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A tale of two basins: Juxtaposition of the Ediacaran fossil-bearing St. John's Basin against the Ediacaran glaciovolcanic Bonavista Basin on the Bonavista Peninsula, Avalon Zone, Newfoundland

Saga de deux bassins : juxtaposition du bassin fossilifère édiacarien de St. John's contre le bassin glaciovolcanique de Bonavista sur la péninsule de Bonavista, zone d'Avalon, Terre-Neuve

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Article abstract

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Magmatic rocks of the Bull Arm Group (basal MSG) were emplaced during protracted regional extension. The onset is marked by eruption of ca. 600 Ma calc-alkaline basalt and coeval deposition of cobble conglomerate on the ca. 605–600 Ma CPG-MSG unconformity on western Bonavista Peninsula. Extension continued through extrusion of ca. 592 Ma tuffs and bimodal volcanics of the Plate Cove volcanic belt east of the Indian Arm Fault. The belt is overlain to the east by the mainly clastic Rocky Harbour Group. Its tuffs and peperite, locally dated at ca. 585 and 576 Ma, respectively, bracket the ca. 580 Ma Trinity diamictite—a shallow-marine equivalent of the deep-marine Gaskiers Formation of the St. John's Basin on Avalon Peninsula. Small-volume alkaline basalts below and above the Trinity diamictite provide a clear spatio-temporal link between glaciation and extensional magmatism. Strata below the Trinity diamictite display features reflecting a glaciogenic origin and increase the thickness and areal extent of Ediacaran Gaskiers glacial deposits. The Gaskiers glaciation likely lasted for several million years and was coeval with ca. 600–576 Ma extensional magmatism within proto-West Avalonia or along its margin.

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A tale of two basins: juxtaposition of the Ediacaran fossil-bearing St. John's Basin against the Ediacaran glaciovolcanic Bonavista Basin on the Bonavista Peninsula, Avalon Zone, Newfoundland

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ABSTRACT

The Musgravetown Supergroup (MSG) of the Bonavista Basin is the central unit of Neoproterozoic strata on the Bonavista Peninsula, Avalon Zone, northeastern Newfoundland. In west Bonavista, the deep-marine ca. 620–600 Ma Connecting Point Group (CPG) is unconformably overlain by the ca. 600–540 Ma terrestrial to shallow-marine volcanic-sedimentary MSG, but fault-bounded to the east by the Indian Arm Fault. On eastern Bonavista Peninsula, the Spillars Cove Fault separates the MSG from St. John's Basin rocks, correlative with Ediacaran strata of the Avalon Peninsula (Conception, St. John's and Signal Hill groups) as corroborated by a U–Pb age of ca. 566 Ma. Age constraints presented here confirm the regional significance of the Spillars Cove Fault that bounds temporally and stratigraphically distinct strata.

Magmatic rocks of the Bull Arm Group (basal MSG) were emplaced during protracted regional extension. The onset is marked by eruption of ca. 600 Ma calc-alkaline basalt and coeval deposition of cobble conglomerate on the ca. 605–600 Ma CPG-MSG unconformity on western Bonavista Peninsula. Extension continued through extrusion of ca. 592 Ma tuffs and bimodal volcanics of the Plate Cove volcanic belt east of the Indian Arm Fault. The belt is overlain to the east by the mainly clastic Rocky Harbour Group. Its tuffs and peperite, locally dated at ca. 585 and 576 Ma, respectively, bracket the ca. 580 Ma Trinity diamictite—a shallow-marine equivalent of the deep-marine Gaskiers Formation of the St. John's Basin on Avalon Peninsula. Small-volume alkaline basalts below and above the Trinity diamictite provide a clear spatio-temporal link between glaciation and extensional magmatism. Strata below the Trinity diamictite display features reflecting a glaciogenic origin and increase the thickness and areal extent of Ediacaran Gaskiers glacial deposits. The Gaskiers glaciation likely lasted for several million years and was coeval with ca. 600–576 Ma extensional magmatism within proto-West Avalonia or along its margin.

RÉSUMÉ

Le supergroupe de Musgravetown (SGM) du bassin de Bonavista constitue l'unité centrale de strates néoprotérozoïques sur la péninsule de Bonavista, dans la zone d'Avalon, dans le nord-est de Terre-Neuve. Dans l'ouest de Bonavista, le groupe marin profond d'environ 620 à 600 Ma, Connecting Point (GCP), est recouvert de façon discordante par le SGM volcanosédimentaire terrestre à marin peu profond d'environ 600 à 540 Ma, mais il est limité par des failles à l'est de la faille Indian Arm. Dans l'est de la péninsule de Bonavista, la faille de l'anse Spillars sépare le SGM des roches du bassin de St. John's, corrélatives des strates édiacariennes de la presqu'île Avalon (groupes de Conception, St. John's et Signal Hill) comme le corrobore une datation U–Pb d'environ 566 Ma. Les limites d'âge citées aux présentes confirment l'importance régionale de la faille de l'anse Spillars qui limite temporellement et stratigraphiquement les strates distinctes.

Les roches magmatiques du groupe Bull Arm (SGM basal) se sont mises en place durant une extension régionale prolongée. Le début de l'épisode est marqué par l'éruption de basalte calcoalcalin il y a environ 600 Ma et le dépôt contemporain de conglomérat de galets sur la discordance d'environ 605 à 600 Ma du GCP-SGM dans l'ouest de la péninsule de Bonavista. L'extension s'est poursuivie par l'extrusion de tufs et de roches volcaniques bimodales d'environ 592 Ma de la ceinture volcanique de l'anse Plate à l'est de la faille Indian Arm. La ceinture est recouverte à l'est par le groupe principalement clastique de Rocky Harbour. Ses tufs et sa pépérite, datées par endroits à environ

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585 et 576 Ma, respectivement, encadrent la diamictite d'environ 580 Ma de Trinity — un équivalent marin peu profond de la Formation marine profonde Gaskiers du bassin de St. John's sur la presqu'île Avalon. Les basaltes alcalins de faible volume au-dessous et au-dessus de la diamictite de Trinity établissent un lien spatio-temporel clair entre la glaciation et le magmatisme d'extension. Les strates au-dessous de la diamictite de Trinity affichent des caractéristiques témoignant d'une origine glaciogène et accroissent l'épaisseur et l'étendue aréale des dépôts glaciaires édiacariens de Gaskiers. La glaciation de Gaskiers a vraisemblablement duré plusieurs millions d'années et a été concomitante au magmatisme d'extension d'environ 600 à 576 Ma à l'intérieur de la zone occidentale de proto-Avalonia ou le long de sa marge.

[*Traduit par la redaction*]

INTRODUCTION

Newfoundland's Avalon Zone is the type locality for the microcontinent Avalonia. West Avalonia, those Avalonian terranes on the west side of the present-day Atlantic Ocean, accreted to the composite Laurentian margin by the Devonian as the result of the closure of the Acadian seaway between West Avalonia and composite Laurentia (van Staal and Barr 2012; van Staal *et al.* 2020). West Avalonia is a collage of fault-bounded Neoproterozoic, mainly juvenile, arc-related volcanic-sedimentary terranes that underwent late Ediacaran deformation and denudation prior to deposition of an overstepping latest Ediacaran–Ordovician platformal sedimentary succession that defines West Avalonia as a coherent microcontinental terrane (e.g., Landing 1996; O'Brien *et al.* 1996). Its pre-cover sequence basement blocks are considered proto-West Avalonia (sensu Beranek *et al.* 2023). The Avalon Zone in Newfoundland is well known for the preservation of Ediacaran volcanic-sedimentary strata of relatively low metamorphic grade, including the ca. 565 Ma Ediacaran macrofossil-bearing Mistaken Point Formation (e.g., Anderson and Misra 1968; Misra 1969; Gehling *et al.* 2000; Narbonne and Gehling 2003; Gehling and Narbonne 2007; Benus 1988; Pu *et al.* 2016; Liu *et al.* 2014, 2015, 2016; Matthews *et al.* 2020) and the ca. 580 Ma glacial deposits of the Gaskiers Formation (Brückner and Anderson 1971; Gravenor 1980; Anderson and King 1981; Gardner and Hiscott 1988; Carto and Eyles 2012; Pu *et al.* 2016). Both these formations are part of the mainly deep marine, turbiditic Conception Group on the Avalon Peninsula.

Rocks of the Musgravetown Supergroup (MSG), on the Bonavista Peninsula of northeastern Newfoundland, record sedimentation and volcanism that precede, overlap with, and follow this important window (ca. 580–565 Ma) of Ediacaran climate change and biotic evolution. Its basal Bull Arm Group is dominated by volcanic rocks and is overlain by a lithostratigraphically complex association of mainly shallow-marine siliciclastic rocks of the Rocky Harbour Group (former Rocky Harbour Formation of Jenness 1963; see Mills and Sandeman 2021), which includes the glaciogenic Trinity diamictite (Normore 2011), a shallow-marine equivalent to the deeper marine Gaskiers Formation (Pu *et al.* 2016). The Crown Hill Group, uppermost MSG, includes red beds that are overlain by quartz arenite and conglomerate of the Terreneuvian (lower Cambrian) Random Formation.

This contribution summarizes existing age and geochemical constraints on magmatic rocks of the Bull Arm and Rocky Harbour groups of the MSG. In addition, it presents new field observations of lower Rocky Harbour Group rocks indicating glaciogenic origins and new U–Pb (zircon; TIMS) age constraints for three samples from the Bonavista Peninsula that inform the local chronostratigraphy. Finally, this contribution highlights the differences in the basin-fill that characterize and distinguish the Bonavista Basin (MSG) from the St. John's Basin.

REGIONAL GEOLOGY

Avalon Peninsula stratigraphy

The central Avalon Peninsula is underlain by Tonian to Ediacaran igneous units including the ca. 620 Ma Holyrood Intrusive Suite (Krogh *et al.* 1988) and subordinate ca. 640 Ma monzonite (O'Brien *et al.* 2001; Fig. 1). The age of the main phase of Avalonian arc activity is considered to range from ca. 640 Ma to 600 Ma or later (van Staal *et al.* 2020 and references therein). The flanking Harbour Main Group is a composite volcanic-dominated unit (Fig. 2), and traditionally, the oldest recognized unit is the ca. 729 Ma Hawke Hills tuff (Israel 1998; O'Brien *et al.* 2001). This heterogeneous tuff has been dated at two localities: the first, located on the eastern shore of Conception Bay South, was documented by Israel (1998), and a follow-up sample of the same unit from the west side of Conception Bay was subsequently dated and yielded the same age (Dunning and O'Brien, unpublished data), confirming the age and lithological distinctiveness of the unit. Rhyolite occurring to the northwest and northeast of these two localities yielded ages of ca. 606 Ma (Krogh *et al.* 1988) and ca. 582 Ma (Sparkes 2005), respectively. These volcanic-dominant units are onlapped by mainly deep-marine turbidites of the Conception Group (Williams and King 1979), including ca. 580 Ma reworked glacial diamictites of the Gaskiers Formation near its base (Pu *et al.* 2016) and the ca. 565 Ma (Benus 1988; Pu *et al.* 2016; Matthews *et al.* 2020) fossiliferous Mistaken Point Formation near its top (Fig. 2). The Conception Group is conformably overlain by the ca. 564 (Matthews *et al.* 2020) to ca. 562 Ma (Canfield *et al.* 2020) marine to deltaic St. John's Group (King 1990), which is transitionally overlain by the coarse clastic, mainly alluvial to fluvial, Signal Hill Group (Beranek *et al.* 2023;

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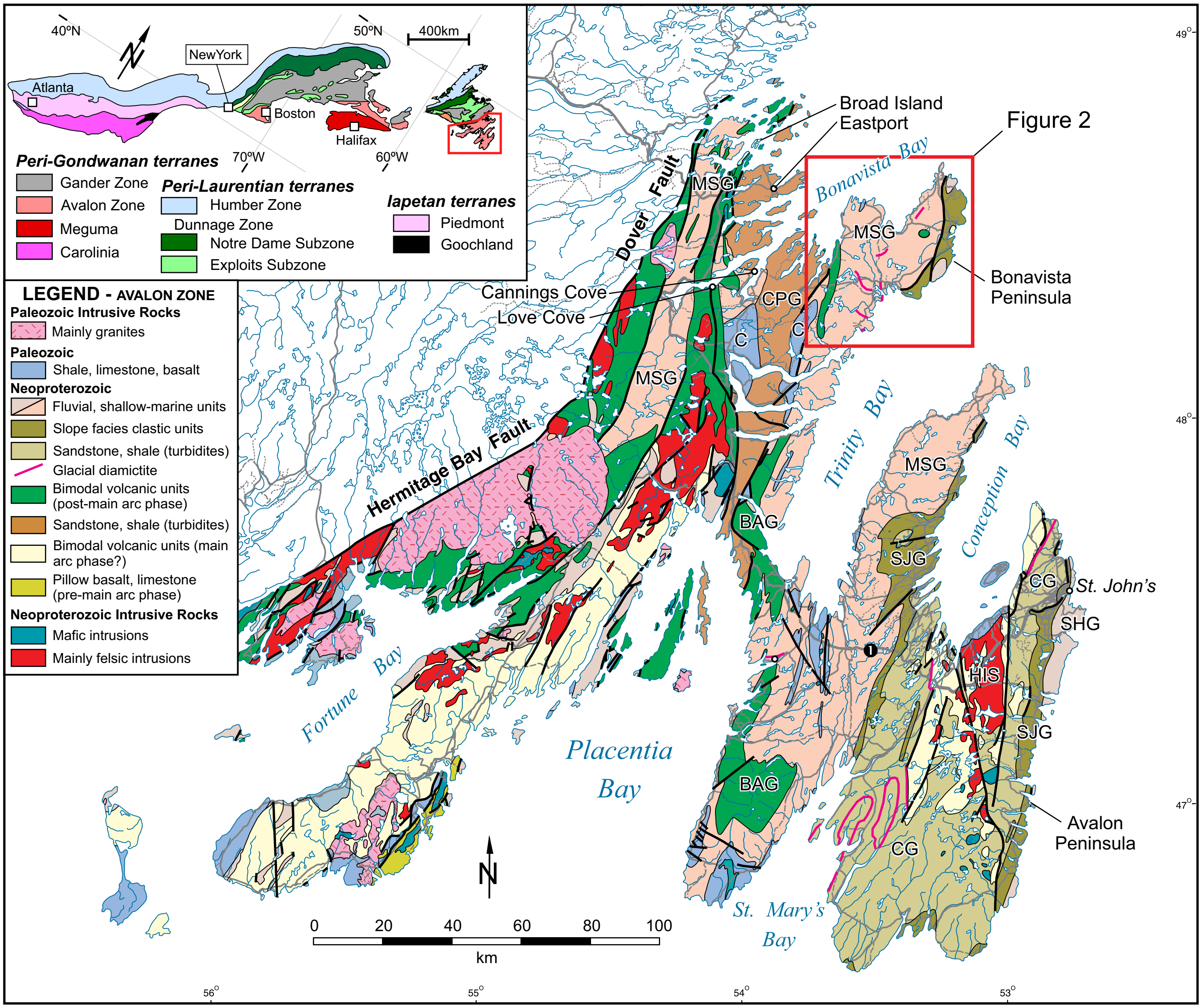

Figure 1. Simplified bedrock geology of the Avalon Zone in Newfoundland, modified from Colman-Sadd *et al.* (1990). Inset map shows the position of the Avalon Zone within the Appalachian orogen (modified from Álvaro and Mills 2024). Pre-main arc phase, arc phase, and post-arc phase delineation of units in the legend are based on Avalon evolution as depicted by van Staal *et al.* (2020). The outlined red box shows the study area. BAG = Bull Arm Group (basal MSG); C = Cambrian units; CG = Conception Group; CPG = Connecting Point Group; HIS = Holyrood Intrusive Suite; MSG = Musgravetown Supergroup; SHG = Signal Hill Group; SJG = St. John's Group.

Serna Ortiz and Lowe 2024). No direct dating of tuffaceous units has been achieved for rocks of the Signal Hill Group, but laser ablation analyses of detrital zircons yielded maximum depositional age estimates for its constituent units that range from 613 to 538 Ma (Beranek *et al.* 2023; Serna Ortiz and Lowe 2024). Deposition of the Signal Hill Group was coeval with transpressive deformation and basement uplift in sediment hinterlands associated with Avalonian orogenesis (Calon 2001; Beranek *et al.* 2023; Serna Ortiz and Lowe 2024; Lowe *et al.* 2024).

Bonavista Peninsula stratigraphy–St. John's Basin

Rocks of the easternmost Bonavista Peninsula (Fig. 3) were first recognized as correlatives of marine and deltaic rocks of the Avalon Peninsula by O'Brien and King (2002). Their subsequent discovery of Ediacaran biota similar to assemblages of the Mistaken Point Formation provided biostratigraphic corroboration of their previous lithostratigraphic correlation (O'Brien and King 2004a). Further detailed mapping in the structural culmination near Catalina (Catalina Dome of Mason *et al.* 2013) led to establishment of a stratigraphic framework that is unique to this area

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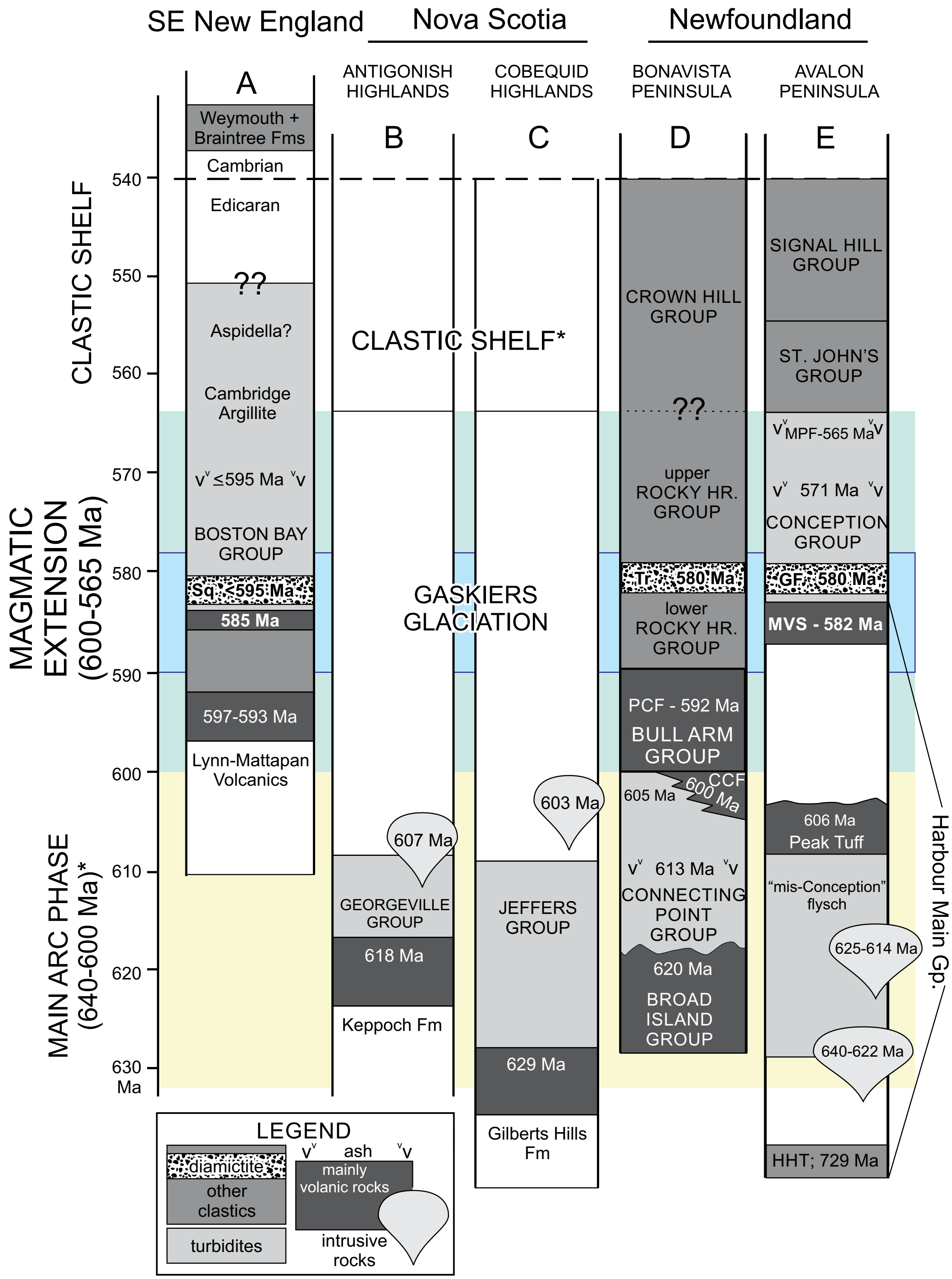

Figure 2. Tectonostratigraphic comparison of selected Ediacaran sequences from West Avalonia terranes: A = Boston Bay area (NE USA); B = Antigonish Highlands (NS); C = Cobequid Highlands (NS); D = Bonavista Peninsula (NL); E = Avalon Peninsula (NL); modified from Thompson *et al.* (2014) and Mills *et al.* (2021). CCF = Cannings Cove Formation; GF = Gaskiers Formation; HHT = Hawke Hills tuff; MPF = Mistaken Point Formation; MVS = Manuels Volcanic Suite; PCF = Plate Cove Formation; Sq = Squantum Member; Tr = Trinity diamictite.

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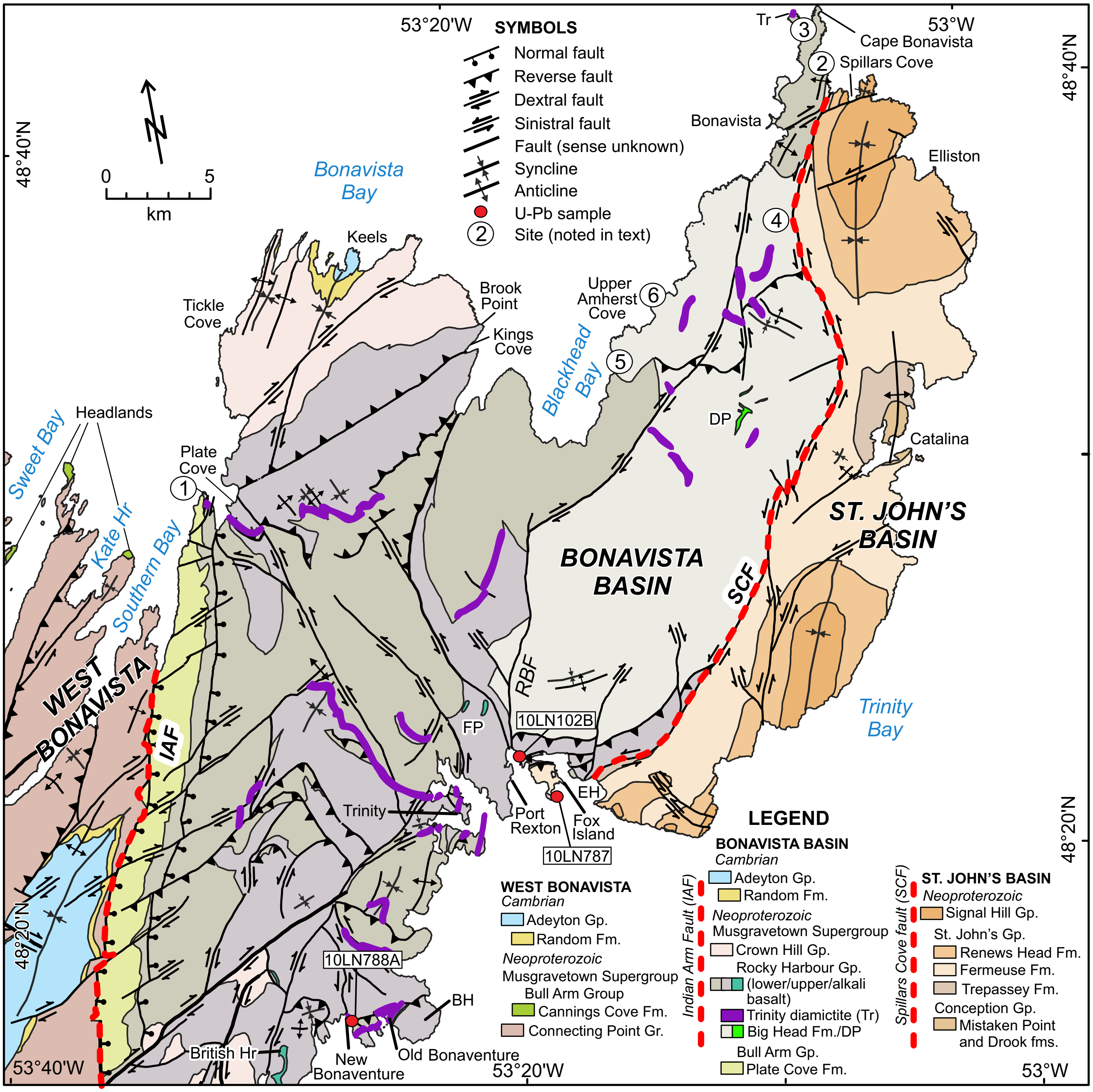

Figure 3. Simplified bedrock geology of the Bonavista Peninsula, showing sites (1–6) with features noted in the text and U–Pb (zircon) sample locations. BH = Bonaventure Head; DP = Dam Pond; EH = English Harbour; FP = Fifields Pit; IAF = Indian Arm Fault; RBF = Robinhood Bay Fault; SCF = Spillars Cove Fault

(O'Brien and King 2005). Normore (2011) assigned this succession of rocks on Bonavista Peninsula to the 'St. John's Basin' to distinguish it from MSG rocks of the 'Bonavista Basin' and extended the former farther south and west to include most of the rocks on Fox Island (Fig. 3). This correlation was based on lithology and the presence of possible *Intrites punctatus* fossils, similar to those documented in Ediacaran fossil-bearing strata of the Avalonian Burway Formation (Stretton Group, Longmyndian Supergroup) in the UK (McIlroy *et al.* 2005) and considered correlative to the type Avalonia rocks on Avalon Peninsula (e.g., Cocks and Fortey 2009). Subsequent work on rocks of the St. John's Basin focused on the Catalina Dome area, either on investigations of the fossils (e.g., Hofmann *et al.* 2008; Liu *et al.* 2014, 2015, 2016) or on their paleoenvironments (Mason *et al.* 2013).

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The oldest rocks of the St. John's Basin on the Bonavista Peninsula, the Drook and Mistaken Point formations of the Conception Group and the Trepassey Formation of the St. John's Group, outcrop only in the Catalina Dome (Hofmann *et al.* 2008; Mason *et al.* 2013). The Drook Formation comprises mainly laminated grey-green siltstone, with lesser thin beds and laminae of sandstone and mudstone. The Mistaken Point Formation consists of a lower siliceous member and an upper argillaceous member that ranges from grey to green to red. The Trepassey Formation comprises a lower mud- and silt-rich member and an upper, sand-rich member (O'Brien and King 2005; Hoffman *et al.* 2008). The conformably overlying Fermeuse Formation consists of mudstone, shale, siltstone and sandstone exhibiting common slump structures and brecciated units and coarsens upward overall (O'Brien and King 2005; Normore 2010). The Renews Head Formation, uppermost St. John's Group, consists of two coarsening upward successions: the lower is sandier and commonly pyritic; the upper has a shaley pyritic base and grades up into interbedded shale and siltstone with lesser lenticular sandstone (King 1990; Normore 2010). The Signal Hill Group gradationally overlies the St. John's Group and comprises massive grey sandstone with granule and pebble beds that are correlated with the Gibbett Hill Formation on the Avalon Peninsula (O'Brien and King 2004b).

West Bonavista (northwestern Avalon Zone)

The oldest exposed rocks in the northwestern Avalon Zone (northwest of West Bonavista in Figure 3) are the calc-alkaline tuffs of the ca. 620 Ma Broad Island Group (former Love Cove Group; *see* Mills *et al.* 2021), which occur north of Eastport in the Bonavista Bay area (Fig. 1). The Broad Island Group is succeeded by the marine turbiditic Connecting Point Group (CPG). Tuffs near the stratigraphic middle of the CPG have yielded ages of ca. 610 Ma and ca. 613 Ma (Dec *et al.* 1992; Mills *et al.* 2016b, 2021). In the Sweet Bay area, the MSG lies unconformably above the CPG, but farther east these units are in fault contact along the north-trending Indian Arm Fault (IAF; Fig. 3). Cambrian outliers unconformably overlie the CPG west of the IAF (Figs. 1, 3).

Bonavista Peninsula stratigraphy–Bonavista Basin

The MSG comprises the primary fill of the Bonavista Basin and underlies much of the western Avalon Zone in Newfoundland (Fig. 1). A Cambrian outlier unconformably overlies the MSG at Keels (Fig. 3). Mills and Sandeman (2021) proposed elevation of the Musgravetown Group to a Supergroup. This change was invoked, in part, because the recognition and continuity of a sub-unit (Trinity diamictite of the former Rocky Harbour Formation) as a mappable unit necessitates its elevation to formation status. If the Trinity diamictite is elevated to a Formation (correlative with the Gaskiers Formation, Conception Group), then Rocky Harbour must be elevated to a Group, and the Musgravetown then becomes a Supergroup. This lithostratigraphic framework better reflects the variation and depositional duration of its constituent units and better matches the shorter age ranges inferred for penecontemporaneous units comprising the lithostratigraphic framework of the Avalon Peninsula (King 1988, 1990), supported by recent geochronological investigations (e.g., Pu *et al.* 2016; Canfield *et al.* 2020; Matthews *et al.* 2020; Beranek *et al.* 2023).

In ascending order, the MSG includes a mainly volcanic basal package (originally defined as the Bull Arm Formation by Jenness (1963) and King (1988)), now termed the Bull Arm Group (Mills and Sandeman 2021), shallow-marine siliciclastic sequences of the overlying Rocky Harbour Group and terrestrial red beds of the Crown Hill Group (Figs. 2, 3). Existing age and lithogeochemical constraints on the Bull Arm and Rocky Harbour groups are summarized below. No direct age constraints are available for the Crown Hill Group, but the youngest two of 68 detrital zircons from a pebble conglomerate from Tickle Cove (Fig. 3) are 557 and 566 Ma (Pollock *et al.* 2009).

Age and chemical constraints

The basal Cannings Cove Formation of the Bull Arm Group includes ca. 600 Ma (Mills *et al.* 2016b) calc-alkaline basalt (Mills and Sandeman 2015; Fig. 4) and interbedded polymictic cobble to boulder conglomerate exposed at Cannings Cove (Fig. 1) and on three promontories, or headlands, in the Sweet Bay area (Fig. 3). The younger Plate Cove Formation includes transitional basalt (continental tholeiite), alkaline rhyolite, and pyroclastic rocks, and forms a north-trending belt that extends southward from Plate Cove (Figs. 3, 4). U–Pb (zircon) age constraints for this unit include 592.0 ± 2.2 Ma and ca. 591.3 ± 1.6 Ma, from pyroclastic strata exposed on the western and eastern margins of the belt, respectively (Mills *et al.* 2017). These ages overlap with that of the highly tectonized 589.1 ± 2.0 Ma pyroclastic rocks at Love Cove, type locality of the former Love Cove Group (Fig. 1; Mills *et al.* 2021), previously interpreted as part of the oldest stratigraphic unit of the western Avalon Zone and comprising two north-trending belts (e.g., Dec *et al.* 1992; O'Brien *et al.* 1996). The oldest unit was renamed Broad Island Group (Fig. 2) after the site of the dated ca. 620 Ma tuff in the northwestern Avalon Zone and interpreted to be spatially limited to only the northernmost part of the eastern belt (Mills *et al.* 2021). The name of those schistose pyroclastic rocks that comprise the volcanic belts to the south reverted back to 'Love Cove schist' (as originally suggested by Widmer 1949) because they are more lithogeochemically similar to the dated ca. 589 Ma schist from Love Cove, which is younger than the Connecting Point Group (Mills *et al.* 2021). The chronostratigraphic position and transitional chemical affinity (between calc-alkaline and tholeiitic) of the Love Cove schist support its correlation with the younger Bull Arm Group, rather than the older Broad Island Group (Mills *et al.* 2021).

The only previous age constraints on the Rocky Harbour

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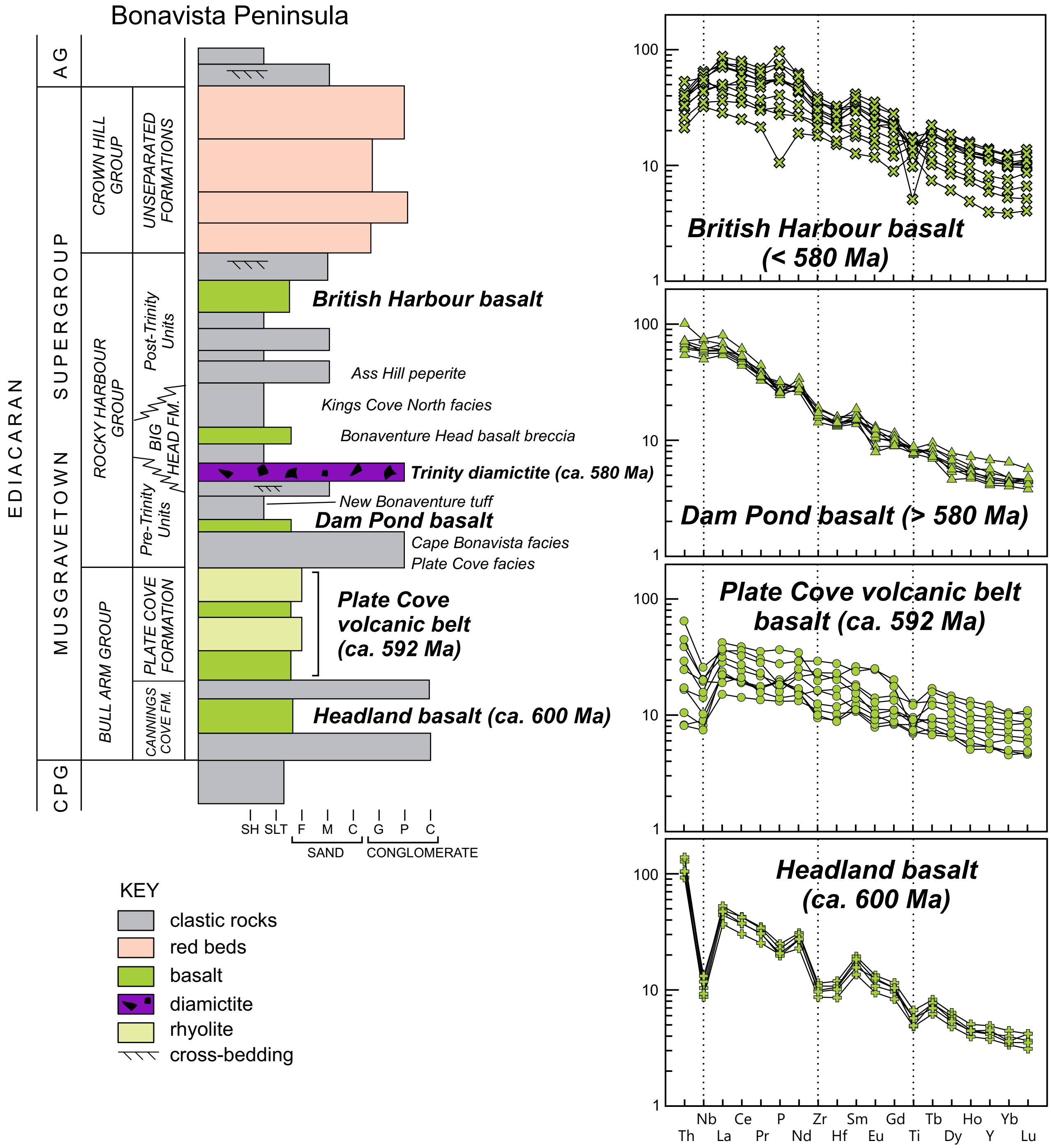

Figure 4. Schematic stratigraphic column through the Musgravetown Supergroup on Bonavista Peninsula, showing the relative stratigraphic position of the main mafic volcanic units, their chemical affinities, and existing radiometric age constraints (prior to this study). AG = Adeyton Group; CPG = Connecting Point Group.

Group are the ca. 580 Ma U–Pb (zircon) ages on tuffs below and above the Trinity diamictite in Old Bonaventure (Pu *et al.* 2016). The Trinity diamictite is therefore used as a chronostratigraphic marker across the Bonavista Peninsula, providing a relative age constraint on older basalts in the Dam Pond area and younger basalts in the British Harbour area (Mills and Sandeman 2021; Figs. 3, 4). Lenses of basaltic conglomerate also occur above the Trinity diamictite at Fifields Pit north of Port Rexton, and at Bonaventure Head, southeast of Old Bonaventure (Fig. 3). All these basalts are alkaline and interpreted as originating from low-degree partial melts of deep (near the garnet-spinel transition), undepleted asthenospheric sources (Mills and Sandeman 2021). Basalts at Dam Pond, Fifields Pit, and Bonaventure Head are primitive relative to the more fractionated British Harbour basalt (Fig. 4).

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Sedimentary features of the Rocky Harbour Group

The Rocky Harbour Group is characterized by major lateral as well as vertical facies changes, and its stratigraphic complexity is exacerbated by structural complications that remain cryptic on parts of the Bonavista Peninsula. Mills and Sandeman (2021) summarized the previously proposed lithostratigraphic frameworks for the former Rocky Harbour Formation and proposed its elevation to Group status based on recognition of the Trinity diamictite as a mappable unit. Here, we provide additional descriptive details of units of the Rocky Harbour Group, with a focus on their most distinctive sedimentary features—particularly those that are consistent with a glaciogenic origin. The sites noted in the text are depicted on Figure 3.

Lower units of the Rocky Harbour Group include polymictic pebble conglomerate, a distinctive medium-grained to pebbly, commonly magnetite-bearing sandstone on the northeastern Bonavista Peninsula (Cape Bonavista facies of O'Brien and King (2002) and Normore (2010)), and heterolithic sedimentary units in the central part of the peninsula (south and west of Blackhead Bay; Fig. 3). The polymictic pebble conglomerate occurs east of, and immediately overlies the volcanic rocks of the Plate Cove Formation. It is generally well cleaved with flattened clasts having aspect ratios that average 4:1. It contains abundant volcanic clasts (60–80%), is dominantly clast-supported (Normore 2011), but also contains subordinate matrix-supported conglomerate or diamictite (Fig. 5a; site 1). Sporadic flat-iron and bullet-shaped clast morphologies (Fig. 5b, c) occur throughout the conglomerate.

The Cape Bonavista sandstone on the northeastern Bonavista Peninsula consists of medium- to coarse-grained, and locally pebbly, planar- and low- to high-angle cross-stratified lithic feldspathic arenite. Pronounced laminae, 0.2–1.0 cm in thickness, lend the rock a streaky appearance, owing to alternations of well-sorted medium-grained sand with poorly sorted coarse-grained sand. Rounded igneous clasts, averaging 2 cm in diameter, commonly occur as lonestones and local basal pebble lags (Fig. 6a, b; site 2). These strata commonly contain detrital magnetite in discrete cm-scale layers and lenses and mm-scale laminae (Fig. 6c; site 3). This unit's distinctive cross-stratification is characterized by scour-based, high- to low-angle cross-stratified sets (Fig. 6d; site 3) that Mills and Lowe (2022) attributed to supercritical stratification in an outwash plain environment. South-southwest of the town of Bonavista, thick-bedded, clast-supported, moderately sorted conglomerate occurs in coarsening- and fining-upward cycles. Angular boulders of laminated siltstone occur locally within the conglomeratic cycles (Fig. 6e; site 4). These conglomeratic strata (Jones Pond facies of O'Brien and King (2002, 2004b, 2005) and Normore (2010) are interstratified within the Cape Bonavista sandstone.

Heterolithic strata in the central Bonavista Peninsula include a lower unit comprising pale grey to pink, medium-grained, lenticular to wavy bedded sandstone interbedded with dark grey siltstone and an upper unit comprising

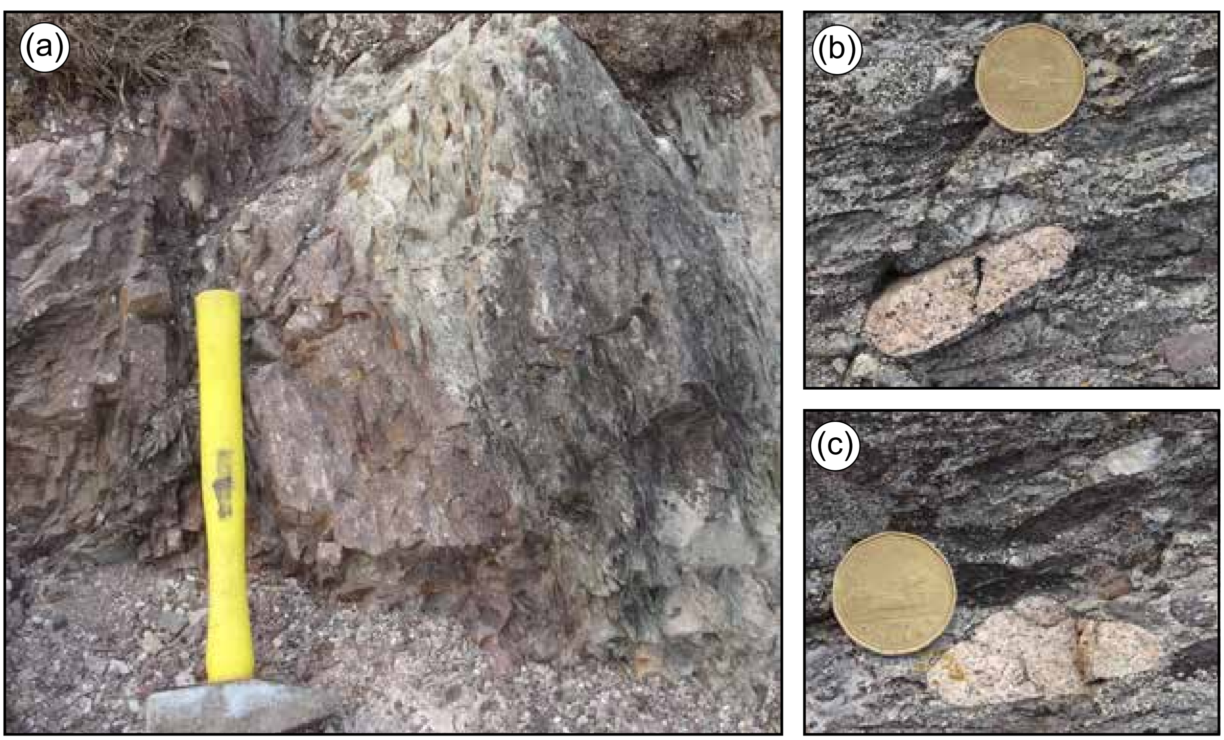

Figure 5. Field photographs from the Plate Cove area (site 1, Fig. 3). (a) Red to grey (white-weathering) matrix-supported conglomerate (diamictite); (b) Bullet-shaped; and (c) Flat-iron shaped clasts from the conglomerate of the basal Rocky Harbour Group.

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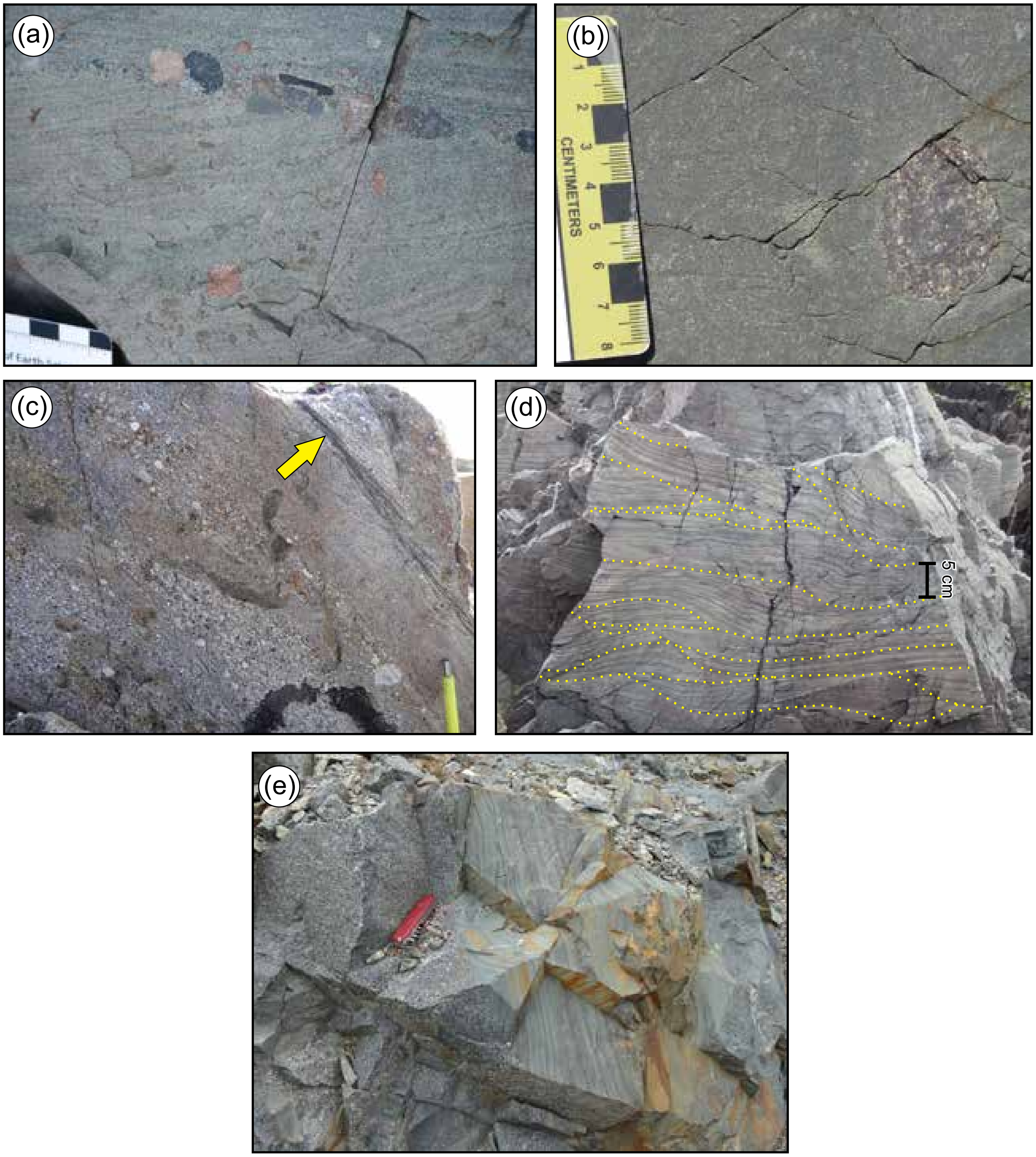

Figure 6. Field photographs showing aspects of the Cape Bonavista sandstone. (a) Lonestones within and pebble lag at the base of a sandstone bed; (b) Well-rounded lonestone in medium-grained sandstone; (c) Detrital magnetite-rich laminae in pebbly variety of sandstone near Cape Bonavista (metal tip of yellow pen magnet is 1 cm in length); (d) Unique cross-stratification characteristic of the Cape Bonavista sandstone (see text for explanation; metal tip of yellow pen magnet is 1 cm in length); (e) Large, angular boulder of laminated siltstone within polymictic pebble conglomerate south of the town of Bonavista (length of red knife is 8.3 cm). Photographs 'a' and 'b' are located at site 2; 'c' and 'd' at site 3; and 'e' at site 4, Figure 3.

lithic feldspathic arenite, granule and pebble conglomerate, and mudstone. Thin horizons of diamictite occur locally. The lower unit (Middle Amherst Cove facies of O'Brien and King (2002, 2004b, 2005) and Normore (2010, 2011)) is characterized by abundant sedimentary structures including convolute bedding, bedding-confined slumping, mega-slumps producing mushroom-shaped synsedimentary fold structures (Fig. 7a; site 5), ripple marked surfaces, abundant and pervasive sandstone dykes (Fig. 7b; site 5), dewatering structures, possible glaciotectonic features (e.g.,

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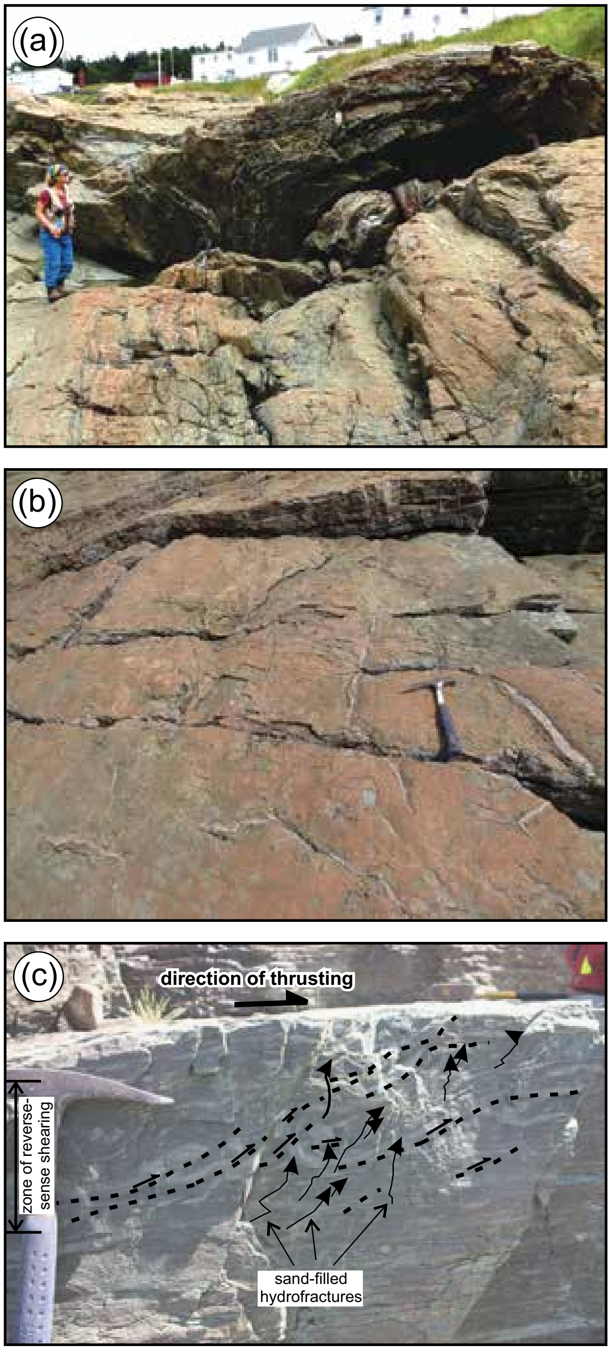

Figure 7. Field photographs showing aspects of the heterolithic sub-Trinity diamictite rocks at Upper Amherst Cove, site 5 and 6, Figure 3. (a) Mushroom-shaped megaslump; (b) Sandstone dykes on bedding surface; and (c) Synsedimentary shears and water-escape structures, consistent with glaciotectonic deformation (viewed toward 070°; movement is to the south).

small-scale synsedimentary thrust faults; Fig. 7c, site 6), and rare outsized clasts. The abundance of slump structures increases up-section.

The upper heterolithic unit (Monk Bay–Hodderville facies of O'Brien and King (2002, 2004b, 2005) and Monk Bay facies of Normore (2010, 2011)) gradationally overlies the lower heterolithic unit and contains a greater variety of facies (see Mills and Lowe 2022). Current- and wave-ripple cross-stratification are present in one facies association of this unit; high-angle dune cross-stratification characterizes another facies association; and mud-draped coarse-grained wave-formed megaripples and associated cross-stratification characterize an upper facies association. Generally, these features are consistent with a tidally influenced, wave/storm-dominated clastic shallow marine shelf environment (Mills and Lowe 2022). Detrital magnetite is present within coarse-grained and conglomeratic layers but is generally disseminated throughout the rock relative to the Cape Bonavista sandstone, where it is concentrated within lenses and laminae. Mudstone occurs as mud drapes within cross-stratified sets and above megarippled layers, and as thin to thick (10 cm to 2 m), massive (structureless) layers, locally with irregular bases indicative of slump scours. The upper parts of this unit exposed below the Trinity diamictite consist of well-defined parasequences that relate to cycles of glacial advance and retreat over a shallow marine shelf (Gómez *et al.* 2024).

Trinity diamictite

The Trinity diamictite consists of a basal, clast-rich, massive diamictite in which clasts commonly exhibit glacially influenced morphologies including faceted, flat-iron and bullet-shaped forms. The matrix is grey-green to purple and consists of a poorly sorted mixture of clay, silt, and sand. The granule to cobble-sized clasts are predominantly bimodal (felsic and mafic) volcanic, and commonly feldspar-phenocrystic. The massive diamictite is overlain by a clast-poor, rhythmically laminated dropstone diamictite. A thinner (2–3-m thick) layer of clast-poor, massive diamictite overlies the laminated layer in some locations (e.g., Pu *et al.* 2016). Notably, the Trinity diamictite is correlated with the coeval Gaskiers Formation on the Avalon Peninsula (Pu *et al.* 2016), and thus provides a unique shallow-marine record of the Gaskiers glaciation (Gómez *et al.* 2024).

Upper Rocky Harbour Group

Grey-green to blue-green, finely laminated, commonly silicified siltstone and mudstone referred to as the Kings Cove North facies overlies the Trinity diamictite (Normore 2011; Pu *et al.* 2016; Gómez *et al.* 2024). The thickness of this unit varies, but averages 40 m. The high portion of silt and mud in the laminae are typical of postglacial shallow-marine varves (Mills and Lowe 2022; Gómez *et al.* 2024). The contact between laminated diamictite of the Trinity diamictite and the overlying laminated siltstone-mudstone is gradational and defined by a decrease in the abundance of dropstones up-section over 1–2 m. A distinctive pistachio-coloured silicified tuffaceous siltstone commonly occurs at the base of this unit (Pu *et al.* 2016). North of Kings Cove (Fig. 3), the Brook Point facies contain similar "pistachio-

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Table 1. U–Pb zircon data for late Precambrian rocks, Bonavista Peninsula.

		Concentration		Measured		Corrected Atomic Ratios[d]							Age [Ma]		
Fraction	Weight[a] (mg)	U (ppm)	Pb[b] (ppm)	Pb[c] (pg)	$^{206}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	± 2σ	$^{207}Pb/^{235}U$	± 2σ	$^{207}Pb/^{206}Pb$	± 2σ	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
10LN788A - New Bonaventure tuff (318657m W, 5350395m N)															
Z1 1 clr euh prm	0.001	163	20.9	1.6	638	0.5063	0.09510	72	0.7745	140	0.05906	94	585.6	582	569
Z2 1 clr euh prm	0.001	134	15.0	3.2	266	0.3178	0.09433	134	0.7715	242	0.05932	170	581.3	581	579
10LN102B - Ass Hills peperite (328187m W, 5361801m N)															
Z1 3 clr prm	0.004	298	32	1.6	5064	0.2739	0.09327	108	0.7649	64	0.05948	48	575.0	577	585
Z2 2 clr euh prm	0.003	416	45.9	1.1	6784	0.3116	0.09351	66	0.7637	42	0.05924	28	576.4	576	576
Z3 4 clr prm	0.006	314	34.5	2.8	3993	0.3032	0.09350	46	0.7584	36	0.05883	20	576.4	573	561
Z4 3 clr euh prm	0.004	401	43.0	1.9	5712	0.2743	0.09338	70	0.7642	50	0.05935	24	575.7	576	580
Z5 1 clr prm	0.002	786	84.9	2.3	3040	0.2817	0.09361	66	0.7611	48	0.05897	18	577.0	575	566
Z6 3 clr prm	0.005	184	21.2	1.3	3628	0.3729	0.09351	48	0.7646	40	0.05930	22	576.3	577	578
10LN787 - Fox Island tuff (329453m W, 5360159m N)															
Z1 4 clr elong prms	0.006	821	79.8	99	301	0.1843	0.09090	102	0.7337	104	0.05854	54	561.0	559	550
Z2 2 clr elong prm	0.003	1250	123.2	39	568	0.1954	0.09134	60	0.7427	52	0.05897	30	563.7	564	566
Z3 3 prm	0.003	164	16.1	6.0	493	0.1834	0.09185	86	0.7462	102	0.05892	64	566.7	566	564
Z4 2 prm	0.002	97	9.5	3.4	348	0.1835	0.09185	76	0.7412	150	0.05852	108	566.7	563	549
Z5 2 prm	0.002	181	17.7	3.0	701	0.1845	0.09160	44	0.7374	96	0.05839	68	565.2	561	544
Z6 1 prm	0.001	223	21.9	1.9	684	0.1810	0.09202	52	0.7414	92	0.05844	70	567.6	563	546

Notes: All zircon grains were annealed then chemically abraded (Mattinson 2005) prior to dissolution. Z = zircon; 1, 2, 3, 4 = number of grains in the analysis; prm, prism; clr, clear; euh, euhedral. (a) weights of grains were estimated, with potential uncertainties of 25−50% for small samples; (b) radiogenic lead; (c) total commom Pb; (d) Atomic ratios corrected for fractionation, spike, laboratory blank of 1.5 picograms (pg) common lead, and initial common lead at the age of the sample calculated from the model of Stacey and Kramers (1975), and 0.3 pg U blank. Two sigma uncertainties are reported after the ratios and refer to the final digits.

beds" (O'Brien and King 2005; Normore 2010) that are interpreted to occur stratigraphically higher (near the base of the Crown Hill Group).

A basaltic lapilli tuff locally overlies the laminated siltstone-mudstone in the southern Bonavista Peninsula (e.g., near Fifields Pit and at Bonaventure Head, Fig. 3; Mills and Sandeman 2021). In the Port Rexton area, lithic arkosic sandstone is interbedded with siltstone above the laminated siltstone of the Kings Cove North facies, with common pebble to cobble-sized siltstone clasts in the sandstone. A distinctive pink peperite horizon occurs near the top of this unit (Normore 2011). A genetic relationship between deposition of pistachio-coloured tuffaceous siltstone, eruption of basaltic tuff, and formation of pink peperite horizons in the Kings Cove North facies is possible but is yet to be demonstrated using geochemical or geochronological data.

On the southwestern part of the Bonavista Peninsula, alkaline basalt flows and pyroclastic rocks occur at British Harbour (Fig. 3), near the top of the Rocky Harbour Group (Mills and Sandeman 2021). These basalts are more chemically evolved than those at Dam Pond, Fifields Pit, and Bonaventure Head, and are interpreted to occur higher in the stratigraphy, just below the transition to red beds of the overlying Crown Hill Group (Fig. 3). Their occurrence in this stratigraphic position contrasts with the Rocky Harbour–Crown Hill transition to the north, near Kings Cove where the sedimentary section is not interrupted by volcanic rocks.

GEOCHRONOLOGY

Three samples were collected for CA-TIMS U–Pb geochronology from siliciclastic rocks on the Bonavista Peninsula. Brief field and petrographic descriptions follow. Locations are depicted in Figure 3; geographic coordinates and analytical data are presented in Table 1. All three samples were analyzed by CA-ID TIMS in 2011 at Memorial University of Newfoundland.

Analytical methods

All samples were processed using standard crushing, mineral separation, and heavy-mineral concentration techniques. Zircon crystals were handpicked under a binocular microscope and single- and multi-grain (2–4 crystals) fractions of similar morphology were isolated. Each fraction was then treated to chemical abrasion whereby grains were annealed at 900°C for 36 hours, then etched in concentrated hydrofluoric acid in a Teflon capsule at 200°C for four hours (cf. Mattinson 2005) to remove radiation-damaged, altered or metamict zones within the zircon grains, thereby effec-

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tively eliminating secondary lead loss. Etched fractions were washed in distilled nitric acid, then double-distilled water, and then loaded onto Teflon pressure-dissolution bombs. Upon addition of a mixed ^{205}Pb–^{235}U spike, proportional to the sample weight, the bomb was sealed and heated at 210°C for five days. Ion exchange chemistry was executed using the procedure of Krogh (1973), using modified columns and reagent volumes scaled down to one-tenth of those reported by Krogh (1973). The purified Pb and U were added to a single drop of phosphoric acid and then loaded on outgassed single Re filaments with silica gel and dilute phosphoric acid. Isotopic ratios were measured using a multi-collector MAT 262, with faraday cups calibrated using NBS 981 lead standard and the ion-counting secondary electron multiplier (SEM) detector calibrated against the faraday cups by measurement of known lead isotopic ratios. Lead was measured by peak jumping on the SEM with measurement times determined according to the abundance of each mass. Further details of the methodology are outlined in Sparkes and Dunning (2014). Ages are reported as the weighted average ^{206}Pb/^{238}U ages or as the concordia age at the 95% confidence interval using ISOPLOT™.

Sample descriptions and results

10LN788A.

This rock sample (Fig. 8a–c) is a yellowish reworked ash tuff spatially associated with the Trinity diamicite at New Bonaventure, 1.2 km west of the Old Bonaventure diamictite site dated at ca. 580 Ma (Pu *et al.* 2016), and about 60 m south-southeast of an excellent shoreline exposure of rhythmically laminated dropstone diamictite. Primary layering in both the tuff and the diamictite is subhorizontal but the gap in the section obscures their stratigraphic relationship. Sygmoidal quartz veins along a thrust fault at the north end of the exposure are consistent with thrusting towards the northwest (Fig. 8b). A cut slab of the sample shows fine, planar, locally pink laminations within a medium-grey rock (Fig. 8c). In thin section, the fine-grained rock contains rare, heavily saussuritized feldspar grains up to 200–250 µm in length and abundant recrystallized glass shards up to 250 µm long (Fig. 8d). The rock sample is interpreted to be an altered ash tuff.

The sample yielded several clear euhedral zircon prisms. Their small size is reflected by their very low estimated weights (0.001 mg each; see Table 1). Two analyses failed as a result of the insufficient lead present in the single-crystal

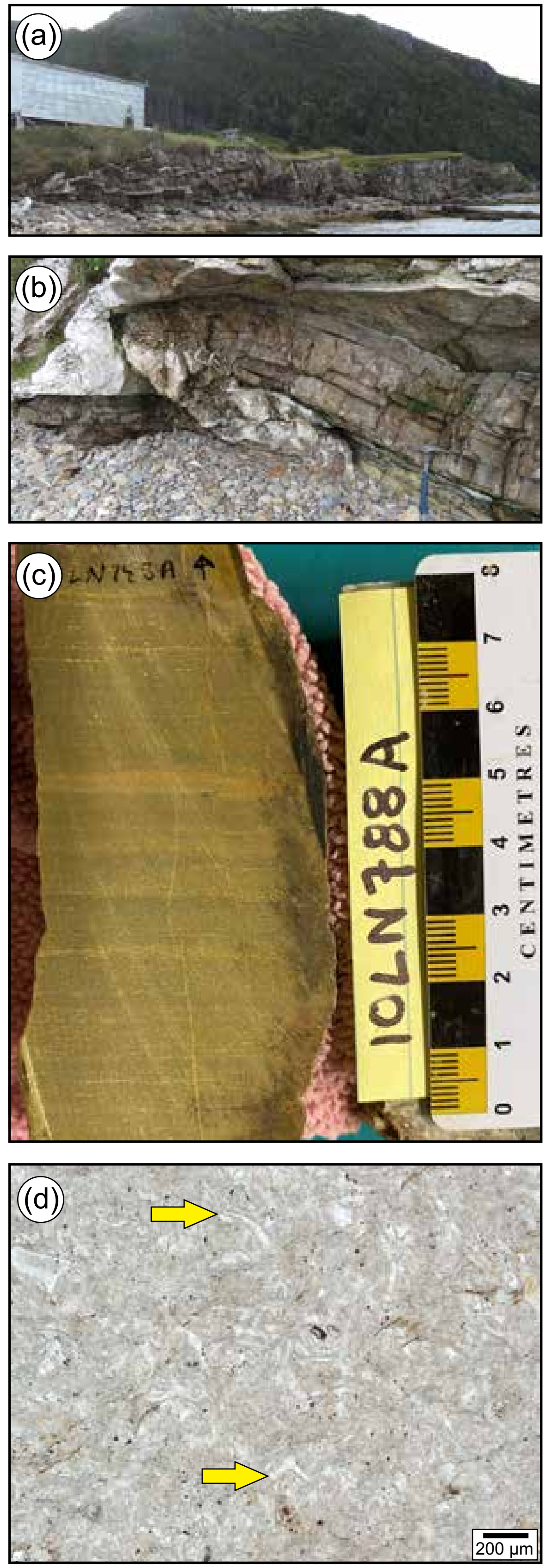

Figure 8. Field and petrographic images of sample 10LN788A. (a) View to east-southeast of subhorizontal, buff-weathering tuffaceous siltstone at New Bonaventure; (b) Close-up of the dated tuff showing sygmoidal quartz veins injected along a thrust fault at the north end of the exposure (viewed to the east, and consistent with thrusting towards the west-northwest); (c) Stained slab of tuffaceous siltstone showing colour variation of laminae; and (d) Thin section under plane-polar light of the dated rock showing possible glass shards (yellow arrows).

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fractions. The two successful analyses yielded overlapping and concordant results and a combined age determination of 584.6 ± 3.6 Ma (Fig. 9a), with a mean square weighted deviation (MSWD) of 1.02. The age of the best analysis (fraction Z1), on its own, is 585.6 ± 4.2 Ma. The combined age is interpreted to best reflect the maximum age of deposition of the rock.

10LN102B.

This rock sample is a medium-grained, immature sandstone of the upper Rocky Harbour Group that occurs on the east side of Robinhood Bay, 250 m north of Herring Cove, north of Fox Island (Fig. 3). The sample was selected because it occurs immediately below a distinctive peperite horizon (Fig. 10a, b), a marker bed in the southern Bonavista Peninsula area between Trinity and English Bay. Compositionally, it is a feldspathic litharenite (Folk 1980; Fig. 10c) comprising 15% lithic fragments, 20% quartz, 55–60% feldspar and minor (5%) chloritized biotite with thin laminations having an argillaceous matrix (Fig. 10d, e).

This sample yielded clear, euhedral to subhedral prismatic zircon. Six fractions, one of which was a single grain, were analyzed. All six gave concordant, overlapping analyses, yielding a concordia age of 576.2 ± 1.2 Ma (Fig. 9b), with an MSWD of 0.10. This age is considered the maximum depositional age for this unit.

10LN787

This rock sample was collected from the east side of southern Fox Island (Fig. 3) and is part of the St. John's Basin sequence (Normore 2011). It is a pale-grey-weathered, fine-grained tuffaceous sandstone and is interbedded with green-grey siltstone (Fig. 11a) interpreted to be part of the Fermeuse Formation of the St. John's Group (Normore 2011); thin sections were unavailable for petrographic investigations. Possible *Intrites punctatus* fossils (Normore 2011) and a discoidal impression fossil (Fig. 11b) were located near the dated rock. Although the cliff face exposes an apparently simple homoclinal sequence, subtle tight folds (Fig. 11c) and slickensides (Fig. 11d) are interpreted to result from compressional deformation related to north- and west-directed thrust imbrication (Mills *et al.* 2016a).

This sample yielded clear to slightly cloudy prismatic zircon, ranging from elongate to stubby. Of the six fractions analyzed, one was a single-grain fraction. Although all six fractions yielded concordant overlapping analyses, fraction Z1 contains higher common lead than the other fractions (Table 1) and yielded a slightly younger age. Fractions Z2–Z6 yielded a weighted average $^{206}Pb/^{238}U$ age of 566 ± 1.5 Ma (Fig. 9c), with an MSWD of 0.86, and is considered the maximum depositional age for this unit.

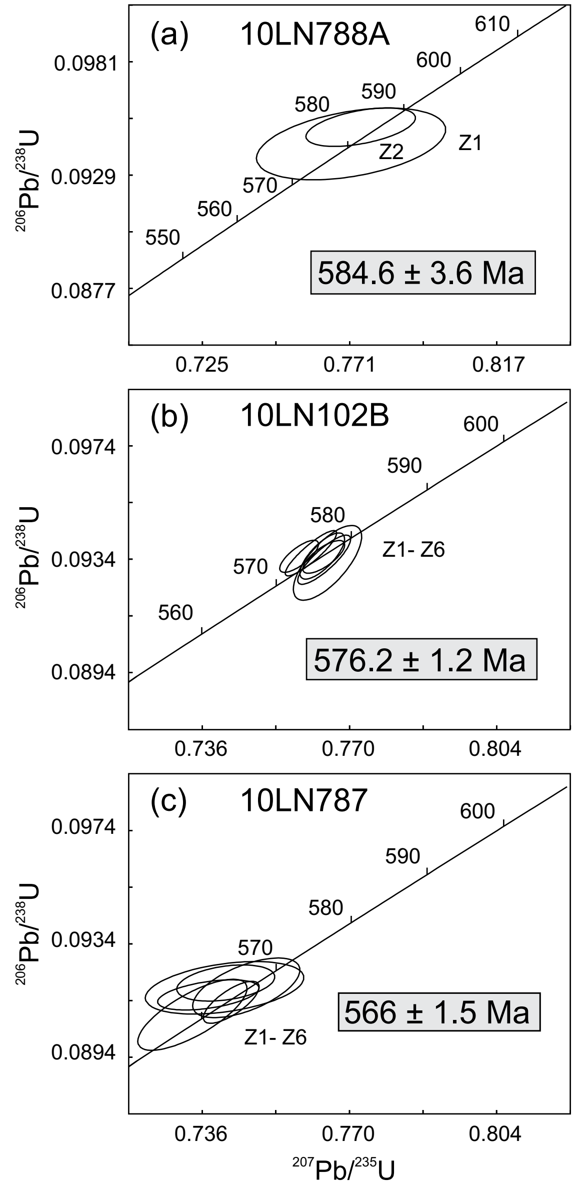

Figure 9. Concordia diagrams of U–Pb (zircon) results from samples of volcanic-sedimentary rocks from the Bonavista Peninsula. Error ellipses are at the 2σ level. Sample locations and corresponding isotopic data are presented in Table 1. (a) New Bonaventure tuff; (b) Ass Hill peperite; and (c) Fox Island tuff.

DISCUSSION

Extension initiated at ca. 600 Ma resulted in the eruption of calc-alkaline basalt and deposition of cobble to boulder conglomerate of the Cannings Cove Formation on the Bonavista Peninsula (Fig. 3). The coarse clastic deposits interbedded with the basalt are consistent with sudden uplift, likely related to normal faulting and creating escarpments along which the coarse debris accumulated thus providing a conduit for lava residing in the pre-existing arc-related magma chamber to ascend. Continued extension to the south

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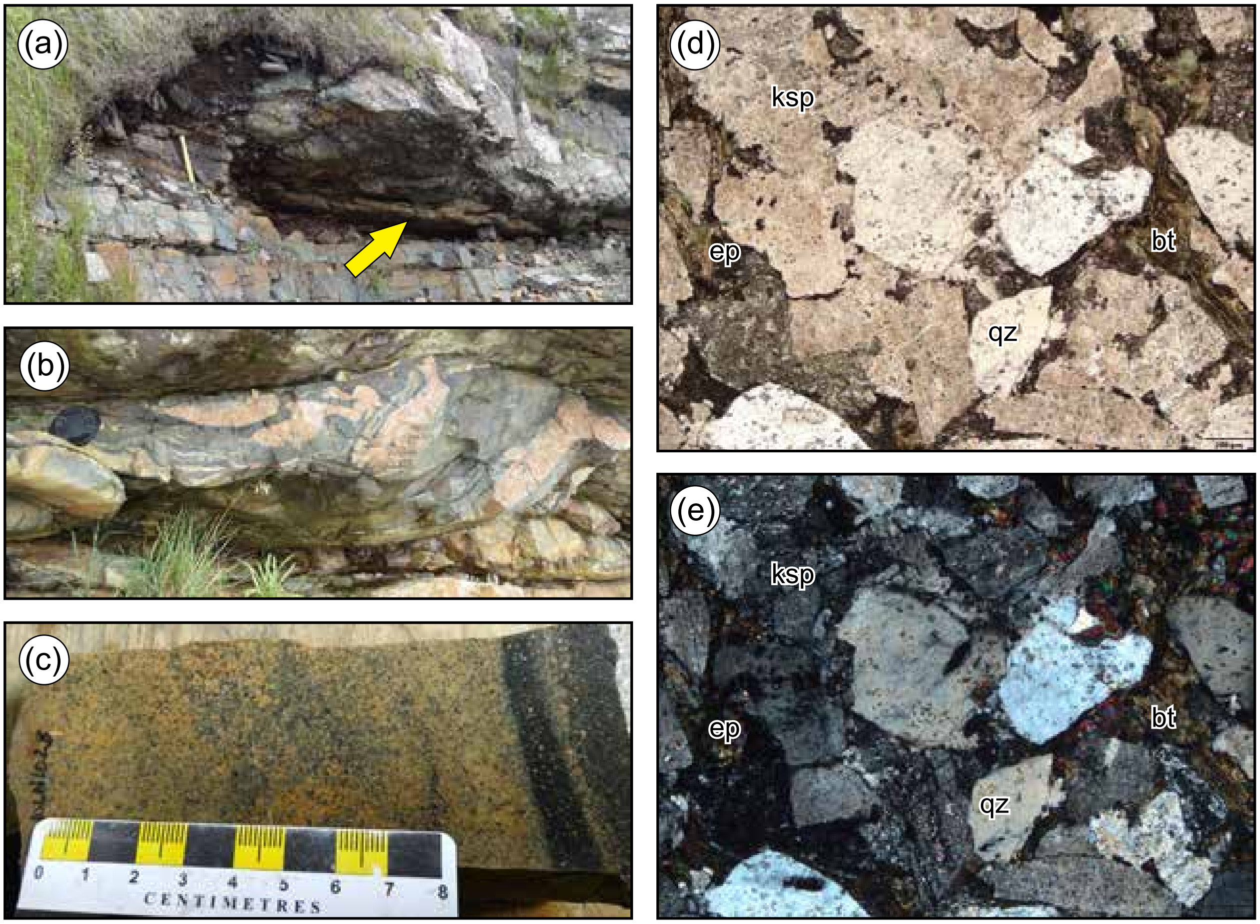

Figure 10. Field and petrographic images of sample 10LN102B. (a) Interbedded sandstone and siltstone below peperite horizon, viewed to the southeast; yellow arrow indicates sandstone bed sampled for geochronology; (b) Close-up of peperite (mixed lava and unconsolidated silt); (c) Stained slab of dated immature arkosic litharenite; (d) Photomicrograph of arkosic litharenite under plane-polar light; and (e) with crossed polars. Mineral abbreviations as per Whitney and Evans (2010).

and east facilitated the ascent of continental tholeiites and alkaline felsic volcanic rocks aligned along the north-trending ca. 592 Ma Plate Cove volcanic belt, east of the Indian Arm Fault (Fig. 3). Primitive alkaline mafic magmatism, the Dam Pond basalt, commenced in the northeastern part of the Bonavista Peninsula before deposition of the ca. 580 Ma Trinity diamictite (Fig. 4). Alkaline basalt tuff, breccia, and monomictic conglomerate at Fifields Pit and Bonaventure Head occur above the Trinity diamictite, indicating that eruption of primitive alkaline basalt both preceded and followed the deglaciation marked by the diamictite. The more chemically evolved British Harbour basalts are interpreted to have erupted still later, as they occur higher in the stratigraphic succession (Fig. 4). A genetic correlation between magmatism and glaciation is plausible, like the increased eruption rates linked to deglaciation in modern glaciovolcanic terranes (e.g., glacial pumping; Maclennan *et al.* 2002; Wilson and Russell 2020), but precise geochronology, detailed mapping and other investigations are needed to properly assess the rates and volumes of magmatism before, during, and after the Gaskiers glaciation.

Strata below the Trinity diamictite, inferred to have been deposited between ca. 591 and ca. 580 Ma, include diverse facies assemblages reflecting varying depositional settings, many of which are consistent with a glacial-proximal origin. Flat-iron and bullet-shaped clasts, consistent with a glaciogenic origin, are common in conglomerates near Plate Cove. Lonestones and pebble lags are common in sandstones near Cape Bonavista, as are recurrent deeply scouring cross-stratification resembling supercritical bedform strata such as chutes-and-pools and cyclic steps (Lowe and Arnott 2016; Mills and Lowe 2022). These, along with angular boulders in thick-bedded conglomerate, record possible catastrophic outburst floods, or jökulhlaups. Notable here also are local brittle structures cross-cut by scours, interpreted to indicate the presence of interstitial ice in an otherwise unconsolidated substrate. Common slump structures, sandstone dykes, water-escape structures, and rare diamictites are preserved at Upper Amherst Cove and are evidence of possible glacial and associated glaciotectonic influence on deposition. These examples collectively point to a periglacial environment that preceded the major deglaciation event marked by the ca.

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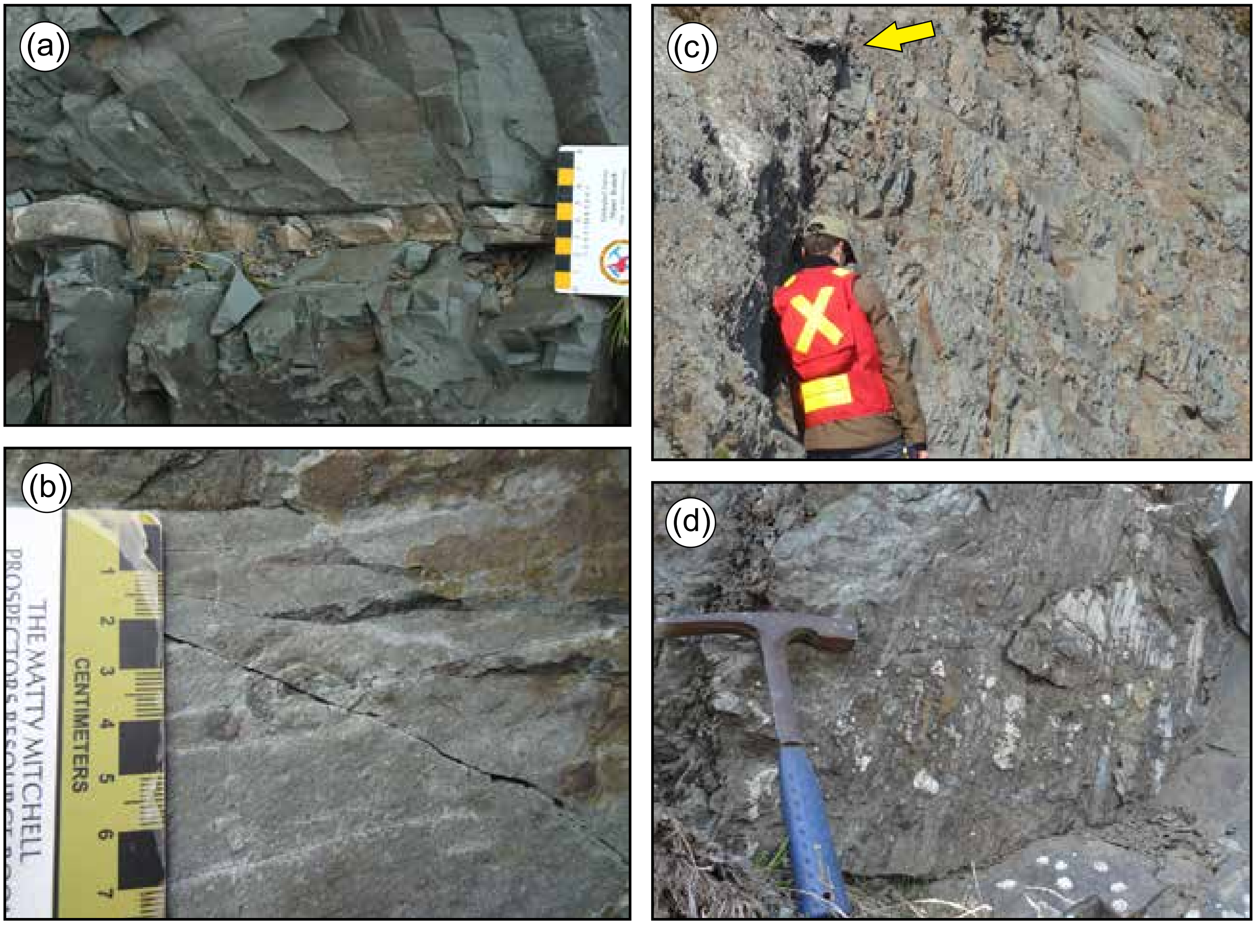

Figure 11. Field photographs from sample 10LN787. (a) Pale grey-weathering, fine-grained tuffaceous sandstone (sampled bed) interbedded with green-grey siltstone; (b) discoidal-impression fossil located near the dated rock; (c) tight anticline (indicated by yellow arrow); and (d) slickenlines on bedding surface and bedding-parallel vein.

580 Ma Trinity diamictite, consistent with recent regional investigations on the Avalon Peninsula indicating a protracted onset of the Gaskiers glaciation before deposition of the Gaskiers Formation (Fitzgerald *et al.* 2024). Possible correlatives outside of Newfoundland include the Squantum member of the Boston Basin (Passchier and Erukanure 2010; Thompson *et al.* 2014), the Mortensnes formation of Baltica in Norway (e.g., Rice *et al.* 2011) and the Serra Azul Formation on the Amazonian Craton (Lamoso *et al.* 2023). Potential correlatives are not known in the Maritime Provinces (Fig. 2). Other potential correlatives worldwide lack robust age constraints and growing evidence of an upper Ediacaran glaciation implies at least episodic glaciation throughout much of the Ediacaran (Wang *et al.* 2023a, b).

The three age constraints presented here (Fig. 12) inform the local stratigraphic framework and augment the current understanding of the geological evolution of the Bonavista Peninsula. Although no tuffaceous horizons correlative to the ca. 585 Ma tuff at New Bonaventure have been identified, the age date confirms that magmatic activity continued after the eruption of the ca. 592 Ma bimodal lavas of the Plate Cove Formation. Erosion and siliciclastic deposition likely predominated over volcanism by ca. 585 Ma, as evidenced by the diverse and widespread dispersal of siliclastic strata with only minor, small-volume magmatic products cropping out locally in the sub-Trinity units (Figs. 3, 4).

A maximum depositional age of 576 Ma for the peperite north of Fox Island provides an approximate age constraint on a significant local marker horizon in the upper Rocky Harbour Group on the southern Bonavista Peninsula. The peperite extends from an easternmost occurrence near English Harbour, westward across the area north of Fox Island, on both sides of the peninsula near Port Rexton, and sporadically around the town of Trinity. Undated sills, dykes and tuffaceous horizons near and stratigraphically above known peperite occurrences may be linked to the same magmatic source that fed the latter (Normore 2011). The pistachio-coloured horizon, commonly associated with rocks overlying the Trinity diamictite and occurring as far north as the Brook Point member in the Kings Cove area, may also be linked to alteration related to a syn-magmatic source. In addition, peperite may be associated with hydrothermal alteration – mineralization and may therefore be linked to the copper endowment previously documented in

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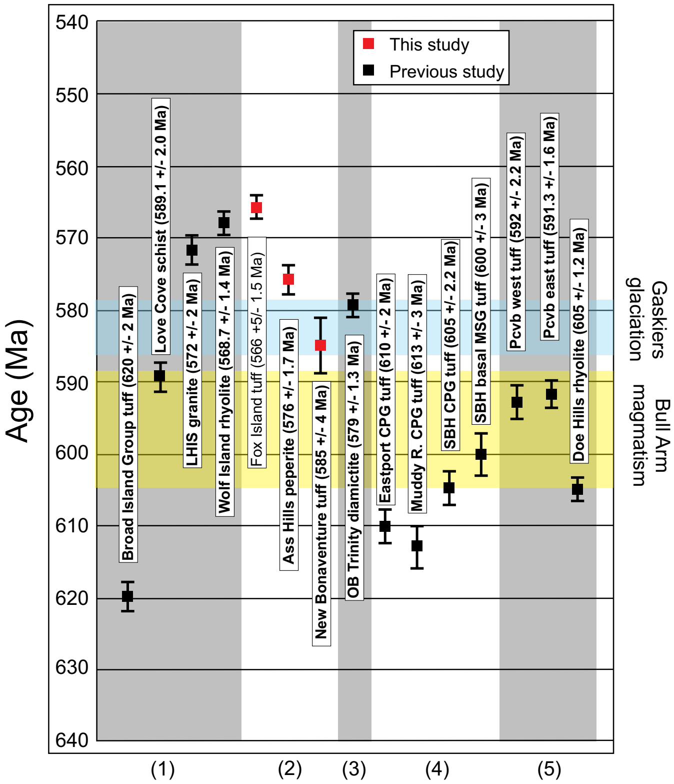

Figure 12. Summary of available U–Pb geochronological data for the Bonavista Peninsula and the adjacent Eastport area to the northwest. Bracketed numbers at the bottom refer to the source for the age data: 1 = Mills *et al.* (2021); 2 = this study; 3 = Pu *et al.* (2016); 4 = Mills *et al.* (2016b); 5 = Mills *et al.* (2017).

the area (Normore 2011; Hinchey 2010, 2012).

The maximum depositional age of ca. 566 Ma for the Fox Island tuff is consistent with Normore's (2011) interpretation that these rocks are part of the St. John's Group. Normore's (2011) provisional identification of *Intrites punctatus* fossils and the presence of rare discoidal impressions in the area are also consistent with the lithological correlation of the Fox Island siltstones with those of the Fermeuse Formation, St. John's Group. This corroborates Normore's extension of the St. John's Basin to the west on the southern Bonavista Peninsula to include Fox Island.

The age constraints presented here show that strata of the Bonavista Basin are distinctly older than the St. John's Basin on the Bonavista Peninsula, and preserve a depositional record spanning before, during, and after the ca. 580 Ma deglacial event marked by the Trinity diamictite and correlative Gaskiers Formation. Strata of the Bonavista Basin mainly range in age from ca. 592 to ca. 576 Ma, except in the northernmost and southernmost parts of the western Bonavista Basin where rocks of the Rocky Harbour pass upward into red beds of the younger, but undated, Crown Hill Group. Much of the Bonavista Basin strata sit stratigraphically below the ca. 580 Ma Trinity diamictite and reflect a near-shore depositional environment. In contrast, the oldest rocks of the St. John's Basin are those of the Catalina Dome, with the core of the Dome correlative to the Drook Formation and overlain by rocks correlative to the ca. 565 Ma Mistaken Point Formation on the Avalon Peninsula. The strata young to the north and south of the Catalina Dome and the succession is interpreted to reflect a relatively deep marine or slope environment that shoals up into deltaic facies through time (Mason *et al.* 2013). The maximum depositional age of ca. 566 Ma for the Fox Island tuff and previously documented north-directed thrust faults in that area (Mills *et al.* 2016a) are consistent with north-directed emplacement of Fermeuse Formation rocks of the St. John's Basin onto ca. 576 Ma rocks of the Bonavista Basin. North-directed displacement of the St. John's Basin at Fox Island implies sinistral movement farther east along parts of the Spillars Cove Fault (Fig. 3). Given the deep marine-to-slope-to-deltaic setting of the St. John's Basin and the shallow-marine setting of the Bonavista Basin, the ages and deformation are taken collectively to indicate local north-directed shortening of the St. John's Basin as it locally abutted against the topographically higher marine shelf of the Bonavista Basin.

CONCLUSIONS

Age and geochemical constraints on magmatic rocks of the Bull Arm and Rocky Harbour groups of the MSG are summarized in Figures 4 and 12. New field observations presented for the lower Rocky Harbour Group indicate a widespread glaciogenic influence on sub-Trinity strata, considerably increasing the thickness and areal extent of deposits related to the Ediacaran Gaskiers glaciation. A clear spatio-temporal link is now established between glaciation and extensional magmatism, with both initiating perhaps as early as ca. 600 Ma. Deposition of the ca. 580 Ma Trinity diamictite likely marked a significant deglaciation event within the greater Gaskiers ice age. The Gaskiers glaciation likely lasted for several million years and was broadly coeval with ca. 600–576 Ma extensional magmatism either within proto-West Avalonia or along a proto-Avalonian margin. New CA-TIMS (zircon) U–Pb age constraints for three rocks from the Bonavista Peninsula inform the local chronostratigraphy and corroborate previous subdivision of Bonavista Peninsula rocks into two temporally and stratigraphically distinct basins: the Bonavista Basin, comprising mainly rocks of the glaciovolcanic Musgravetown Supergroup, and the St. John's Basin, comprising units correlative with those of the eastern Avalon Peninsula, *viz.* the Conception, St. John's, and Signal Hill groups.

ACKNOWLEDGEMENTS

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