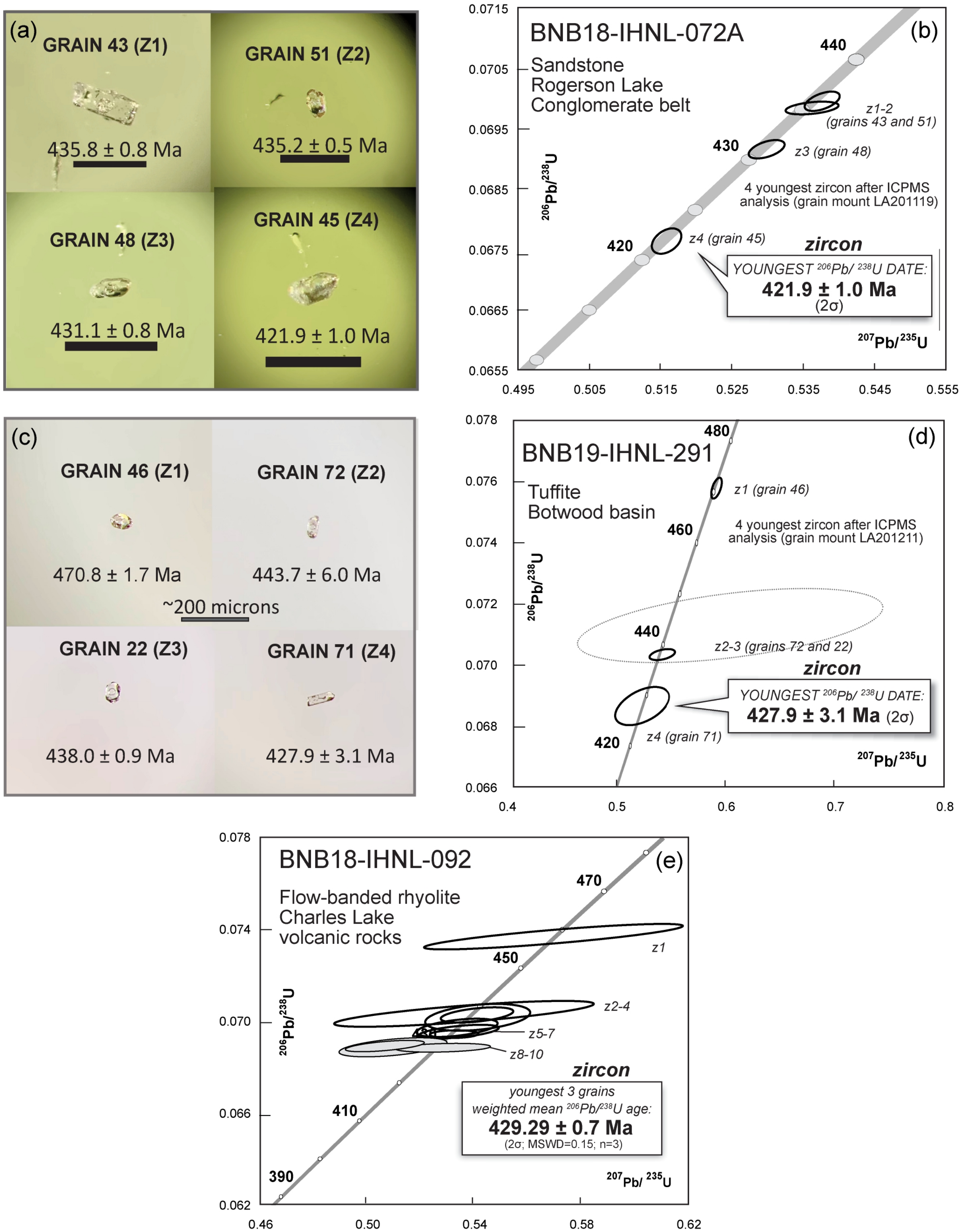
LA-ICPMS detrital zircon age distributions for the sandstone and felsic tuffite are very similar (Fig. 6), suggesting that the felsic tuffite sample includes detrital zircon grains from the intercalated sedimentary (siltstone) fraction. Although analysis of provenance is limited by the relatively small numbers of individual LA-ICPMS zircon analyses, both the sandstone and tuffite-siltstone samples display Neoproterozoic to Cambrian peaks, compatible with detrital zircon grains sourced from the underlying Victoria Lake Supergroup and its Ganderian basement (Evans *et al.* 1990, Rogers *et al.* 2006). The ca. 1000 to 1300 Ma zircon grains in both samples correspond with typical Mesoproterozoic ages for metamorphic rocks of the eastern Laurentian margin in western Newfoundland and southern Labrador (e.g., Connelly and Heaman 1993; Tucker and Gower 1994; Gower and Krogh 2002; Heaman *et al.* 2002; Kuiper and Hepburn 2021). Furthermore, the 1600–1700 Ma grains overlap in age with the oldest dated rocks of the Long Range Inlier in western Newfoundland (ca. 1631 Ma, Heaman *et al.* op. cit.) and, as well, with Trans-Labrador and Pre-Labradorian orogenic events documented in Laurentian basement of southern Labrador (Gower and Krogh 2002). The ages of the few Archean zircon grains are similar to Meso- to Neoarchean rocks of Laurentia that occur in the Makkovik and Nain provinces of central and northern Labrador (e.g., James *et al.* 2002; Ketchum *et al.* 2002; Hinchey *et al.* 2020).

Overall, the U–Pb LA-ICPMS zircon age spectra corroborate the provenance study of Pollock *et al.* (2007) in that strong Paleoproterozoic and Mesoproterozoic Laurentian detrital zircon signatures are represented (e.g., Waldron *et al.* 2012; Fig. 6). However, the geochronological results herein for the sandstone and tuffite-siltstone samples also establish a Neoproterozoic to Cambrian detrital zircon source typical of the peri-Ganderian Valentine Lake and Crippleback Lake intrusive suites (ca. 565 Ma, Evans *et al.* 1990; Rogers *et al.* 2006; Fig. 6). A mixed Laurentian-Gondwanan provenance for rocks of the Rogerson Lake Conglomerate sequence and Botwood basin, combined with the occurrence of Wenlock to Pridoli zircon grains (Figs. 6 and 7), is consistent with local depositional sources.

U–Pb CA-ID-TIMS dating of four of the youngest, best preserved zircon grains from each of the Rogerson Lake Conglomerate sandstone and Botwood basin tuffite-siltstone produced maximum $^{206}Pb/^{238}U$ depositional ages of 421.9 ± 1.0 Ma (Pridoli) and 427.9 ± 3.1 Ma (Wenlock; Homerian), respectively (Supplementary data Table S2 - see footnote 1) (Fig. 7). The ages are considered maxima because it cannot be discounted that younger detrital and/or igneous zircon grains are present in portions of the rock units that were not processed for geochronology. Absolute minimum depositional age constraints for the basal Rogerson Lake Conglomerate are ca. 410 Ma (Honsberger *et al.* 2022) and ca. 390 Ma (Willner *et al.* 2018), which are, respectively, for rutile and white mica in quartz veins that crosscut the Rogerson Lake Conglomerate. U–Pb CA-ID-TIMS zircon geochronology produced an igneous crystallization age of 429.29 ± 0.70 Ma (Wenlock; Homerian) for the auto-brecciated, flow-banded rhyolite dome of the Charles Lake volcanic belt along the western margin of the Botwood basin (Fig. 7e); therefore, these volcanic rocks appear to be genetically related to the felsic tuffite.

The maximum depositional ages for the rhyolite dome and tuffite are interpreted to represent the time of Homerian (ca. 430–427 Ma) volcanism and associated volcanogenic sedimentation in the western Botwood basin. In this interpretation, felsic volcanism was active between at least ca. 429 and 428 Ma, with deposition of felsic tuff and siltstone of the Wigwam Formation at ca. 428 Ma, accompanied by minor physical reworking of the tuffaceous material. The Pridoli maximum age for deposition of the Rogerson Lake Conglomerate sandstone suggests that sedimentation may have been initiated later along this belt than to the northwest and northeast in the Botwood basin. Furthermore, the maximum ca. 422 Ma detrital zircon age for the Rogerson Lake Conglomerate sandstone sample confirms that ca. 422–420 Ma igneous rocks in central Newfoundland are included as clasts and grains within the Rogerson Lake Con-glomerate sequence, again, consistent with locally derived sediment sources. The new U–Pb CA-ID-TIMS zircon ages establish that Wenlock to Pridoli magmatism preceded sedimentation in both the Botwood basin and along the Rogerson Lake Conglomerate belt (Fig. 8).

The ca. 429 (rhyolite dome) age and ca. 428 Ma (tuffite) maximum age for felsic volcanism and volcanogenic sedimentation are consistent with available age determinations for the bimodal Hodges Hill Intrusive Suite (ca. 429–426 Ma, Dickson 2000; G. Dunning, personal communication 2021), thus, the rhyolite dome and other volcanic rocks of the Charles Lake belt are confirmed as contemporaneous



with Hodges Hill plutonism. The ca. 429 and 428 Ma dates also fall within the age range of the Topsails Intrusive Suite and Springdale Group in the Notre Dame Subzone (ca. 429–426 Ma, Chandler *et al.* 1987; Whalen *et al.* 1997, 2006). Further, the ca. 422 Ma youngest zircon date from the Rogerson Lake Conglomerate sandstone sample falls within the age range of the Mount Peyton Intrusive Suite (ca. 424–418 Ma, Sandeman *et al.* 2017), and is also similar to age constraints for some rocks of the composite Fogo Island Intrusive Suite (e.g., ca. 422 Ma, Elliot *et al.* 1991; Aydin 1995).

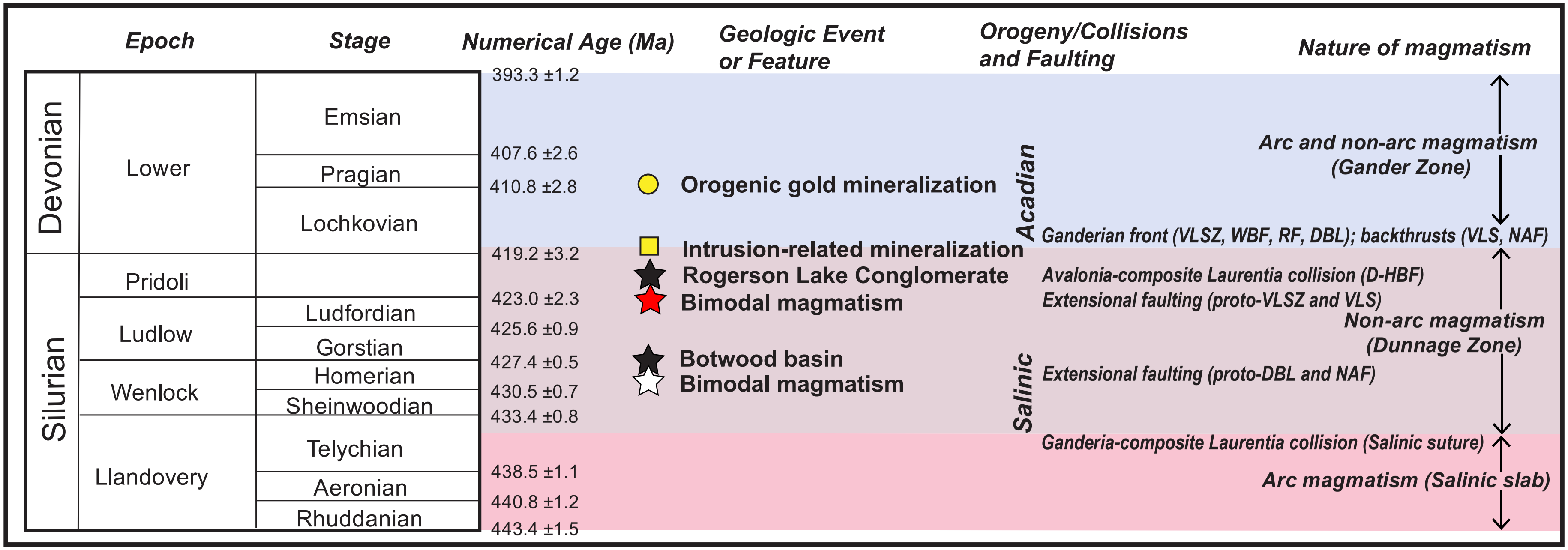


Figure 8. Silurian–Devonian geochronological summary of new U–Pb data (white and black stars) and previously published constraints on orogenesis and fault zone development in central Newfoundland (van Staal and Barr 2012; this study). Magmatic intervals are colour-coded as defined by Whalen *et al.* (2006) and van Staal *et al.* (2014). Additional age references are as follows: red star (Dunning *et al.* 1990; McNicoll *et al.* 2006; Sandeman *et al.* 2017; Honsberger *et al.* 2022); yellow square (Sandeman *et al.* 2017); and yellow circle (Honsberger *et al.* 2022). Time-scale from the International Commission on Stratigraphy (Cohen *et al.* 2013: updated 2021). Abbreviations: DBL – Dog Bay Line; D-HBF – Dover – Hermitage Bay Fault; NAF – Northern Arm Fault; RF – Reach Fault; VLS – Valentine Lake Shear Zone; VLSZ – Victoria Lake Shear Zone; WBF – Wood Brook Fault.

Additionally, the ca. 422 Ma date is consistent with ages reported for felsic volcanic rocks of the Laurenceton Formation (ca. 421 Ma, van Staal *et al.* 2014), as well as for felsic igneous rocks along the Rogerson Lake Conglomerate belt and within the southern Botwood basin (ca. 422–420 Ma, Honsberger *et al.* 2022; Figs. 1 and 2). In sum, the new geochronological data from this study, in combination with these previously published ages, indicate that volcanism and sedimentation along the western Botwood basin were active between ca. 429 and 428 Ma, whereas plutonism, volcanism, and sedimentation in the southeastern and eastern Botwood basin were active between ca. 424 and 418 Ma, with a strong pulse of felsic magmatism and associated sedimentation along the Rogerson Lake Conglomerate belt at ca. 422 Ma (Figs. 8 and 9; see Honsberger *et al.* 2022).

Transient lithospheric extension is inferred to have controlled the formation of bimodal magmatic suites and associated sedimentary rocks in the Botwood basin and Rogerson Lake Conglomerate belt of central Newfoundland (Fig. 9). Lithospheric extension provides a mechanism to explain mixing and emplacement of mantle-derived mafic magmas with their felsic anatectic products, such as the Mount Peyton Intrusive Suite (Strong 1979; Strong and Dupuy 1982) and the Fogo Island Intrusive Suite (Aydin 1995; Sandeman and Malpas 1995). Furthermore, Wenlock to Pridoli magmatism and associated clastic sedimentation corresponds to a time-period between the largely compressive stress regimes associated with the Salinic and Acadian orogenic cycles in central Newfoundland (Fig. 8), when orogenic collapse and extension would have been expected (e.g., Barbarin 1999). The occurrence of mature sandstones and siltstones in the Botwood basin is consistent with longer-lived, more-evolved extension in north-central Newfoundland compared to along the structurally thinner Rogerson Lake Conglomerate belt to the south and southwest. As such, extension, clastic sedimentation, and magmatism were time-transgressive both across- and along-strike of the Exploits Subzone, with resultant along-strike variations in the volume of sedimentary input (Fig. 9). Therefore, the Rogerson Lake Conglomerate belt is not correlative temporally with the stratigraphic base of the Botwood basin, even though the polymict conglomerate is a basal unit.

In our model, predominantly southeast-dipping (present-day coordinates) extensional fault systems were active along the western Botwood basin at ca. 429 Ma, and propagated southeastward (across-strike) and to the southwest and northeast (along-strike) between ca. 424 and 418 Ma (Fig. 9). The Wenlock to Pridoli spatio-temporal development of this extensional fault network is consistent with the findings of van Staal *et al.* (2014), who noted that Silurian magmatism gets progressively younger west-to-east across the Dunnage Zone. Such extensional fault systems may have formed during thinning associated with asthenospheric and lithospheric decompression melting and upwelling related to slab rollback and break-off, and potentially lithospheric delamination, following the terminal Salinic collision of Ganderia with composite Laurentia (Pitcher 1983, 1993; Barbarin 1990, 1999; Whalen *et al.* 1997, 2006; van Staal and Barr 2012; van Staal *et al.* 2014; Whalen and Hildebrand 2019). In this context, listric normal faults facilitated exhumation of the middle and lower crust of the Exploits Subzone (Victoria Lake Supergroup and correlatives), and erosion and deposition of such rocks contributed to the formation of clastic sedimentary cover sequences of the Botwood basin and Rogerson Lake Conglomerate belt (Fig. 9). Wenlock to Pridoli lithospheric thinning may have been an important primer for orogenic gold mineralization (e.g., Bleeker 2015) because it increased heat and fluid flow in the crust prior to Early Devonian compression, metamorphism, and magmatism.

Considering that latest Silurian extensional faulting in central Newfoundland overlaps in time with far-field collision of Avalonia and composite Laurentia (Fig. 8), extension may have involved some components of strike-slip and transtension (Dewey *et al.* 1998) because sinuous collisional boundaries would have produced oblique deformation zones (e.g., O'Brien *et al.* 1993; Dubé *et al.* 1996; O'Brien 2003; Hibbard *et al.* 2006; van Staal and Barr 2012). The relative influence of extension compared to transtension in central Newfoundland, however, remains ambiguous because of fault reactivation and deformational overprint. Thrust fault reactivation appears to have occurred throughout the Devonian to accommodate Acadian, intra-terrane, thick-skinned thrusting and shortening associated with the emplacement of structurally controlled, gold-bearing quartz veins (e.g., O'Brien *et al.* 1993; O'Brien 2003; van Staal and Barr 2012; Willner *et al.* 2018; Honsberger *et al.* 2022). Such Devonian thrust fault systems then may have been reactivated as later oblique, dextral strike-slip, transpressional deformation zones (e.g., Lafrance 1989; O'Brien *et al.* 1993; de Roo and van Staal 1994; O'Brien 2003), which we interpret to have produced the "lazy Z"-shape (Mann *et al.* 1983) of the Botwood basin and its southwesterly (Rogerson Lake Conglomerate belt) and north-easterly extensions (Figs. 1 and 2). This interpretation is consistent with the occurrence of post-Silurian, dextral strike-slip faults (e.g., Northern Arm Fault-Reach Fault) along the margins of the Botwood basin, implying that a Wenlock to Pridoli extensional fault system in central Newfoundland may have been more linear than the present map pattern suggests (Fig. 9; cf. Kusky *et al.* 1987; Kusky and Kidd 1996). The occurrence of orogenic gold-mineralized, Wenlock to Pridoli igneous and sedimentary rocks in the overall footwall of the Victoria Lake Shear Zone (Figs. 1–4) indicates that thrust burial played an essential role in the preservation of syn-extensional rocks along the central Newfoundland gold belt, opposed to uplifting these rocks and exposing them to erosion (e.g., Bleeker 2015).

In the Chaleur Bay synclinorium of northern New Brunswick, latest Silurian, extension-related magmatic suites and clastic sedimentary rock sequences of the Dickie Cove Group are associated with orogenic gold-mineralized fault splays of the Early Devonian, or younger, Rocky Brook–Millstream Fault Zone (Tremblay and Dubé 1991; Tremblay

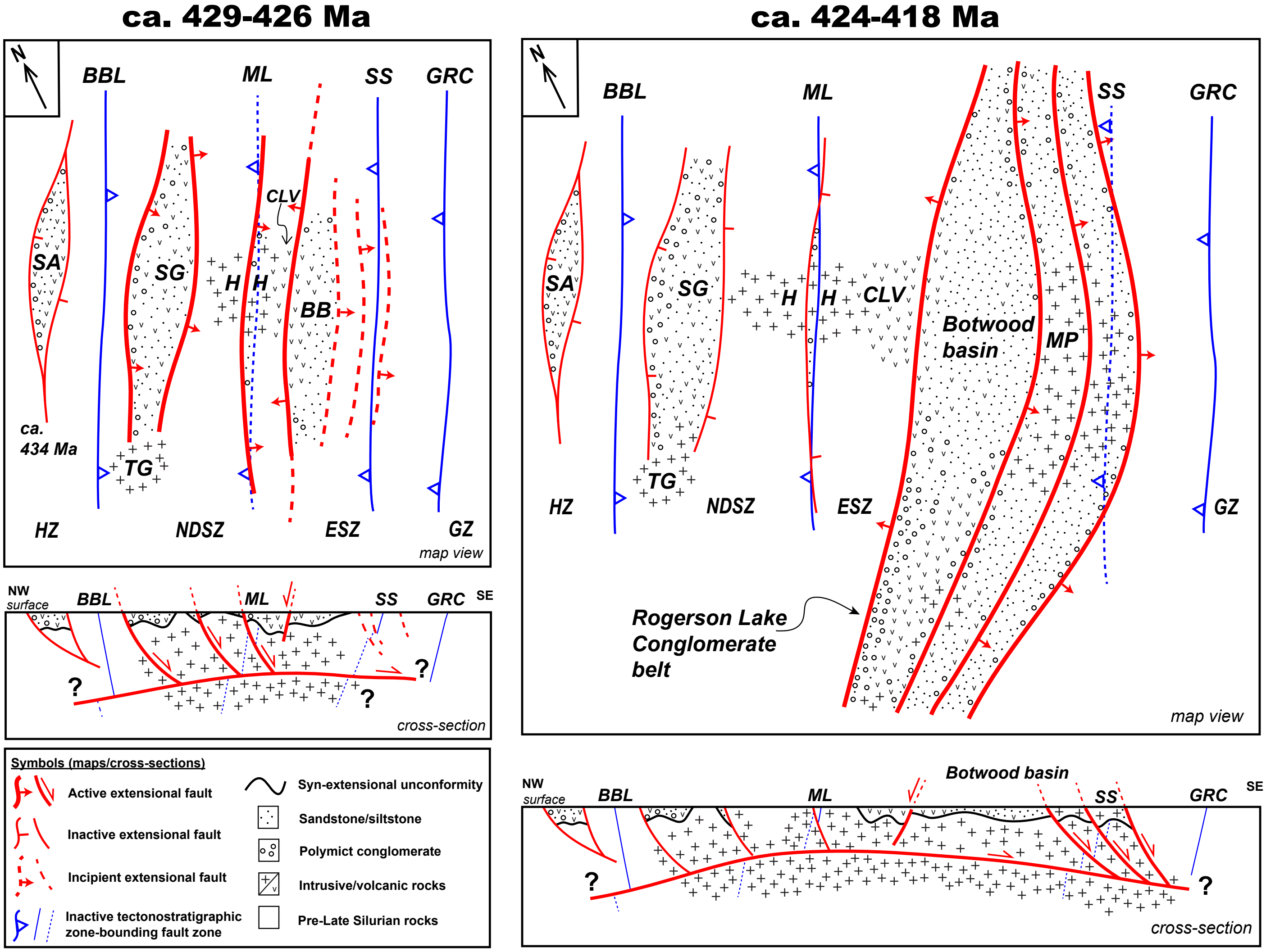


Figure 9. Structural synthesis illustrating the Late Silurian (Wenlock to Pridoli) evolution of transient extensional faults across the Dunnage Zone as a prelude to Devonian orogenic gold mineralization. Not drawn to scale. Extension in the western Botwood basin, and farther northwest in the Dunnage Zone, is inferred between ca. 429 and 426 Ma (left side), whereas extension in the southeastern and eastern Botwood basin and along the Rogerson Lake Conglomerate belt is inferred between ca. 424 and 418 Ma (right side). Cross-section interpretations are given below each map view. In this model, exhumation and erosion of pre-Late Silurian rocks (Victoria Lake Supergroup and correlatives) contributed to the formation of syn-extensional igneous and clastic sedimentary rocks along the central Newfoundland orogenic gold belt. Tectonostratigraphic zone-bounding fault zones are blue lines (dotted lines where approximate) and younger, cross-cutting extensional faults are red lines, which are interpreted to have been reactivated subsequently as thick-skinned thrusts in the Devonian. As per our interpretation of the Dog Bay Line, "Salinic suture" is used to denote the Dunnage-Gander accretionary boundary, which may not be traceable at the present erosional surface. Abbreviations: BB – Botwood basin; BBL – Baie Verte – Brompton Line; ESZ – Exploits Subzone; GRC – Gander River Complex; GZ – Gander Zone; HH/CLB – Hodges Hill Intrusive Suite and Charles Lake volcanic belt; HZ – Humber Zone; MP – Mount Peyton Intrusive Suite; ML – Mekwe'jit Line; NDSZ – Notre Dame Subzone; SA – Sops Arm Group; SG – Springdale Group; SS – Salinic suture; TG – Topsails Group/Intrusive Suite.

et al. 1993; Wilson 2007; Wilson *et al.* 2017; Dostal *et al.* 2020; Bustard *et al.* 2021). This fault zone appears to correlate with the Cape Ray–Victoria Lake–Valentine Lake fault corridor in southwestern and central Newfoundland, strongly suggesting that the orogenic gold system of central Newfoundland is continuous along-strike in the northern Appalachians.

CONCLUSIONS

Late Silurian (Wenlock to Pridoli), extension-related, bimodal magmatic suites and clastic sedimentary rocks of the Rogerson Lake Conglomerate belt and Botwood basin sequence delineate the central Newfoundland gold belt. Integrated LA-ICPMS and CA-ID-TIMS U–Pb zircon techniques produced a maximum date for deposition of the Rogerson Lake Conglomerate sequence at 421.9 ± 1.0 Ma (Pridoli); therefore, it is younger than, and stratigraphically overlies, ca. 422 Ma igneous rocks that occur along the gold belt. The same analytical approach applied to a tuffite layer toward the stratigraphic middle of the Wigwam Formation in the Botwood basin produced a maximum eruption age of 427.9 ± 3.1 Ma (Wenlock; Homerian), which is interpreted to be contemporaneous and cogenetic with the Hodges Hill Intrusive Suite, the Charles Lake volcanic belt, and associated volcanogenic sedimentation in the western Botwood basin. Although provenance interpretations are limited by the relatively small numbers of individual zircon analyses, LA-ICPMS detrital zircon age distributions are consistent with a mixed Laurentian-Gondwanan provenance for sedimentary rocks of the Rogerson Lake Conglomerate sequence and Botwood basin. An autobrecciated, flow-banded rhyolite of the Charles Lake volcanic belt from the northwestern Botwood basin has a U–Pb zircon CA-ID-TIMS age of 429.3 ± 0.7 Ma (Wenlock; Homerian), which we interpret as the eruptive age. Collectively, the new U–Pb zircon geochronological data confirm a clear spatio-temporal link between syn-extensional, Wenlock to Pridoli magmatism and sedimentation both along and across strike of the central Newfoundland gold belt (Figs. 8 and 9).

Wenlock to Pridoli magmatic and depositional ages are consistent with a structural model involving the overall southeastward (present day coordinates) propagation of a transient, time-transgressive, extensional fault system across the Exploits Subzone between ca. 429 and 418 Ma. Extensional faulting may have contributed to basin formation, subsidence, and exhumation of pre-Silurian rocks of the Exploits Subzone during that time-period. The earlier part of the history is marked by ca. 429–426 Ma syn-extensional magmatism (Hodges Hill Intrusive Suite and Charles Lake volcanic belt) and sedimentation along the northwestern margin of the Botwood basin and farther west in the Dunnage Zone (Topsails Intrusive Suite and Springdale Group). The later part is preserved as ca. 424–418 Ma syn-extensional magmatic suites and clastic sedimentary rocks along the Rogerson Lake Conglomerate belt and its extensions to the northeast along and within the Botwood basin (e.g., Mount Peyton Intrusive Suite and associated rocks). Transient lithospheric extension appears to mark the transition between the Salinic and Acadian orogenic cycles (e.g., Sandeman *et al.* this volume) and may have been important for increasing heat and fluid flow in the lithospheric mantle and crust leading to Devonian fault reactivation, crustal thickening, fluid focussing, and orogenic gold mineralization.

ACKNOWLEDGEMENTS

This research constitutes part of Natural Resources Canada's Targeted Geoscience Initiative. Thanks to Dave Evans, Cees van Staal, and Tyler Nickson for assistance with fieldwork. Appreciation is extended to the staff of the Jack Satterly Geochronology Laboratory at the University of Toronto for their on-going support and dedication. Hamish Sandeman acknowledges colleagues and staff of the Geological Survey of Newfoundland and Labrador. Internal review by Jean-Luc Pilote and external reviews by Graham Layne and David West improved the manuscript. NRCan Contribution 20220005.

REFERENCES

Aydin, N.S. 1995. Petrology of the composite mafic-felsic rocks of the Fogo Island batholith: a window to mafic magma chamber processes and the role of mantle in the petrogenesis of granitoid rocks. Unpublished Ph.D. Thesis, Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador, 307 p.

Barbarin, B. 1990. Granitoids: main petrogenetic classification in relation to origin and tectonic setting. Geological Journal 25, pp. 227–238. https://doi.org/10.1002/gj.3350250306

Barbarin, B. 1999. A review of the relationships between granitoid types, their origins and their geodynamic environments. Lithos, 46, pp. 605–626. https://doi.org/10.1016/S0024-4937(98)00085-1

Blackwood, R.F. 1982. Gander (Mount Peyton E.), Newfoundland. Map 80-198, scale 1:50 000. Geology of the Gander Lake (2D/15) and Gander River (2E/2) Area. Government of Newfoundland and Labrador, Department of Mines and Energy, Mineral Development Division, Report 82-04, 63 p.

Bleeker, W. 2002 "Timiskaming-type" conglomerate-sandstone sequences: indicators of the buoyant ascent and unroofing of composite Archean granitoid-gneiss domes. *In* Geological Association of Canada-Mineralogical Association of Canada, Program with Abstracts 27. Joint annual meeting, Saskatoon, May 27–29, 2002, p. 11.

Bleeker, W. 2012. Lode gold deposits in ancient deformed and metamorphosed terranes: the role of extension in the formation of Timiskaming basins and large gold deposits, Abitibi greenstone belt—a discussion. *In* Targeted Geoscience Initiative (TGI-4), Summary of Field Work and Other Activities 2012. Ontario Geological Survey, Open File Report 6280, pp. 47-1–47-12.

Bleeker, W. 2015. Synorogenic gold mineralization in granite-greenstone terranes: the deep connection between extension, major faults, synorogenic clastic basins, magmatism, thrust inversion, and long-term preservation. *In* Targeted Geoscience Initiative (TGI-4), Contributions to the Understanding of Precambrian Lode Gold Deposits and Implications for Exploration. *Edited by* B. Dubé and P. Mercier-Langevin. Geological Survey of Canada, Open File 7852, pp. 25–47. https://doi.org/10.4095/296626

Bleeker, W. and Honsberger, I.W. 2022. Triangle zone thrust geometry as a natural focusing mechanism in orogenic gold systems. Geological Association of Canada, Mineralogical Association of Canada, International Association of Hydrogeologists/Canadian National Committee, and the Canadian Society of Petroleum Geologists May 15–18, 2022. (Halifax2022-Abstract 1), p. 57. https://halifax2022.atlanticgeosciencesociety.ca/technical-program/

Boyce, W.D. and Dickson, W.L. 2006. Recent fossil finds in the Indian Islands Group, central Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 6-1, pages 221–231.

Buchan K.L. and Hodych J.P. 1992. Early Silurian paleolatitude for central Newfoundland from paleomagnetism of the Wigwam Formation. Canadian Journal of Earth Sciences, 29, pp. 1652–1661. https://doi.org/10.1139/e92-130

Bustard, A.L. Lentz, D.R., and Walker, J.A. 2021. Geochemical evaluation of mineralization and igneous activity in the vicinity of the Elmtree deposit, northeastern New Brunswick, Canada. Atlantic Geoscience Society Abstracts. Atlantic Geology, 57, p. 107.https://doi.org/10.4138/atlgeol.2021.001

Chandler, F., Sullivan, R., and Currie, K. 1987. The age of the Springdale Group, western Newfoundland, and correlative rocks–evidence for a Llandovery overlap assemblage in the Canadian Appalachians. Transactions of the Royal Society of Edinburgh, Earth Sciences, 78, pp. 41–49. https://doi.org/10.1017/S0263593300010944

Cohen, K.M., Finney, S.C., Gibbard, P.L., and Fan, J.X. 2013. Updated 2021. The ICS International Chronostratigraphic Chart. Episodes, 36, pp. 199–204. https://doi.org/10.18814/epiiugs/2013/v36i3/002

Colman-Sadd, S.P. 1980. Geology of south–central Newfoundland and evolution of the eastern margin of Iapetus. American Journal of Science 280, pp. 991–1017. https://doi.org/10.2475/ajs.280.10.991

Colman-Sadd, S.P. 1985. Geology of the Burnt Hill map area (NTS 2D/5), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-3, 108 p. includes map 85-001 Burnt Hill, scale 1:50 000.

Colman-Sadd, S.P. 1994. Silurian subaerial rocks near Lewisporte, central Newfoundland. *In* Current Research, Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 94-1, pp. 65–76.

Colman-Sadd, S., Hayes, J., and Knight, I. 1990. The geology of the Island of Newfoundland. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Map 90-01, GS# NFLD/2192, scale 1:1 000 000.

Connelly, J.N. and Heaman, L.M. 1993. U–Pb geochronological constraints on the tectonic evolution of the Grenville Province, western Labrador. Precambrian Research, 63, pp. 123–142. https://doi.org/10.1016/0301-9268(93)90008-P

Currie, K. L. 1995. The northeastern end of the Dunnage Zone in Newfoundland. Atlantic Geology, 31, pp. 25–38. https://doi.org/10.4138/2096

Dallmeyer, R.D., Kean, B.F., Odom, A.L., and Jayasinghe, N.R. 1983. Age and contact-metamorphic effects of the Overflow Pond granite: an undeformed pluton in the Dunnage Zone of the Newfoundland Appalachians. Canadian Journal of Earth Sciences, 20, pp. 1639–1645. https://doi.org/10.1139/e83-155

Davis, D.W. 2002. U–Pb geochronology of Archean metasediments in the Pontiac and Abitibi subprovinces, Quebec, constraints on timing, provenance and regional tectonics. Precambrian Research, 115, pp. 97–117. https://doi.org/10.1016/S0301-9268(02)00007-4

de Roo, J.A. and van Staal, C.R. 1994. Transpression and extensional collapse: steep belts and flat belts in the Appalachian Central Mobile Belt, northern New Brunswick, Canada. Geological Society of America Bulletin, 106, pp. 541–552. https://doi.org/10.1130/0016-7606(1994)106<0541:TAECSB>2.3.CO;2

Dec, T. and Colman-Sadd, S.P. 1990. Timing of ophiolite emplacement onto the Gander Zone: evidence from providence studies in the Mount Cormack Subzone. *In* Current Research, Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 90-1, pp. 289–303.

Dewey, J.F., Holdsworth, R.E., and Strachan, R.A. 1998. Transpression and transtension zones. *In* Continental transpressional and transtensional tectonics. *Edited by* R.E. Holdsworth, R.A. Strachan, and J.F. Dewey. Geological Society, London, Special Publications, 135, pp. 1–14. https://doi.org/10.1144/GSL.SP.1998.135.01.01

Dickson, W.L. 1993. Geology of the Mount Peyton map area (NTS 2D/14), central Newfoundland. *In* Current Research, Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 93-1, pp. 209–220.

Dickson, W.L. 1999. Geology of the Hodges Hill (NTS 2E/04) map area, north-central Newfoundland. *In* Current Research, Newfoundland Department of Mines and Energy, Geological Survey, Report 99-1, pp. 317–342.

Dickson, W.L. 2000. Geology of the Hodges Hill (NTS 2E/04) map area, central Newfoundland. Newfoundland Department of Mines and Energy, Geological Survey, Map 2000-23, Open File 002E/04/1082, scale 1:50 000.

Dickson, W.L. 2006. The Silurian Indian Islands Group and its relationships to adjacent units. *In* Current Research, Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 06-1, pp. 1–24.

Dickson, W.L., O'Brien, B.H., and Colman-Sadd, S.P. 2000. Geology of the Botwood map area [NTS 2E/3], central Newfoundland. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Open File 2E/03/1067 Version 2.0, Map 2000-11, scale 1:50 000.

Dickson, W.L., McNicoll, V.J., Nowlan, G.S., and Dunning, G.R. 2007. The Indian Islands Group and its relationships to adjacent units: recent Data. *In* Current Research, Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 07-1, pp. 1–9.

Donaldson, C., Sood, R., Barth, A., Christie, H., and Kerr, A. 2015. Geological relationships in northwestern Fogo Island and their implications for the timing of orogenic events. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 15-1, pp. 27–42.

Dostal, J., Wilson, R.A., and Jutras, P. 2020. Petrogenesis of Siluro-Devonian rhyolite of the Tobique Group in the northwestern Appalachians (northern New Brunswick, Canada): tectonic implications for the accretion history of peri-Gondwanan terranes along the Laurentian margin. *In* Pannotia to Pangea: Neoproterozoic and Paleozoic orogenic cycles in the Circum-Atlantic region. *Edited by* J.B. Murphy, R.A. Strachan, and C. Quesada. Geological Society of London Special Publications, 503, pp. 391–407. https://doi.org/10.1144/SP503-2019-229.

Dubé, B., Dunning, G.R., Lauzière, K., and Roddick, J.C. 1996. New insights into the Appalachian Orogen from geology and geochronology along the Cape Ray fault zone, southwest Newfoundland. Geological Society of America Bulletin, 108, pp. 101–116. https://doi.org/10.1130/0016-7606(1996)108<0101:NIITAO>2.3.CO;2

Dunning, G.R., O'Brien, S.J., Colman-Sadd, S.P., Blackwood, R.F., Dickson, W.L., O'Neill, P.P., and Krogh, T.E. 1990. Silurian Orogeny in the Newfoundland Appalachians. Journal of Geology, 98, pp. 895–913. https://doi.org/10.1086/629460

Dunsworth, S. and Walford, P. 2018. Marathon's Valentine Lake Property – A developing multi-million-ounce gold camp in central Newfoundland, Canada. Geological Association of Canada-Newfoundland and Labrador section abstracts. Atlantic Geology, 54, 136–137 p. https://doi.org/10.4138/atlgeol.2018.003

Elliot, C.G., Dunning, G.R., and Williams, P.F. 1991. New U–Pb zircon age constraints on the timing of deformation in north-central Newfoundland and implications for early Paleozoic Appalachian orogenesis. Geological Society of America Bulletin, 103, pp. 125–135. https://doi.org/10.1130/0016-7606(1991)103<0125:NUPZAC>2.3.CO;2

Evans, D.T.W. 1996. Epigenetic gold occurrences, eastern and central Dunnage Zone, Newfoundland. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Mineral Resources Report 9, 135 p.

Evans, D.T.W. 2004. Epigenetic gold occurrences, Baie Verte Peninsula, (NTS 12H/09,16 and 12I/01) Newfoundland. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Mineral Resource Report 11, 159 p.

Evans, D.T.W., Kean, B.F., and Dunning, G.R. 1990. Geological studies, Victoria Lake Group, central Newfoundland. *In* Current Research, Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 90-1, p. 135–144.

Froude, T. 2021. Sokoman reports first barge-based drill results Moosehead Gold Project, Central Newfoundland; Phase 6 drill Program doubled to 100 000 m. Sokoman Minerals Corp. press release, November 10, 2021. URL https://sokomanmineralscorp.com/2021/11/10/sokoman-reports-first-barge-based-drill-results-moosehead-gold-project-central-newfoundland/ 10 December 2021.

Gerstenberger, H. and Haase, G. 1997. A highly effective emitter substance for mass spectrometric Pb isotope ratio determinations. Chemical Geology, 136, pp. 309–312. https://doi.org/10.1016/S0009-2541(96)00033-2

Gower, C.F. and Krogh, T.E. 2002. A U–Pb geochronological review of the Proterozoic history of the eastern Grenville Province. Canadian Journal of Earth Sciences, 39, pp. 795–829. https://doi.org/10.1139/e01-090

Heaman, L.M., Erdmer, P., and Owen, J.V. 2002. U–Pb geochronologic constraints on the crustal evolution of the Long Range Inlier, Newfoundland. Canadian Journal of Earth Sciences, 39, pp. 845–865. https://doi.org/10.1139/e02-015

Henderson, B.J., Collins, W.J., Murphy, J.B., and Hand, M. 2018. A hafnium isotopic record of magmatic arcs and continental growth in the Iapetus Ocean: the contrasting evolution of Ganderia and the peri-Laurentian margin. Gondwana Research, 58, pp. 141–160. https://doi.org/10.1016/j.gr.2018.02.015

Hibbard, J.P., van Staal, C.R. Rankin, D.W., and Williams, H. 2006. Lithotectonic map of the Appalachian Orogen, Canada-United States of America. Geological Survey of Canada Map 2096A, scale 1:1 500 000. https://doi.org/10.4095/221912

Hinchey, A.M., Rayner, N., and Davis, W.J. 2020. Episodic Paleoproterozoic crustal growth preserved in the Aillik Domain, Makkovik Province, Labrador. Precambrian Research, 337, 105526. https://doi.org/10.1016/j.precamres.2019.105526

Hodgson, C.J. 1993. Mesothermal lode-gold deposits. *In* Mineral Deposit Modelling. *Edited by* R.V. Kirkham, W.D. Sinclair, R.I. Thorpe, and J.M. Duke. Geological Association of Canada, Special Paper 40, pp. 635–678.

Honsberger, I.W., Bleeker, W., Sandeman, H.A.I., and Evans, D.T.W. 2019. Lithological and structural setting of structurally controlled gold mineralization in the Wilding Lake region, central Newfoundland. *In* Targeted Geoscience Initiative 2018 report of activities. *Edited by* N. Rogers. Geological Survey of Canada, Open File 8549, pp. 59–69. https://doi.org/10.4095/313640

Honsberger, I.W., Bleeker, W., Kamo, S.L., Sandeman, H.A.I., and Evans, D.T.W. 2020. The emerging Paleozoic gold district of central Newfoundland: new insights on structural controls and tectonic drivers of gold mineralization and preservation. *In* Targeted Geoscience Initiative 5: Contributions to the Understanding of Gold Deposits. *Edited by* P. Mercier-Langevin, C.J.M. Lawley, and S. Castonguay. Geological Survey of Canada, Open File 8712, pp. 193–210. https://doi.org/10.4095/326024

Honsberger, I.W., Bleeker, W., Kamo, S.L., Sandeman, H.A.I., Evans, D.T.W., van Staal, C.R., Rogers, N., and Dunning, G.R. 2022. Latest Silurian syntectonic sedimentation and magmatism and Early Devonian orogenic gold mineralization, central Newfoundland Appalachians, Canada: setting, structure, lithogeochemistry, and high-precision U–Pb geochronology. Geological Society of America Bulletin 133, Published on-line March 3, 2022. https://doi.org/10.1130/B36083.1

Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C., and Essling, A.M. 1971. Precision measurement of half-lives and specific activities of ^{235}U and ^{238}U. Physical Review C 4, pp. 1889–1906. https://doi.org/10.1103/PhysRevC.4.1889

James, D.T., Kamo, S., and Krogh, T. 2002. Evolution of 3.1 and 3.0 Ga volcanic belts and a new thermotectonic model for the Hopedale Block, North Atlantic craton, Canada. Canadian Journal of Earth Sciences, 39, pp. 687–710. https://doi.org/10.1139/e01-092

Karlstrom K. E., van der Pluijm B. A., and Williams P. F. 1982. Structural interpretation of the eastern Notre Dame Bay area, Newfoundland: regional post-Middle Silurian thrusting and asymmetrical folding. Canadian Journal of Earth Sciences, 19, pp. 2325–2341. https://doi.org/10.1139/e82-204

Kean, B.F. and Evans, D.T.W. 1988. Regional metallogeny of the Victoria Lake Group. *In* Current Research, Newfoundland Department of Mines, Mineral Developments Division, Report 88-1, pp. 319–330.

Kean, B.F. and Jayasinghe, N.R. 1980. Geology of the Lake Ambrose (12A/10) and Noel Paul's Brook (12A/9) map areas, Newfoundland. Newfoundland Department of Mines and Energy Report 88-1, 29 p.

Kerr, A. 1997. Space-time composition relationships among Appalachian plutonic suites in Newfoundland. *In* The Nature of Magmatism in the Appalachian orogen. *Edited by* A.K. Sinha, J.B. Whalen, and J.P. Hogan. Geological Society of America Memoirs, 191. pp. 193–220. https://doi.org/10.1130/0-8137-1191-6.193

Kerr, A. 2013. The Fogo Process from a geologist's perspective: a discussion of models and research problems. *In* Current Research, Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 13-1, pp. 233–265.

Ketchum, J.W.F., Culshaw, N.G., and Barr, S.M. 2002. Anatomy and orogenic history of a Paleoproterozoic accretionary belt: the Makkovik Province, Labrador, Canada. Canadian Journal of Earth Sciences, 39, pp. 711–730. https://doi.org/10.1139/e01-099

Krogh, T.E. 1973. A low-contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations. Geochimica et Cosmochimica Acta, 37, pp. 485–494. https://doi.org/10.1016/0016-7037(73)90213-5

Kuiper, Y.D. and Hepburn, J.C. 2021. Detrital zircon populations of the eastern Laurentian margin in the Appalachians. Geology, 49, pp. 233–237. https://doi.org/10.1130/G48012.1

Kusky, T.M. and Kidd, W.S.F. 1996. Tectonic implication of early Silurian thrust imbrication of the northern Exploits Subzone, central Newfoundland. Journal of Geodynamics 22, pp. 229–265. https://doi.org/10.1016/0264-3707(96)00011-7

Kusky T.M., Kidd W.S.F., and Bradley D.C. 1987. Displacement history of the Northern Arm Fault, and its bearing on the post-Taconic evolution of North-central Newfoundland. Journal of Geodynamics, 7, pp. 105–133. https://doi.org/10.1016/0264-3707(87)90067-6

Lafrance, B. 1989. Structural evolution of a transpression zone in north central Newfoundland. Journal of Structural Geology, 11, pp. 705–716. https://doi.org/10.1016/0191-8141(89)90006-0

Lincoln, N., Farmer, R., Eccles, R., and Deering, P.D. 2018. Preliminary economic assessment of the Valentine Lake gold project Newfoundland, NL, Canada. Lycopodium Minerals Canada Ltd. for Marathon Gold. <www.marathongold.com/site/assets/files/5047/2018-10-pea.pdf> December 2, 2018.

Ludwig, K.R. 1998. On the treatment of concordant uranium-lead ages. Geochimica et Cosmochimica Acta, 62, pp. 665–676. https://doi.org/10.1016/S0016-7037(98)00059-3

Ludwig, K.R. 2003. User's manual for Isoplot 3.00 a geochronological toolkit for Excel. Berkeley Geochronological Center Special Publication 4, 71 p.

Mann, W.P., Hempton, M., Bradley, D., and Burke, K. 1983. Development of pull-apart basins. Journal of Geology, 91, pp. 529–554. https://doi.org/10.1086/628803

Mattinson, J.M. 2005. Zircon U–Pb chemical abrasion ("CA-TIMS") method: combined annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages. Chemical Geology 220, pp. 47–66. https://doi.org/10.1016/j.chemgeo.2005.03.011

McNicoll, V.J., Squires, G.C., Wardle, R.J., Dunning, G.R., and O'Brien, B.H. 2006. U–Pb geochronological evidence for Devonian deformation and gold mineralization in the eastern Dunnage Zone, Newfoundland. *In* Current Research, Report 06-1, pp. 45–60.

Miller, H.G. 1988. Geophysical interpretation of the geology of the northeast Gander Terrane, Newfoundland. Canadian Journal of Earth Sciences 25, pp. 1161–1174. https://doi.org/10.1139/e88-114

O'Brien, B.H. 1993. Geology of the region around Botwood (parts of 2E/3,4,6), north-central Newfoundland. Newfoundland Department of Mines and Energy, Geological Survey, Map 93-168, Open File 002E/0869, scale 1:50 000

O'Brien, B.H. 2003. Geology of the central Notre Dame Bay region (Parts of NTS areas 2E/3,6,11) northeastern Newfoundland. Newfoundland and Labrador Department of Mines and Energy, Geological Survey Report 03-03, 147 p.

O'Brien, B.H., O'Brien, S.J., Dunning, G.R., and Tucker, R.D. 1993. Episodic reactivation of a Late Precambrian mylonite zone on the Gondwana margin of the Appalachians, southern Newfoundland. Tectonics, 12, pp. 1043–1055. https://doi.org/10.1029/93TC00110

O'Neill, P. and Blackwood, F. 1989. A proposal for revised stratigraphic nomenclature of the Gander and Davidsville Groups and the Gander River Ultrabasic belt of northeastern Newfoundland. *In* Current Research, Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 89-1, pp. 127–130.

Pitcher, W.S. 1983. Granite type and tectonic environment. *In* Mountain Building Processes. *Edited by* K.J. Hsü. London, Academic Press, pp. 19–40.

Pitcher, W.S. 1993. The Nature and Origin of Granite. London, Blackie, 321 p. https://doi.org/10.1007/978-94-017-3393-9

Pollock, J.C., Wilton, D.H.C., van Staal, C.R., and Morrissey, K.D. 2007. U–Pb detrital zircon geochronological constraints on the Early Silurian collision of Ganderia and Laurentia along the Dog Bay Line: the terminal Iapetan suture in the Newfoundland Appalachians. American Journal of Science, 307, pp. 399–433. https://doi.org/10.2475/02.2007.04

Poulsen, K.H., Robert, F., and Dubé, B. 2000. Geological classification of Canadian gold deposits. Geological Survey of Canada, Bulletin 540, 106 p. https://doi.org/10.4095/211094

Rogers, N. and van Staal, C.R. 2005. Geology, Grand Falls, Newfoundland and Labrador. Geological Survey of Canada, Open File 4545, scale 1: 50 000. https://doi.org/10.4095/221290

Rogers, N., van Staal, C.R., McNicoll, V.J., Squires, G.C., Pollock, J., and Zagorevski, A. 2005. Geology, Lake Ambrose and part of Buchans, Newfoundland and Labrador. Geological Survey of Canada, Open File 4544, scale 1:50 000. https://doi.org/10.4095/221289

Rogers, N., van Staal, C.R., McNicoll, V.J., Pollock, J., Zagorevski, A., and Whalen, J. 2006. Neoproterozoic and Cambrian arc magmatism along the eastern margin of the Victoria Lake Supergroup: a remnant of Ganderian basement in central Newfoundland? Precambrian Research, 147, pp. 320–341. https://doi.org/10.1016/j.precamres.2006.01.025

Sambridge, M.S. and Compston, W. 1994. Mixture modeling of multi-component data sets with application to ion-probe zircon ages. Earth Planetary Science Letters, 128, p. 373–390. https://doi.org/10.1016/0012-821X(94)90157-0

Sandeman, H.A.I. 2021. The Dog Bay Line in northeast Newfoundland, Canada: an overview of the current state of knowledge. Geological Association of Canada-Newfoundland and Labrador section abstracts. Atlantic Geology, 57, p. 144. https://doi.org/10.4138/atlgeol.2021.001

Sandeman, H.A.I. and Malpas, J.G. 1995. Epizonal I- and A-type granites and associated ash-flow tuffs, Fogo Island, northeast Newfoundland. Canadian Journal of Earth Sciences, 32, pp. 1835–1844. https://doi.org/10.1139/e95-141

Sandeman, H.A.I., Dunning, G.R., McCullough, C.K., and Peddle, C. 2017. U–Pb geochronology, petrogenetic relationships and intrusion-related precious-metal mineralization in the northern Mount Peyton Intrusive Suite: implications for the origin of the Mount Peyton trend, central Newfoundland (NTS 2D/04). *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 17-1, pp 189–217.

Sandeman, H.A.I., Honsberger, I.W., and Camacho, A. 2022 (this volume). Overview of age constraints for gold mineralization in central and western Newfoundland and new $^{40}Ar/^{39}Ar$ ages for white mica from selected auriferous zones. Atlantic Geoscience, 58,. https://doi.org/10.4138/atlgeo.2022.010.

Stacey, J.S. and Kramers, J.D. 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. Earth and Planetary Science Letters 26, pp. 207–221. https://doi.org/10.1016/0012-821X(75)90088-6

Strong, D.F. 1979. The Mount Peyton batholith, central Newfoundland: a bimodal calc-alkaline suite. Journal of Petrology 20, pp. 119–138. https://doi.org/10.1093/petrology/20.1.119

Strong, D.F. and Dupuy, C. 1982. Rare earth elements in the bimodal Mount Peyton batholith: evidence of the crustal anataxis by mantle-derived magma. Canadian Journal of Earth Sciences, 19, pp. 308–315. https://doi.org/10.1139/e82-022

Todd, S.E., Pufahl, P.K., Murphy, J.B., and Taylor, K.G. 2018. Sedimentology and oceanography of Early Ordovician ironstone, Bell Island, Newfoundland: ferruginous seawater and upwelling in the Rheic Ocean. Sedimentary Geology, 379, pp. 1–15. https://doi.org/10.1016/j.sedgeo.2018.10.007

Tomlinson, K.Y., Davis, D.W., Stone, D., and Hart, T.R. 2003. U–Pb age and Nd isotopic evidence for crustal recycling and Archean terrane development in the south-central Wabigoon subprovince, Canada. Contributions to Mineralogy and Petrology, 144, pp. 684–702. https://doi.org/10.1007/s00410-002-0423-0

Tremblay, A. and Dubé, B.1991. Structural relationships between some gold occurrences and fault zones in the Bathurst area, northern New Brunswick. *In* Current Research, Part D. Geological Survey of Canada, Paper 91-1D, pp. 89–99. https://doi.org/10.4095/132590

Tremblay, A., Faure, S., and Dubé, B. 1993. Gold occurrences of the Rocky Brook–Millstream Fault, northern Appalachians, New Brunswick. *In* Current Research, Part E. Geological Survey of Canada, Paper 93-1E, pp. 337–346. https://doi.org/10.4095/184129

Tuach, J. 1992. List of gold occurrences and deposits on the Island of Newfoundland. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File 2188, 107 p.

Tuach, J., Dean, P.L., Swinden, H.S., O'Driscoll, C., Kean, B.F., and Evans, D.T.W. 1988. Gold mineralization in Newfoundland: a 1988 review. Newfoundland Department of Mines, Mineral Development Division, Report 88-1, p. 279–306.

Tucker, R.D. and Gower, C.F. 1994. A U–Pb geochronological framework for the Pinware Terrane, Grenville Province, Southeast Labrador. Journal of Geology, 102, pp. 67–78. https://doi.org/10.1086/629648

Valverde-Vaquero, P. and van Staal, C.R. 2002. Geology and magnetic anomalies of the Exploits-Meelpaeg boundary zone in the Victoria Lake area (central Newfoundland): regional implications. *In* Current Research, Newfoundland Department of Mines and Energy, Geological Survey, Report 02-1, p. 197–209.

Valverde-Vaquero, P., van Staal, C.R., McNicoll, V., and Dunning, G.R. 2006. Mid-Late Ordovician magmatism and metamorphism along the Gander margin in central Newfoundland. Journal of the Geological Society of London, 163, pp. 347–362. https://doi.org/10.1144/0016-764904-130

van der Velden, A.J., van Staal, C.R., and Cook, F.A. 2004. Crustal structure, fossil subduction, and the tectonic evolution of the Newfoundland Appalachians: evidence from a reprocessed seismic reflection survey. Geological Society of America Bulletin, 116, pp. 1485–1498, https://doi.org/10.1130/B25518.1

van Staal, C.R. and Barr, S.M. 2012. Lithospheric architecture and tectonic evolution of the Canadian Appalachians and associated Atlantic margin. *In* Tectonic Styles in Canada Revisited: the LITHOPROBE Perspective. *Edited by* J.A. Percival, F.A. Cook, and R.M. Clowes. Geological Association of Canada Special Paper 49, pp. 41–95.

van Staal, C.R., Valverde-Vaquero, P., Zagorevski, A., Rogers, N., Lissenberg, C.J., and McNicoll, V.J. 2005. Geology, Victoria Lake, Newfoundland and Labrador. Geological Survey of Canada, Open File 1667, scale 1:50 000. https://doi.org/10.4095/221287

van Staal, C.R., Zagorevski, A., McNicoll, V.J., and Rogers, N. 2014. Time-transgressive Salinic and Acadian orogenesis, magmatism, and Old Red Sandstone sedimentation in Newfoundland. Geoscience Canada, 41, pp. 138–164. https://doi.org/10.12789/geocanj.2014.41.031

Waldron, J.W.F., McNicoll, V.J., and van Staal, C.R. 2012. Laurentia-derived detritus in the Badger Group of central Newfoundland: deposition during closing of the Iapetus Ocean. Canadian Journal of Earth Sciences, 49, pp. 207–221. https://doi.org/10.1139/e11-030

Wardle, R.J. 2005. Gold. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Commodity Series Report 4, 12 p.

Whalen, J.B. and Hildebrand, R. S. 2019. Trace element discrimination of arc, slab failure, and A-type granitic rocks. Lithos, 348-349, 105179. https://doi.org/10.1016/j.lithos.2019.105179

Whalen, J.B., Jenner, G.A., Longstaffe, F.J., Gariepy, C., and Fryer, B. 1997. Implications of granitoid geochemical and isotopic (Nd, O, Pb) data from the Cambro–Ordovician Notre Dame arc for the evolution of the Central Mobile Belt, Newfoundland Appalachians. *In* The Nature of Magmatism in the Appalachian Orogen. *Edited by* A.K. Sinha, J.B. Whalen, and J.P. Hogan. Geological Society America Memoir, 191, pp. 367–395. https://doi.org/10.1130/0-8137-1191-6.367

Whalen, J.B., McNicoll, V.J., van Staal, C.R., Lissenberg, C.J., Longstaffe, F.J., Jenner, G.A., and van Breemen, O. 2006. Spatial, temporal and geochemical characteristics of Silurian collision zone magmatism, Newfoundland Appalachians: an example of a rapidly evolving magmatic system related to slab break-off. Lithos, 89, pp. 377–404. https://doi.org/10.1016/j.lithos.2005.12.011

White, S.E. and Waldron, J.W.F. 2022. Along-strike variations in the deformed Laurentian margin in the Northern Appalachians: role of inherited margin geometry and colliding arcs. Earth Science Reviews 226, 103931. https://doi.org/10.1016/j.earscirev.2022.103931

Willner, A.P., van Staal, C.R., Zagorevski, A., Glodnye, J., Romere, R.L., and Sudof, M. 2018. Tectonometamorphic evolution along the Iapetus suture zone in Newfoundland: evidence for polyphase Salinic, Acadian and Neoacadian very low- to medium-grade metamorphism and deformation. Tectonophysics, 742–743, pp. 137–167. https://doi.org/10.1016/j.tecto.2018.05.023

Willner, A.P., van staal, C.R., Glodny, J., Sudo, M., Zagorevski, A. 2022. Conditions and timing of metamorphism near the Baie Verte Line (Baie Verte Peninsula, NW Newfoundland, Canada): multiple reactivations within the suture zone of an arc-continent collision. *In* New Developments in the Appalachian-Caledonian-Variscan Orogen. *Edited by* Y.D. Kuiper, J.B. Murphy, R.D. Nance, R.A. Strachan, and M.D. Thompson. Geological Society of America Special Paper 554. https://doi.org/10.1130/2022.2554(09)

Williams, H. 1962. Botwood (West Half) Map-area, Newfoundland. Geological Survey of Canada Paper 62-9, 16 p. https://doi.org/10.4095/123914

Williams, H. 1972. Stratigraphy of Botwood map-area, northeastern Newfoundland. Geological Survey of Canada, Open File Report 113, 98 p.

Williams, H. 1978. Tectonic lithofacies map of the Appalachian Orogen. Memorial University of Newfoundland, St John's, Newfoundland and Labrador, scale 1:1 000 000.

Williams, H. 1993. Stratigraphy and structure of the Botwood Belt and definition of the Dog Bay Line in northeastern Newfoundland. *In* Current Research, Part D, Geological Survey of Canada, Paper 93-1D, pp. 19–27. https://doi.org/10.4095/134267

Williams, H., Colman-Sadd, S.P., and Swinden, H.S. 1988. Tectonic-stratigraphic subdivisions of central Newfoundland. Geological Survey of Canada Paper 88-1B, pp. 91–98. https://doi.org/10.4095/122425

Williams, H., Currie, K.L., and Piasecki, M.A.J. 1993. The Dog Bay Line: a major Silurian tectonic boundary in northeast Newfoundland. Canadian Journal of Earth Sciences, 30, pp. 2481–2494. https://doi.org/10.1139/e93-215

Williams, H., Dean, P.L., and Pickering, K.T. 1995. Botwood Belt. *In* Geology of the Appalachian–Caledonian Orogen in Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada, 6, pp. 413–420. https://doi.org/10.4095/205242

Wilson, R. 2007. Silurian–Devonian stratigraphy and structure in the Arleau Brook region, northern margin of the Miramichi Highlands, New Brunswick. *In* Abstracts 2007, Exploration and Mining New Brunswick. *Edited by* S.A.A Merlini. New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division Information Circular 2007-1, pp. 53-56.

Wilson, R.A., van Staal, C.R., and Kamo, S.L. 2017. Rapid transition from the Salinic to Acadian orogenic cycles in the northern Appalachian orogen: evidence from northern New Brunswick, Canada. American Journal of Science, 317, pp. 449–482. https://doi.org/10.2475/04.2017.02

Zagorevski, A., van Staal, C.R., McNicoll, V., and Rogers, N. 2007. Tectonic architecture of an arc-arc collision zone, Newfoundland Appalachians. *In* Formation and Applications of the Sedimentary Record in Arc Collision Zones. *Edited by* A. Draut, P.D. Clift, and D.W. Scholl. Geological Society of America Special Paper 436, pp. 1–26. https://doi.org/10.1130/2008.2436(14)

Editorial responsibility: Mitchell Kerr