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Résumé de l'article

On a déterminé par datation sur zircon détritique les âges d’échantillons de conglomérat et de grès provenant de six ceintures délimitées par des failles au Nouveau-Brunswick et sur la côte du Maine. Les formations échantillonnées comprenaient Martinon (ceinture de Brookville), Flagg Cove (ceinture de l’île Grand Manan), Matthews Lake (ceinture de New River), Ellsworth (ceinture d’Ellsworth), Calais (ceinture de St. Croix) et Baskahegan Lake (ceinture de Miramichi). Le moment maximal de leur sédimentation est basé sur la population de zircons détritiques la plus récente et le moment minimal, sur les liens stratigraphiques et paléontologiques ainsi que sur les intrusions transversales. L’éventail défini des périodes de sédimentation s’établit comme suit : Martinon, entre 602 ± 8 (zircons les plus récents) et 546 ± 2 Ma (âge de l’intrusion transversale); Flagg Cove, entre 574 ± 7 (zircons les plus récents) et 535 ± 3 Ma (âge de l’intrusion transversale); Matthews Lake, entre 539 ± 5 (zircons les plus récents) et 514 ± 2 Ma (âge des roches volcaniques sus-jacentes); Ellsworth, entre 507 ± 6 (zircons les plus récents) et 504 ± 3 Ma (âge des roches volcaniques sus-jacentes); Calais, entre 510 ± 8 (zircons les plus récents) et 479 ± 2 Ma (zone de graptolites); et Baskahegan Lake, entre 525 ± 6 (zircons les plus récents) et 488 ± 2 Ma (zone de graptolites).

Tous les échantillons présentent une prédominance de populations de zircons néoprotérozoïques (gondwaniennes). Les formations du Paléozoïque précoce de Matthews Lake, d’Ellsworth et de Calais présentent les principaux sommets des populations à 539 ± 5 Ma, 545 ± 4 Ma et 556 ± 7 Ma, respectivement, ce qui correspond à une origine essentiellement en provenance des roches magmatiques des ceintures de Brookville, de l’île Grand Manan ou de New River, précédemment situées à environ 553 à 528 Ma. À l’opposé, le principal sommet de la Formation du Paléozoïque précoce de Baskahegan Lake remonte à plus de 585 ± 5 Ma. Le principal sommet de la Formation du Néoprotérozoïque au Cambrien précoce de Flagg Cove se situe à 611 ± 7 Ma, et un sommet secondaire, à 574 ± 7 Ma; le premier provient vraisemblablement d’unités ignées affleurant localement et datées à environ 618 à 611 Ma. Les sommets prédominants à l’intérieur de la Formation du Néoprotérozoïque de Martinon remontent à 674 ± 8 Ma et 635 ± 4 Ma. Le gneiss gandérien du socle, situé à environ 675 Ma et pénétré par des roches plutoniques d’un âge estimatif de 584 Ma dans la charnière d’Hermitage à Terre-Neuve, constitue la source possible de ces composantes de zircons plus âgées à l’intérieur des formations de Martinon et de Baskahegan Lake. Les roches plutoniques de la ceinture de New River, datées à environ 629 à 622 Ma, pourraient représenter la source de la composante plus récente à l’intérieur de la Formation de Martinon.

Les échantillons renferment en outre un nombre modeste de grains de zircons du Mésoprotérozoïque, du Paléoprotérozoïque et de l’Archéen, les derniers ayant jusqu’à 3,23 Ga. La présence de zircons de l’ordre de 1,07 à 1,61 milliard d’années est compatible avec une origine du long de la marge périgondwanienne de l’Amazonie plutôt que de l’Afrique occidentale. La similarité générale de la provenance des zircons des échantillons du Nouveau-Brunswick et du littoral du Maine permet de supposer que toutes les ceintures gandériennes faisaient partie d’un microcontinent unique s’étant détaché du craton amazonien.

Les ceintures de l’île Grand Manan et de New River consignent toutes deux deux périodes distinctes de magmatisme de type arc du Néoprotérozoïque (vers 629 à 611 Ma ainsi que vers 553 à 535 Ma), tandis que la ceinture de Brookville a connu seulement une période de magmatisme d’arc ayant duré d’environ 553 à 528 Ma. Ces différences sont attribuées à une migration de la période plus récente du magmatisme d’arc plus à l’intérieur de Ganderia en raison de l’exhaussement de la zone de subduction. Un système à arc de divergence de Penobscot est enregistré dans les ceintures de New River et d’Ellsworth vers 514 à 502 Ma, à la suite de la migration de Ganderia dans l’océan grandissant Iapetus. Les époques de sédimentation progressivement plus récentes des séquences de grès quartzeux de la ceinture de Brookville (Formation de Martinon), de la ceinture de l’île Grand Manan (Formation de Flagg Cove) et de la ceinture de New River (Formation de Matthews Lake) peuvent être attribuées à ces périodes épisodiques de quiescence et d’activité d’arc le long de la marge convergente de Ganderia. Une distension subséquente de l’arc de l’Ordovicien précoce de Meductic-Popelogan le long d’un segment de la marge gandérienne a mené au développement de l’activité volcanique d’arrière-arc de l’Ordovicien moyen de Tetagouche à l’intérieur de la ceinture de Miramichi, dans le Centre et le Nord du Nouveau-Brunswick.

[Traduit par la redaction]

Detrital zircon ages from Neoproterozoic and Early Paleozoic conglomerate and sandstone units of New Brunswick and coastal Maine: implications for the tectonic evolution of Ganderia

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ABSTRACT

Detrital zircon ages were determined for conglomerate and sandstone samples from six fault-bounded belts in New Brunswick and coastal Maine. Formations sampled included the Martinon (Brookville belt), Flagg Cove (Grand Manan Island belt), Matthews Lake (New River belt), Ellsworth (Ellsworth belt), Calais (St. Croix belt), and Baskahegan Lake (Miramichi belt). Their maximum age of deposition is based on the youngest detrital zircon population and minimum age of deposition based on stratigraphic, paleontological, and cross-cutting intrusive relationships. The determined range of depositional ages are: Martinon between 602 ± 8 (youngest zircons) and 546 ± 2 Ma (age of cross-cutting intrusion); Flagg Cove between 574 ± 7 (youngest zircons) and 535 ± 3 Ma (age of cross-cutting intrusion); Matthews Lake between 539 ± 5 (youngest zircons) and 514 ± 2 Ma (age of overlying volcanic rocks); Ellsworth between 507 ± 6 (youngest zircons) and 504 ± 3 Ma (age of overlying volcanic rocks); Calais between 510 ± 8 (youngest zircons) and 479 ± 2 Ma (graptolite zone); and Baskahegan Lake between 525 ± 6 (youngest zircons) and 488 ± 2 Ma (graptolite zone).

All samples are dominated by Neoproterozoic (Gondwanan) zircon populations. The Early Paleozoic Matthews Lake, Ellsworth, and Calais formations contain main population peaks at 539 ± 5 Ma, 545 ± 4 Ma, and 556 ± 7 Ma, respectively, consistent with derivation mainly from magmatic rocks of the Brookville, Grand Manan Island, and/or New River belts, previously dated at ~553 to ~528 Ma. In contrast, the main peak in the Early Paleozoic Baskahegan Lake Formation is older at 585 ± 5 Ma. The main peak in the Neoproterozoic to Early Cambrian Flagg Cove Formation is at 611 ± 7 Ma with a secondary peak at 574 ± 7 Ma; the former was likely derived from locally exposed igneous units dated at ~618 to ~611 Ma. The Neoproterozoic Martinon Formation exhibits dominant peaks at 674 ± 8 Ma and 635 ± 4 Ma. Ganderian basement gneiss dated at ~675 Ma and intruded by plutonic rocks dated at ~584 Ma in the Hermitage Flexure of Newfoundland are possible sources for these older zircon components in the Martinon and Baskahegan Lake formations. Plutonic rocks in the New River belt dated at ~629 to ~622 Ma may be the source of the younger component in the Martinon Formation.

The samples also contain a small number of Mesoproterozoic, Paleoproterozoic, and Archean zircon grains, the latter as old as 3.23 Ga. The presence of zircons in the range 1.07 to 1.61 Ga is consistent with an origin along the peri-Gondwanan margin of Amazonia rather than West Africa. The general similarity of zircon provenance for samples from New Brunswick and coastal Maine suggests that all the Ganderian belts were part of a single microcontinent rifted from the Amazonian craton.

The Grand Manan Island and New River belts both record two distinct periods of Neoproterozoic arc magmatism (~629 to ~611 Ma and at ~553 to ~535 Ma) whereas the Brookville belt experienced only a single period of arc magmatism lasting from ~553 to ~528 Ma. These differences are attributed to migration of the younger period of arc magmatism further inboard into Ganderia due to shallowing of the subduction zone. A Penobscot rifted arc system is

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recorded in the New River and Ellsworth belts from ~514 to ~502 Ma, following migration of Ganderia into the widening Iapetus Ocean. The progressively younger depositional ages of the quartzose sandstone sequences of the Brookvlle belt (Martinon Formation), Grand Manan Island belt (Flagg Cove Formation) and New River belt (Matthews Lake Formation) can be attributed to these episodic periods of quiescence and arc activity along the convergent margin of Ganderia. Subsequent rifting of the Early Ordovician Meductic-Popelogan arc along a segment of the Ganderian margin led to the development of the Middle Ordovician Tetagouche back-arc volcanic activity in the Miramichi belt of central and northern New Brunswick.

RÉSUMÉ

On a déterminé par datation sur zircon détritique les âges d'échantillons de conglomérat et de grès provenant de six ceintures délimitées par des failles au Nouveau-Brunswick et sur la côte du Maine. Les formations échantillonnées comprenaient Martinon (ceinture de Brookville), Flagg Cove (ceinture de l'île Grand Manan), Matthews Lake (ceinture de New River), Ellsworth (ceinture d'Ellsworth), Calais (ceinture de St. Croix) et Baskahegan Lake (ceinture de Miramichi). Le moment maximal de leur sédimentation est basé sur la population de zircons détritiques la plus récente et le moment minimal, sur les liens stratigraphiques et paléontologiques ainsi que sur les intrusions transversales. L'éventail défini des périodes de sédimentation s'établit comme suit : Martinon, entre 602 ± 8 (zircons les plus récents) et 546 ± 2 Ma (âge de l'intrusion transversale); Flagg Cove, entre 574 ± 7 (zircons les plus récents) et 535 ± 3 Ma (âge de l'intrusion transversale); Matthews Lake, entre 539 ± 5 (zircons les plus récents) et 514 ± 2 Ma (âge des roches volcaniques sus-jacentes); Ellsworth, entre 507 ± 6 (zircons les plus récents) et 504 ± 3 Ma (âge des roches volcaniques sus-jacentes); Calais, entre 510 ± 8 (zircons les plus récents) et 479 ± 2 Ma (zone de graptolites); et Baskahegan Lake, entre 525 ± 6 (zircons les plus récents) et 488 ± 2 Ma (zone de graptolites).

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[Traduit par la redaction]

INTRODUCTION

The nature and provenance of the Ganderian microcontinent is a contentious issue, but vital to understanding the tectonic evolution of the northern Appalachians during the Paleozoic. Most workers agree that Ganderia is a piece of Gondwana that rifted away during the Late Cambrian/Early Ordovician, based mainly on faunal and paleomagnetic data (van Staal *et al*. 1996, 1998; van Staal 2007). There also appears to be general agreement that collisions of peri-Gondwanan terranes (Ganderia, Avalonia, Meguma) with Laurentia were responsible for Paleozoic orogenesis along the eastern seaboard of New Brunswick and Maine. However, debate continues on the particular timing of these collisions and on which lithotectonic belts in coastal New Brunswick and Maine should be included in Ganderia versus Avalonia (Currie 1986; Nance 1987; van Staal and Fyffe 1991, 1995a; van Staal *et al*. 1996,1998; Barr and White 1996; Fyffe *et al*. 1999; Johnson 2001; Tucker *et al*. 2001; Barr *et al.* 2003a; Landing *et al*. 2008).

Based mainly on differences in their pre-Late Ordovician stratigraphy and magmatic history, several fault-bounded lithotectonic belts have been recognized in the northern Appalachians of Atlantic Canada and New England (Hibbard *et al.* 2006, 2007). Those in New Brunswick and coastal Maine are considered to have been situated along the southeastern, i.e. Gondwanan, margin of the Iapetus Ocean in the Early Paleozoic (Fig. 1), and include Caledonia, Brookville, New River, Ellsworth, Annidale, St. Croix, and Miramichi (Fyffe and Fricker 1987; Ruitenberg *et al.* 1993; van Staal and Fyffe 1995a; Barr and White 1996; Johnson and McLeod 1996; Shultz *et al.* 2008). In addition, Grand Manan Island is considered herein as a separate belt because of its isolation from, and uncertain relationship to rocks exposed on the New Brunswick mainland (Fig. 2). All but the Caledonia belt are herein included in Ganderia (Figs.1, 2), based in part on the common presence of lithologically similar, Late Neoproterozoic to Early Ordovician, predominantly continent-derived, quartzose sedimentary sequences; and/or Neoproterozoic volcanic and plutonic rocks characterized by negative ε_{Nd} signatures (Whalen *et al.* 1994, 1996a,b; van Staal *et al.* 1996; van Staal *et al*. 1998; Samson *et al.* 2000; Hibbard *et al.* 2006; Shultz *et al.* 2008) and non-depleted δ^{18}O-isotope signatures (Potter *et al*. 2008). The Caledonia belt is included in Avalonia on the basis of its distinctive Neoproterozoic volcanic and plutonic rocks with positive ε_{Nd} signatures indicative of derivation from juvenile crust (Samson *et al.* 2000), and depleted δ^{18}O-isotope signatures (Potter *et al*. 2008). Both Avalonia and Ganderia were amalgamated with the Laurentian margin of North America by subduction of various oceanic tracts and back-arc basins during the Late Ordovician and Silurian (van Staal and Fyffe 1995a,b; Barr and White 1996; van Staal *et al*.1998, 2008; Barr *et al*. 2002; Wintsch *et al.* 2007).

The present boundaries of the lithotectonic belts in coastal New Brunswick and Maine are obscured by Late Ordovician (Ashgillian) and younger cover rocks and by Silurian - Devonian plutons, so that deciphering their original relationships is commonly difficult. Whereas the boundaries of many of these belts are currently defined by transcurrent faults known to have been active during Silurian and Devonian orogenesis and subsequent development of the Maritimes Basin (Mann *et al.* 1983; Stewart *et al*. 1995; Lin *et al.* 1994; van Staal and de Roo 1996; Tucker *et al.* 2001), their distinctive stratigraphies and magmatic histories (Fig. 3) are at least in part products of much older Iapetan and pre-Iapetan tectonic regimes. It is

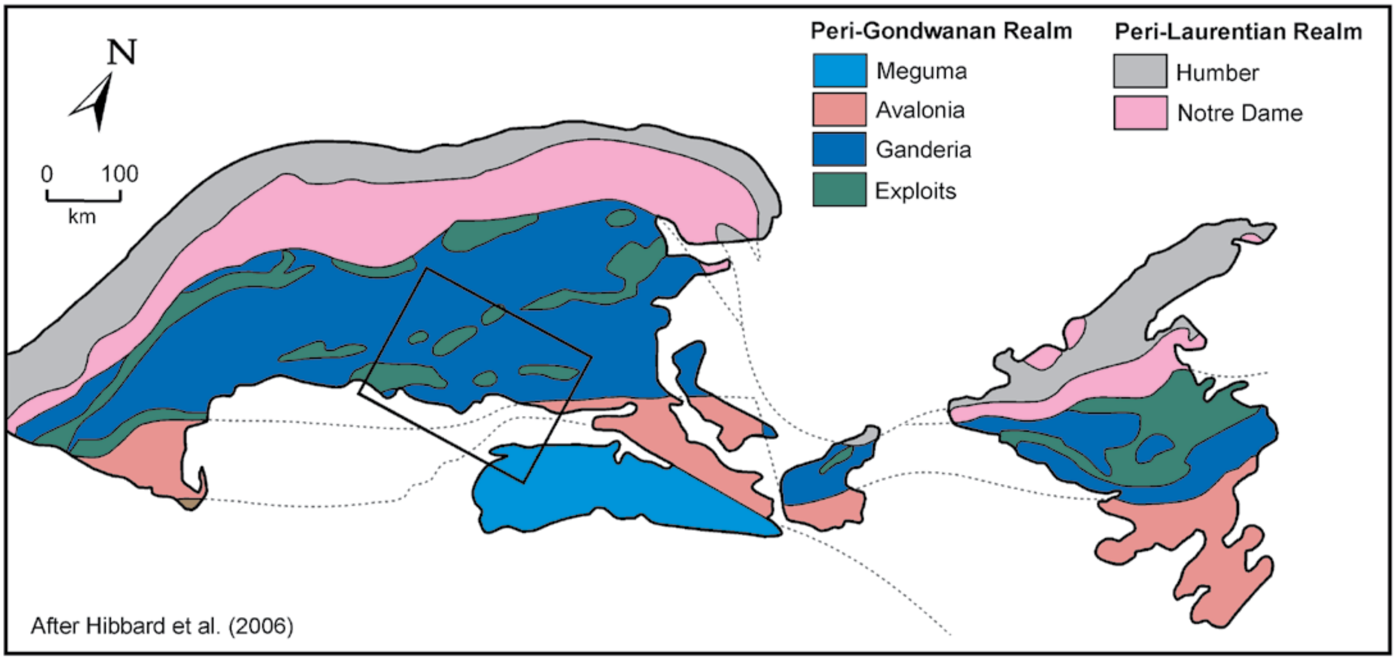

Fig. 1. Lithotectonic divisions of the northern Appalachian orogen (after Hibbard *et al.* 2006). The area shown in Fig. 2 is outlined.

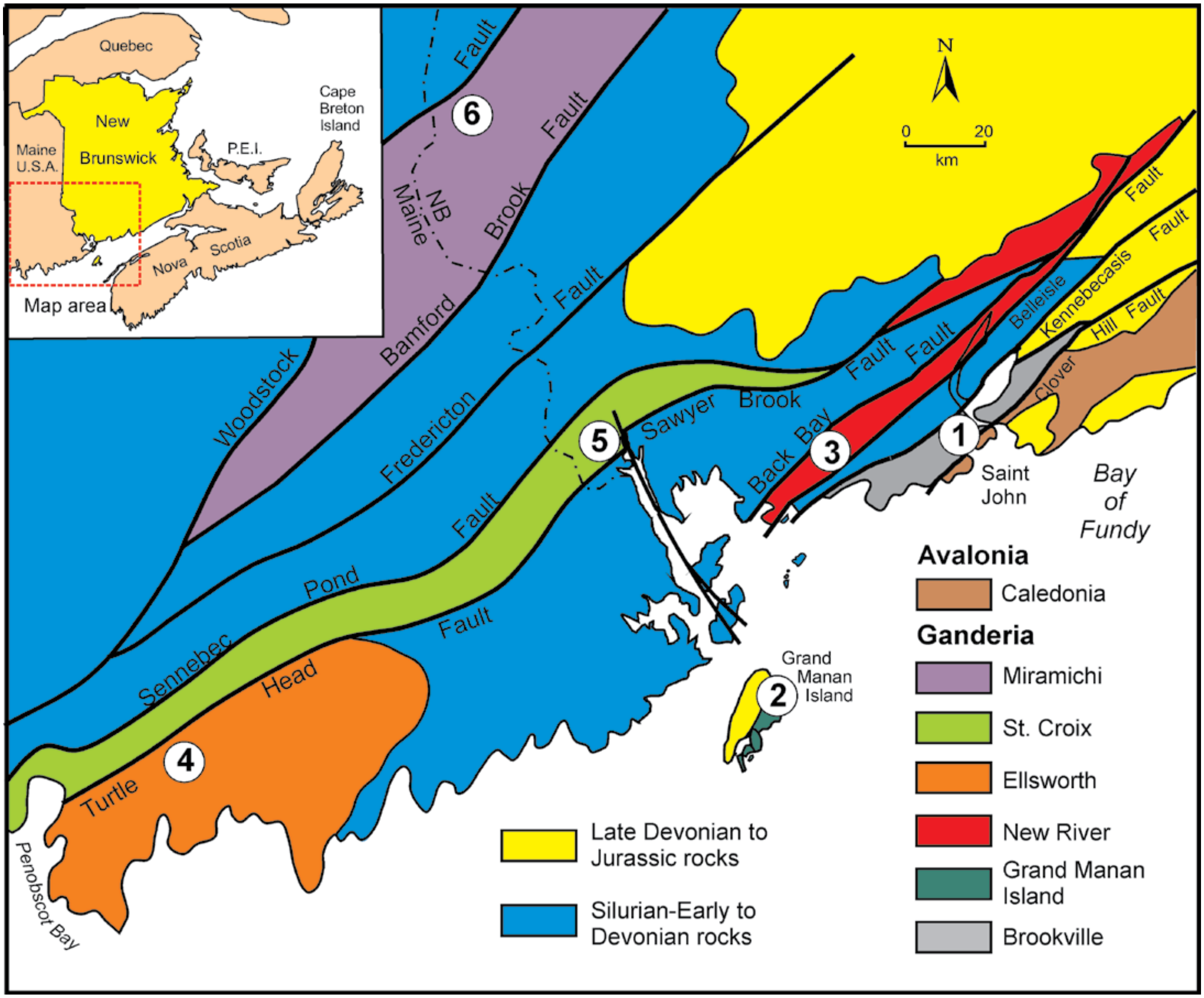

Fig. 2. Simplified geology and tectonostratigraphic belts in southern New Brunswick and adjacent Maine. Sample locations are shown by circled numbers.

argued below that many of the belts presently defined in New Brunswick and Maine should be viewed as dismembered and dispersed fragments of older continental-margin and oceanic-arc systems. As demonstrated, for example, by Wintsch *et al.* (2007), detrital zircon studies in this part of the Appalachians can provide a test as to whether juxtaposed fault slices have been derived from similar or different source areas.

The purpose of this paper is to present results from analyses of detrital zircon from lithologically similar, Neoproterozoic to Early Ordovician, quartzose sedimentary rocks in the Brookville, Grand Manan Island, New River, Ellsworth, St. Croix, and Miramichi belts to test their proposed affinity to Ganderia. If the zircon populations are essentially the same, it would strengthen the assumptions that they all form part of Ganderia. If not, these data could provide supporting evidence for the existence of other Gondwanan terranes. The data provide information on both provenance and on the maximum age of deposition of these mainly unfossiliferous units. These results are integrated with known stratigraphic relationships, magmatic history, and geochemical characteristics to suggest possible paleotectonic linkages among the various fault-bounded lithotectonic belts in New Brunswick and coastal Maine.

GANDERIAN BELTS

Geological features of the six sampled pre-Late Ordovician Ganderian belts are summarized briefly here to provide context for the individual detrital zircon sample locations (Figs. 2, 3, 4).

Fig. 3. Stratigraphic columns for the Ganderian belts in New Brunswick and coastal Maine. Location of detrital zircon samples are shown by a circled "D".

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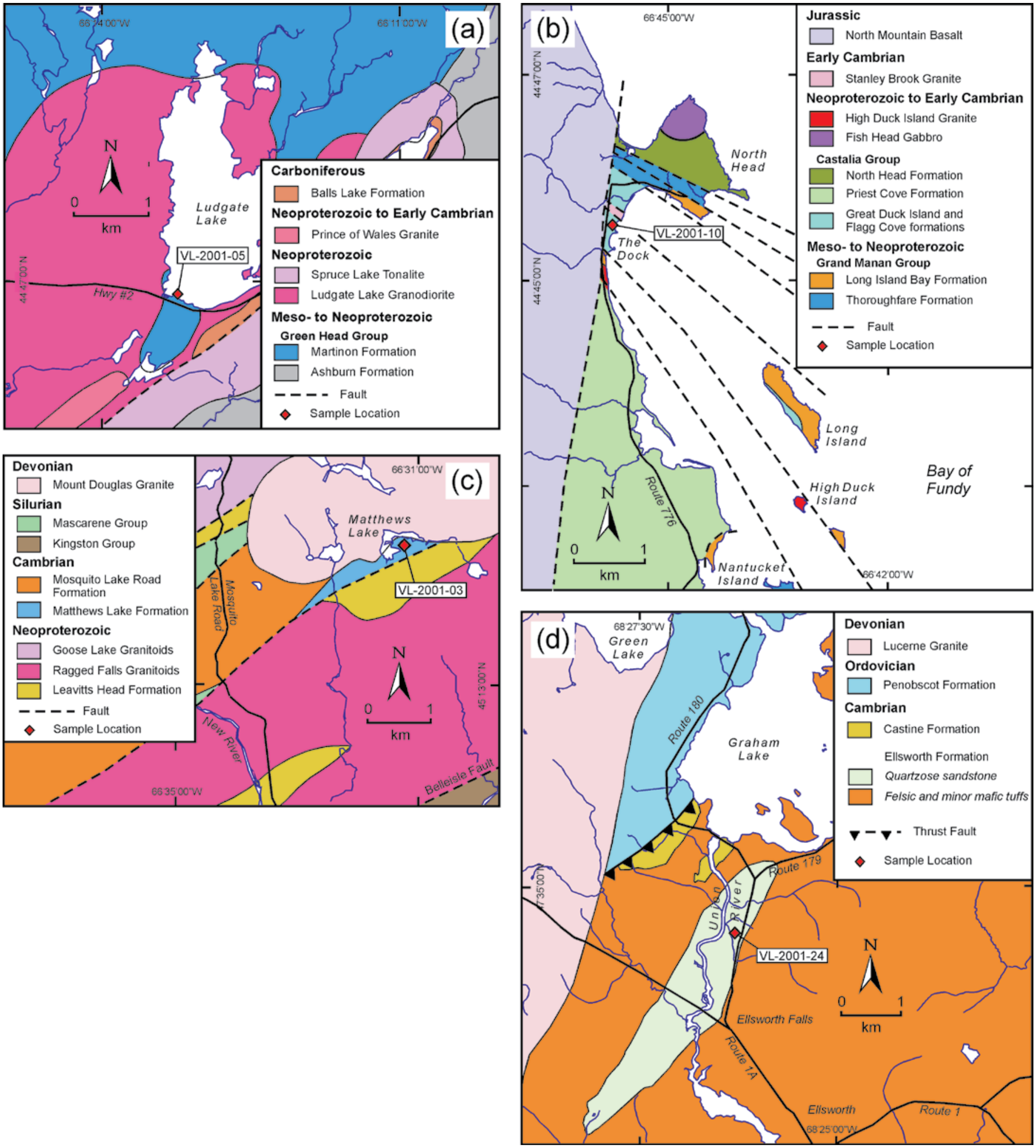

Fig. 4. Simplified geological maps showing location of analysed samples: (a) Martinon Formation (Brookville belt), modified from White *et al.* (2002); (b) Flagg Cove Formation (Grand Manan Island), modified from Fyffe and Grant (2005); (c) Matthews Lake Formation (New River belt), modified from Johnson and McLeod (1996); and (d) Ellsworth Formation (Ellsworth belt), modified from Pollock (2008). [Continued next page.]

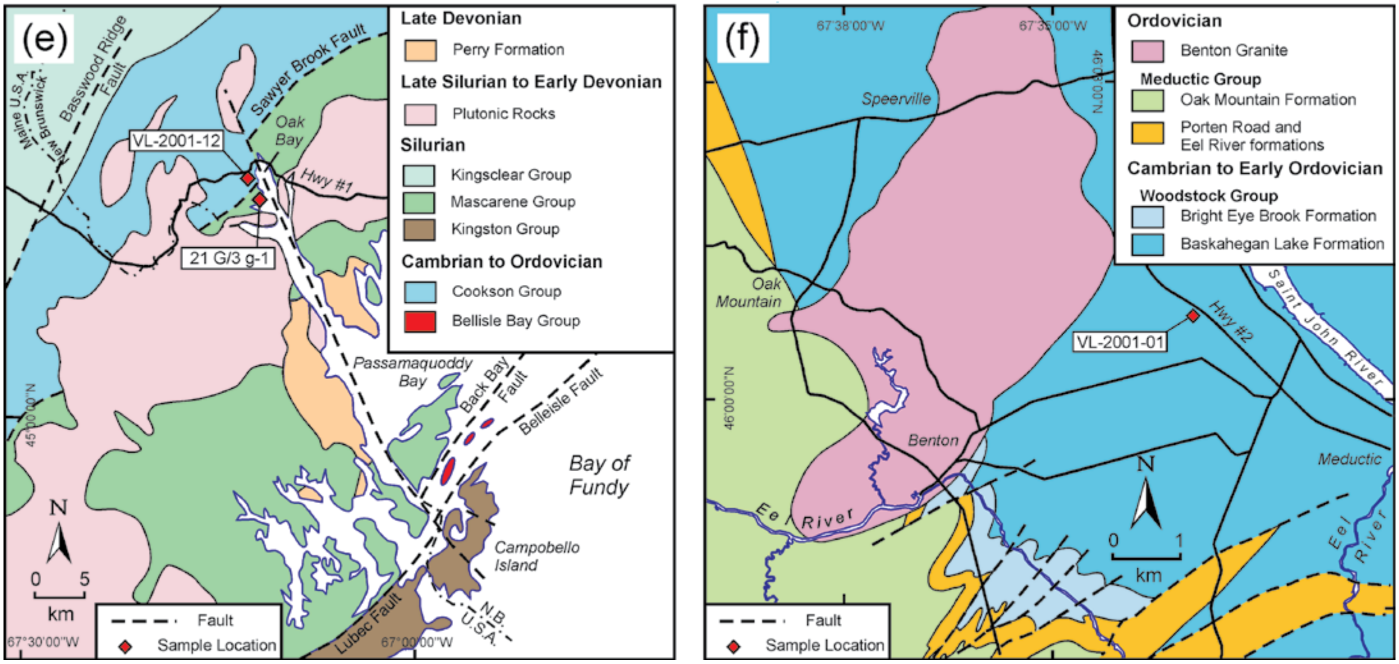

Fig. 4. [Continued from previous page.] **Simplified geological maps showing location of analysed samples: (e) Calais and Oak Bay formations (St. Croix Belt), modified from Fyffe *et al.* (1999); and (f) Baskahegan Lake Formation (Miramichi belt), modified from Fyffe (2001).**

Brookville Belt

Sedimentary and gneissic rocks of the Brookville belt (Fig. 4a) possibly range from Mesoproterozoic to Neoproterozoic and are intruded by Neoproterozoic to Early Cambrian plutons that largely possess calc-alkaline trends interpreted to represent continental margin magmatism (Eby and Currie 1996; White and Barr 1996; Currie and McNicoll 1999; White *et al.* 2002). The sedimentary rocks include stromatolitic marble and lesser quartzose sandstone of the Ashburn Formation; and siltstone, quartzose sandstone, quartzite-pebble conglomerate, and marble breccia of the overlying Martinon Formation that together comprise the Green Head Group (Alcock 1938; Leavitt 1963; Hofmann 1974). The Green Head Group is in sheared contact with the Brookville Gneiss, a unit of paragneiss and orthogneiss, the latter dated at ~605 Ma (Bevier *et al.* 1990; Dallmeyer *et al.* 1990). The Golden Grove Plutonic Suite and minor volcanic rocks of the Dipper Harbour Formation in the Brookville belt have yielded ages of ~553 to ~528 Ma. (Currie and McNicoll 1999; White *et al.* 2002; Barr *et al.* 2003a). Sample VL-2001-05 was collected from a quartzite-pebble conglomerate bed in the Martinon Formation at Ludgate Lake (Fig. 4a) to provide information on provenance and to constrain the depositional age of the formation.

The Brookville belt is interpreted to form basement to Ganderia based on the presence of late Mesoproterozoic cobbles with negative ε_{Nd} signatures in Early Ordovician limestone of the Miramichi belt (van Staal *et al.* 1996), and the relationship of equivalent rocks in the Bras d'Or terrane of Cape Breton Island and Newfoundland to Paleozoic Ganderian units (White and Barr 1996; Barr *et al.* 1998). The Clover Hill Fault marks the boundary between the Ganderian Brookville belt and the Avalonian Caledonia belt (Fig. 2).

Grand Manan Island Belt

The oldest Neoproterozoic rocks on Grand Manan and nearby islands (Figs. 2, 3, 4b) include the Kent Island, The Thoroughfare, Ingalls Head, and Long Island Bay formations of the Grand Manan Group (Fyffe and Grant 2001, 2005; Barr *et al.* 2003b; Black *et al.* 2004). Carbonate rocks of the Kent Island Formation are known only from marble inclusions in the ~611 Ma Three Islands Granite exposed on Kent Island off the southern coast of Grand Manan (Miller *et al.* 2007). The Thoroughfare Formation is characterized by the presence of very thick-bedded, white quartzite interstratified with carbonaceous black shale. The marble and quartzite have been correlated with the Ashburn Formation in the Brookville belt (Alcock 1948). Although Grand Manan Island lacks the abundant ~553 to 528 Ma plutons that characterize the Brookville belt, it does include small granitic plutons with ages of ~547 and ~535 Ma (see below), consistent with such a correlation (Fig. 3).

Felsic and mafic flows, and intermediate tuff and breccia (locally interbedded with iron-rich green to maroon volcaniclastic siltstone) of the Ingalls Head Formation on the southern part of Grand Manan Island has been dated at ~618 Ma (Barr *et al.* 2003b; Black *et al.* 2004; Miller *et al.* 2007). A sequence of plagioclase-phyric basaltic mafic flows, felsic lithic tuff, and green and maroon siltstone, exposed north of Castalia, and on Long, High Duck, Low Duck, and Great Duck islands (Fig. 4b), considered by Fyffe and Grant (2001, 2005) to correlate with the Ingalls Head Formation, has been referred to as the Long Island Bay Formation by Barr *et al. (*2003b), Black *et al.* (2004), and Miller *et al.* (2007). Maroon siltstone of the Long Island Bay Formation exposed on the shore north of Castalia has been intruded by a fine-grained, felsic dyke (referred to as the High Duck Island Granite after exposures offshore) dated at ~547 Ma (Barr *et al.* 2003b; Black *et al*. 2004; Miller *et al.* 2007). Geochemical data suggest a suprasubduction-zone origin for the volcanic rocks of the Ingalls Head and Long Island Bay formations (Pe-Piper and Wolde 2000; Black *et al.* 2004).

Younger Neoproterozoic to Cambrian strata of the Castalia Group are divided into four formations (Figs. 3, 4b); two sedimentary (Great Duck Island and Flagg Cove), and two that are volcanic-rich (Priest Cove and North Head). Contacts of the Castalia Group with the older volcanic rocks of the Grand Manan Group are generally faulted but an unconformity is preserved on Long Island, where pebble to cobble conglomerate of the Great Duck Island Formation contains volcanic clasts derived from an immediately underlying plagioclase-phyric mafic flow of the Long Island Bay Formation*.* A similar conglomerate, exposed at The Dock on Grand Manan Island, contains abundant quartzite clasts likely derived from The Thoroughfare Formation of the Grand Manan Group (Fyffe and Grant 2001).

The Flagg Cove Formation comprises thin- to medium-bedded, graded, quartzose sandstone, shale, and minor quartzite-pebble conglomerate. It contains the trace fossil *Planolites* and is intruded by the Stanley Brook Granite dated at ~535 Ma (Fyffe and Grant 2001, 2005; Miller *et al.* 2007). A sample of quartzose sandstone (VL-2001-10) from the Flagg Cove Formation was collected approximately 250 m north of The Dock (Fig. 4b) to provide information on provenance and to further constrain its depositional age.

The Priest Cove Formation, the areally most extensive unit on Grand Manan Island, comprises mainly mafic tuff and volcaniclastic sandstone. A felsic lithic-crystal tuff, interbedded with the mafic tuff, has been dated at ~539 Ma (Black *et al*. 2004; Miller *et al*. 2007), suggesting a cogenetic relationship with the Stanley Brook Granite. Such a cogenetic relationship would indicate that the Priest Cove volcanic rocks overlie the sedimentary rocks of the Flagg Cove Formation. Massive mafic flows and breccia of the North Head Formation (Fig. 4b) are considered to be proximal facies of the Priest Cove Formation by Fyffe and Grant (2001, 2005). The Early Cambrian age of the Priest Cove Formation is identical to that of volcanic rocks of the Simpsons Island Formation in the New River belt (see below) on the New Brunswick mainland (Fig. 4b,c).

New River Belt

Neoproterozoic volcanic and plutonic rocks of the New River belt extend from the New River area in southwestern New Brunswick to the Belleisle Bay area in the northeast (Fig. 2, 3, 4c). Plutonic rocks along the southeastern flank of the New River belt include the Lingley and Blacks Harbour granites, dated respectively at ~629 Ma (Currie and McNicoll 1999) and ~622 Ma (Barr *et al* . 2003a). Felsic volcanic rocks of the Leavitts Head Formation dated at 549 ± 6 Ma (McLeod *et al.* 2003), and intrusive rocks of the Ragged Falls Granite dated at ~553 Ma (Currie and Hunt 1991; Johnson and McLeod 1996; Johnson 2001; McLeod *et al.* 2003) in the New River area lie along the northwestern flank of the New River belt.

Interbedded shallow-water volcanic and sedimentary rocks of the Cambrian Buckmans Creek "group" are faulted against the Blacks Harbour Granite along the Belleisle fault, which defines the southeastern boundary of the New River belt (Fig. 2). The "group" consists of a lower section of conglomerate and quartzose sandstone, a middle section of basaltic volcanic rocks and pyroclastic rocks, and an upper section of pyritiferous black shale (Greenough *et al.* 1985; Johnson 2001). Early to Middle Cambrian trilobites are found in thin nodular limestone beds near the base of the middle section (Helmstaedt 1968; Landing *et al.* 2008). The basaltic volcanic rocks have an evolved, tholeiitic geochemical signature suggesting an intraplate continental origin (Greenough *et al.* 1985).

Felsic and mafic volcanic rocks and arkosic sandstone of the Simpsons Island Formation (Belleisle Bay Group) lie along the faulted northwestern flank of the Blacks Harbour Granite marked by the Letang Harbour fault (McLeod 1995; Johnson and McLeod 1996; McLeod *et al.* 2001; Johnson 2001; Johnson and Barr 2004). A felsic flow from the Simpsons Island Formation has been dated at ~539 Ma, i.e. early Early Cambrian (Barr *et al.* 2003a). Deeper water Cambrian sedimentary and volcanic sequences along the northwestern flank of the Ragged Falls Granite are included in the Matthews Lake and Mosquito Lake Road formations (Fig. 4c). The Mosquito Lake Road Formation contains iron-rich volcaniclastic sandstone interbedded with felsic flows and tuff dated at ~514 Ma, indicative of a late Early Cambrian age (Johnson and McLeod 1996; Ruitenberg *et al*. 1993; McLeod *et al*. 2003). The close proximity of these deeper water Cambrian facies to essentially coeval shallow-water facies of the Buckmans Creek "group" suggests that considerable structural telescoping has taken place along the Letang Harbour fault within the New River belt (Johnson 2001; Johnson and Barr 2004). Geochemical data on the mafic volcanic rocks of the Simpsons Island and Mosquito Lake Road formations suggest both were produced in suprasubduction-zone setting (Johnson and McLeod 1996).

Quartzose sandstone and intraformational quartzite-pebble conglomerate of the Matthews Lake Formation were originally correlated with a polymictic conglomeratic sequence that contains felsic volcanic clasts derived from the immediately underlying Mosquito Lake Road Formation (Johnson and McLeod, 1996). However, the textural and mineralogical maturity of the quartz-rich sandstone and conglomerate in the type section near Matthews Lake suggests that the Matthews Lake Formation may lie beneath the Mosquito Lake Road Formation. The contact between the sedimentary rocks of the Matthews Lake Formation and New River basement rocks in the Matthews Lake area is not exposed. Sample VL-2001-03 was collected from quartzose sandstone at the type section (Fig. 4c) to provide information on provenance and to constrain the depositional age of the Matthews Lake Formation.

Annidale Belt

Cambrian volcanic and sedimentary rocks also occur to the northeast in the Annidale belt of the Belleisle Bay area (Fig. 2). The Annidale Group comprises a fault-imbricated assemblage of mafic pillow basalt and hyaloclastic tuff, rhyolite flows and domes (dated at ~493 Ma), and sandstone and black shale (McLeod *et al*. 1992, 1994; Ruitenberg *et al.* 1993). Ordovician rhyolite dome complexes dated at ~478 to ~472 Ma intrude the Annidale Group (G. Dunning, unpublished data). Tectonic interleaving of the Annidale Group and its juxtaposition with Neoproterozoic New River basement to the southeast occurred prior to ~476 Ma, the age of the Stewarton gabbro pluton (G. Dunning, unpublished data). Basalt to basaltic andesite predominant in the Annidale Group and possess tholeiitic geochemical characteristics consistent with a suprasubduction-zone setting. Less common basaltic volcanic rocks associated with plagiogranite intrusions within a narrow thrust sliver display a N-MORB-like geochemical pattern (McLeod *et al*. 1994).

Ellsworth Belt

The lithological characteristics of the Middle Cambrian volcanic sequences in the Ellsworth belt of the Penobscot Bay area of coastal Maine (Stewart and Wones 1974; Stewart *et al*. 1995) are generally similar to both those of the somewhat older Mosquito Lake Road Formation of the New River belt and somewhat younger Annidale Group of the Annidale belt in New Brunswick (Figs. 2, 3, 4d). Felsic tuff of the Ellsworth Formation and a felsic dome in the Castine Formation have been dated at ~509 and ~504 Ma, respectively (Ruitenberg *et al.* 1993; Schultz *et al.* 2008). Pillowed to massive mafic volcanic rocks in the Ellsworth and Castine formations possess geochemical characteristics similar to depleted to evolved, mid-oceanic-ridge tholeiitic basalts (Schultz *et al.* 2008).

The exposed contact between Ellsworth Formation of the Ellsworth belt and Ordovician Penobscot Formation of the St. Croix belt in Maine is marked by the Turtle Head fault (Stewart and Wones 1974; Stewart *et al*. 1995). Sample VL-2001-24 was collected from quartzose sandstone (VL-2001-24) that is infolded with tuffaceous rocks of the Ellsworth Formation at Ellsworth Falls in coastal Maine (Fig. 4d) to compare its provenance with that of broadly correlative rocks in the Mosquito Lake Road Formation in the New River belt of New Brunswick.

St. Croix Belt

The St. Croix belt in New Brunswick and adjacent Maine is characterized by the Cookson Group (Ruitenberg 1967), a thick sequence of clastic sandstone and shale ranging in age from Late Cambrian to Middle Ordovician (Figs. 2, 3, 4e) The Cookson Group is divided from the base upward into the Crocker Hill, Calais, Woodland, and Kendall Mountain formations (Ludman 1987, 1991; Fyffe and Riva 1990). The Crocker Hill Formation is characterized by thick-bedded quartzose sandstone containing pods of pink garnet (coticules). Its stratigraphic position and garnetiferous nature strongly suggest a correlation with the Megunticook Formation in the Penobscot Bay area of Maine (Tucker *et al.* 2001). The Calais Formation is mostly carbonaceous black shale containing minor thin beds of silty sandstone; a pillow basalt unit occurs just above the contact with the Crocker Hill Formation. The geochemical characteristics of the pillow basalt are similar to evolved, mid-oceanic-ridge tholeiites (Fyffe *et al.* 1988). Sample VL-2001-12 was collected from a bed of sandstone in the Calais Formation at Oak Bay about 250 m south of the tombolo opposite Cookson Island (Fig. 4e) in order to compare its provenance with samples from the New River and Miramichi belts.

Graptolites found on Cookson Island in Oak Bay indicate that the Calais Formation is as young as Tremadocian (Early Ordovician) (Fyffe and Riva, 1990). A U-Pb date of ~503 Ma on a tuff bed interbedded with black shale of the equivalent Penobscot Formation in Maine suggests that age of the Calais Formation it extends down into the Middle Cambrian (Tucker *et al.*, 2001). The Woodland Formation comprises thin- to medium-bedded, convolute-laminated, feldspathic sandstone interbedded with siltstone and shale. The Kendall Mountain Formation comprises thick-bedded, quartzose sandstone interbedded with carbonaceous black shale, and minor quartz-pebble conglomerate. Graptolites from the shale are indicative of Caradocian (Late Ordovician) age (Fyffe and Riva, 1990).

Basement to the St. Croix belt is not exposed in New Brunswick. However, in coastal Maine a fault sliver of marble, quartzite, and amphibolite (Seven Hundred Acre Island Formation) cross-cut by an ~670 Ma pegmatite is juxtaposed against the St. Croix belt along the Turtle Head fault. Greenschist-facies siltstone, limestone, and quartzite-pebble conglomerate of the Islesboro Formation are interpreted to represent a platformal sedimentary sequence that unconformably overlies the amphibolite-facies basement rocks of the Seven Hundred Acre Island Formation, although the actual contact is not exposed (Stewart *et al.* 2001). In a paleogeographic reconstruction of fault-bounded slices on the adjacent mainland, Tucker *et al.* (2001) interpreted a sequence of limestone and conglomerate, equivalent to the Islesboro Formation, on Islesboro Island to be stratigraphically overlain by the Megunticook Formation. They also suggested that the Islesboro sequence has lithologic similarities to the Ashburn and Martinon formations in the Brookville belt. However, it should be mentioned that neither the Islesboro Formation nor Seven Hundred Acre Island Formation is intruded by the Neoproterozoic plutons that characterize the Brookville belt in New Brunswick (Fig. 3).

Miramichi Belt

The Miramachi belt in the Bathurst area of northeastern New Brunswick (Fig. 3) is characterized by a Cambrian to Early Ordovician quartzose sedimentary sequence (Miramichi Group) and overlying Middle to Late Ordovician volcanic rocks of the Tetagouche Group (van Staal and Fyffe 1991, 1995a,1995b; van Staal *et al.* 1992, 1996, 2003; Fyffe *et al.* 1997). The Miramichi Group is divided into a lower unit of thick-bedded quartzose sandstone (Chain of Rocks Formation), a middle unit of medium-bedded quartzose sandstone and shale (Knights Brook Formation), and an upper unit of medium-bedded, felspathic sandstone and shale (Patrick Brook Formation).

The base of the overlying Tetagouche Group is exposed near Tetagouche Falls on the Tetagouche River, where a thin unit of conglomerate, and calcareous sandstone and siltstone (Vallée Lourdes Formation) lies unconformably on sandstone beds of the Patrick Brook Formation. The calcareous siltstone on the Tetagouche River and correlative limestone beds in central New Brunswick contain Arenigian brachiopods of the Celtic biogeographic province (Fyffe 1976; Neuman 1984; Fyffe *et al.* 1997; Poole and Neuman 2003). The corresponding unconformity between the Cambrian Grand Pitch Formation and Early Ordovician Shin Pond Formation in adjacent Maine defines the Penobscot disturbance of the northeastern Appalachian orogen (Neuman 1964).

Volcanic rocks overlying the Vallée Lourdes Formation are divided into a lower unit of quartz-feldspar crystal tuff and iron formation (Nepisiguit Falls Formation), a middle unit of aphyric to sparsely feldspar-phyric felsic flows (Flat Landing Brook Formation), and an upper unit of mafic volcanic rocks interbedded with ferromanganiferous cherty siltstone and black shale (Little River Formation). The bimodal volcanic rocks of the Tetagouche Group are considered on the basis of their geochemical composition to have been generated in an intra-arc rift to back-arc basin transitional setting (van Staal 1987; van Staal *et al.* 1991, 2008; van Staal and Fyffe 1995a).

The Miramichi belt near Woodstock in west-central New Brunswick (Figs. 2, 3, 4f) is underlain by quartz-rich sedimentary and volcanic sequences referred to respectively as the Woodstock and Meductic groups (Fyffe 2001). The Woodstock Group includes quartzose sandstone and shale of the Baskahegan Lake Formation and conformably overlying carbonaceous black shale of the Bright Eye Brook Formation. Trace fossils recovered near Woodstock suggest that the Baskahegan Lake Formation may be as young as Early Ordovician (Pickerill and Fyffe 1999). Graptolites from the Bright Eye Brook Formation are indicative of an Early Ordovician (Tremadocian-early Arenigian) age (Fyffe *et al*. 1983). Sample VL-2001-1 was collected from a quartzose sandstone bed in the Baskahegan Lake Formation along Rte. 2 north of Meductic (Fig. 4f) in order to compare its provenance with that of the Miramichi Group, and with samples from the St. Croix, New River, and Ellsworth belts.

The conformably overlying Meductic Group is divided into the Porten Road Formation (felsic volcanic flows and tuff), Eel River Formation (intermediate tuff and volcaniclastic rocks), Oak Mountain Formation (mafic volcanic flows and tuff), and Belle Lake Formation (felspathic sandstone and shale). Graptolites from the Belle Lake Formation are indicative of an early Caradocian (early Late Ordovician) age (Fyffe *et al*. 1983). The Benton pluton, which is comagmatic with the volcanic rocks of the Meductic Group, has been dated at ~479 Ma (Whalen *et al.* 1998), thus indicating that volcanic activity in the Woodstock area began prior to that of the Tetagouche Group (dated at ~474 Ma to ~457 Ma) in the Bathurst area. The Meductic volcanic rocks possess geochemical characteristics consistent with a suprasubduction-zone setting, and therefore, have been interpreted to represent a volcanic arc that developed just prior to opening of the Tetagouche back-arc basin (van Staal and Fyffe 1995b; Dostal 1989; Fyffe 2001).

LATE ORDOVICIAN TO SILURIAN COVER ROCKS

Cover rocks of predominately Silurian age generally are in faulted contact with, but locally unconformably overlie, the Neoproterozoic to Middle Ordovician belts described above. A belt of Early Silurian mainly felsic volcanic rocks of the Kingston Group and related plutons, bounded by the Kennebecasis and Lubec-Belleisle faults (Fig. 2), separates the Brookville belt from the New River belt (McLeod and Rast 1988; Eby and Currie 1993; McLeod *et al*. 2001; Barr et al. 2002). Fyffe *et al.* (1999) and Barr *et al.* (2002) proposed that the Kingston Group and related granitic plutons and younger mafic dykes represent an extensional volcanic arc formed during subduction of an oceanic tract separating Avalonia from Ganderia.

An extensive belt of Silurian volcanic and sedimentary rocks comprising the Mascarene Group (including the Oak Bay, Waweig, Eastport, and Letete formations) underlies the area between the Back Bay fault, which marks the northwestern boundary of the New River belt, and the Sawyer Brook fault, which marks the southeastern boundary of the St. Croix belt in New Brunswick (Johnson and McLeod 1996; Fyffe *et al.* 1999; Johnson 2001; Miller and Fyffe 2002). As such, the actual contact between the New River and St. Croix belts is hidden beneath the Silurian cover (Figs. 2, 4e). Strata of the Mascarene Group are also locally preserved on the southeastern side of the Back Bay fault and presumably lie unconformably on rocks of the New River belt. These cover rocks include Late Ordovician (Ashgillian) limestone of the Goss Point Formation and Early Silurian quartzose sandstone of the Back Bay Formation in the Letang Harbour area (Donohoe 1973; McLeod *et al*. 2001; Johnson and McLeod 1996). Silurian rocks correlative with the Mascarene Group also cover much of the Ellsworth belt in adjacent Maine (Gates 1969, 1989; Stewart *et al*. 1995). Such relationships led Fyffe and Fricker (1987) to propose that volcanic rocks correlative with the Ellsworth Formation extend from Maine into New Brunswick beneath Mascarene cover rocks.

Early Silurian feldspathic sandstone and shale of the

Digdeguash Formation at the base of the Kingsclear Group lie disconformably on quartzose sandstone and shale of the Ordovician Kendall Mountain Formation along most of the northwestern margin of the St. Croix belt (Fyffe and Riva 1990, 2001; Fyffe *et al*. 1999). However along strike to the southwest, the contact is marked by the Basswood Ridge fault near the Maine border, by the South Princeton-Crawford fault across the border in Maine, and the Sennebec Pond fault in the Penobscot Bay area of coastal Maine (Ludman 1991; Stewart *et al.* 1995; Fyffe *et al*. 1999). The contact of the Silurian Kingsclear Group with the Miramichi belt to the northwest is marked by the Bamford Brook fault (Fyffe 1995).

Along the Sawyer Brook fault, Early Silurian conglomerate of the Oak Bay Formation at the base of the Mascarene Group lies with faulted angular unconformity on polydeformed Early Ordovician black shale of the Calais Formation along the southeastern boundary of the St. Croix belt. The conglomerate contains clasts of black shale obviously of local derivation but also contains an abundance of mafic and felsic igneous clasts of uncertain origin (Fyffe *et al*. 1999). A sample of this conglomerate (21G/3g -1) was collected along the western shore of Oak Bay (Fig. 4e) to determine the provenance of the igneous clasts.

ANALYTICAL METHODS

SHRIMP II (Sensitive High Resolution Ion Microprobe) analyses were conducted at the Geological Survey of Canada using analytical and data reduction procedures described in detail by Stern (1997) and Stern and Amelin (2003) and briefly summarized here. Detrital zircons from the samples and fragments of the GSC laboratory zircon standard (z6266 zircon with ^{206}Pb/^{238}U age = 559 Ma) were cast in an epoxy grain mounts (GSC mounts IP286, IP295, and IP296), polished with diamond compound to reveal the grain centres, and photographed in transmitted light (Fig. 5). The mount was evaporatively coated with 10 nm high purity Au, and the internal features of the zircons were characterized with backscattered electrons (BSE) utilizing a scanning electron microscope (SEM). Representative SEM images of the grains with location of the SHRIMP spots marked are shown for each sample (Fig. 6). The numbers on the SEM images refer to the grain that was analysed and the age of the spot.

Analyses were conducted using an O^- primary beam projected onto the zircons with an elliptical spot size ranging from about 15–20 µm (in the longest dimension). The count rates of ten isotopes of Zr^+, U^+, Th^+, and Pb^+ in zircon were sequentially measured with a single electron multiplier. Off-line data processing was accomplished using customized in-house software. The SHRIMP analytical data are presented in tables A1–A7. Common-Pb corrected ratios and ages are reported with 1σ analytical errors, which incorporate external uncertainties of 1.10% (IP286), 1.00% (IP295) and 1.00% (IP296) in calibrating the standard zircon (Stern and Amelin 2003). The ^{206}Pb/^{238}U ages for analyses < 1000 Ma have been corrected for common Pb using both the 204- and 207-methods (Stern 1997), but generally no significant difference is apparent in the results (Appendix tables A1–A7).

The precision of single analyses and the possibility of Pb make evaluation of the single analyses difficult. In some cases, additional analyses of the same age (i.e. additional spot analyses) were retrieved allowing the data to be pooled for a better-constrained age for the detrital grain. Data from the detrital samples, in particular the younger data, are examined in terms of statistical age populations, which are interpreted to be more robust than a single analysis. Data that are < 5% discordant are represented in cumulative probability plots (Sircombe 2000). For detrital grains > 1000 Ma, the ^{207}Pb/^{206}Pb age is used in the cumulative probability plot and for data < 1000 Ma, the ^{206}Pb/^{238}U age is used (Compston *et al.* 1992; Nemchin and Cawood 2005) (Figs. 7, 8, 9).

ANALYTICAL RESULTS

Martinon Formation (Brookville belt)

Sample VL-2001-05 from quartzite-pebble conglomerate of the Martinon Formation contains detrital zircons ranging in size from about 60 to ~250 µm in the longest dimension. Well faceted, euhedral crystals ranging in morphology from equant and multifaceted to elongate are abundant. Subround to round, frosted and pitted grains ranging in colour from colourless to light brown are also present in the sample. The zircons range in quality from beautiful clear crystals to those with abundant fractures, inclusions, and apparent cores (Fig. 5a, 6a).

A statistical age population, defined by 24% of the analyses, has a Neoproterozoic age of 635 ± 4 Ma (MSWD = 1.05, probability = 0.40, n = 13). Other statistically significant Neoproterozoic populations are at 674 ± 8 Ma (MSWD = 1.5, probability = 0.13, n = 10) and 602 ± 8 Ma (MSWD = 1.4, probability = 0.21, n = 8), and the latter is considered to represent the maximum depositional age of the conglomerate (Fig. 7a). Analyses from grain 43 (two spots – 43.1, 43.2 in Table A1) and grain 34 (two spots – 34.1, 34.2, in Table A1) are not considered in the cumulative probability plot as both of these grains show evidence for Pb loss. Detritus of Mesoproterozoic age comprise 27% of the analyses and range in age from ~1.58 to ~1.07 Ga. A few Paleoproterozoic (~2.18 to ~1.91 Ga) grains and a single Archean (~2.57 Ga) grain were also analysed (Fig. 8a; Table A1).

Flagg Cove Formation (Grand Manan Island belt)

Sample VL-2001-10 from quartzose sandstone of the Flagg Cove Formation contains detrital zircon grains with a range of morphologies including well faceted crystals ranging from equant to elongate in shape, and abundant subround to round grains. Overall, the size of zircon grains in the sample is fairly consistent and quite small (mostly < 50 to < 100 µm in the

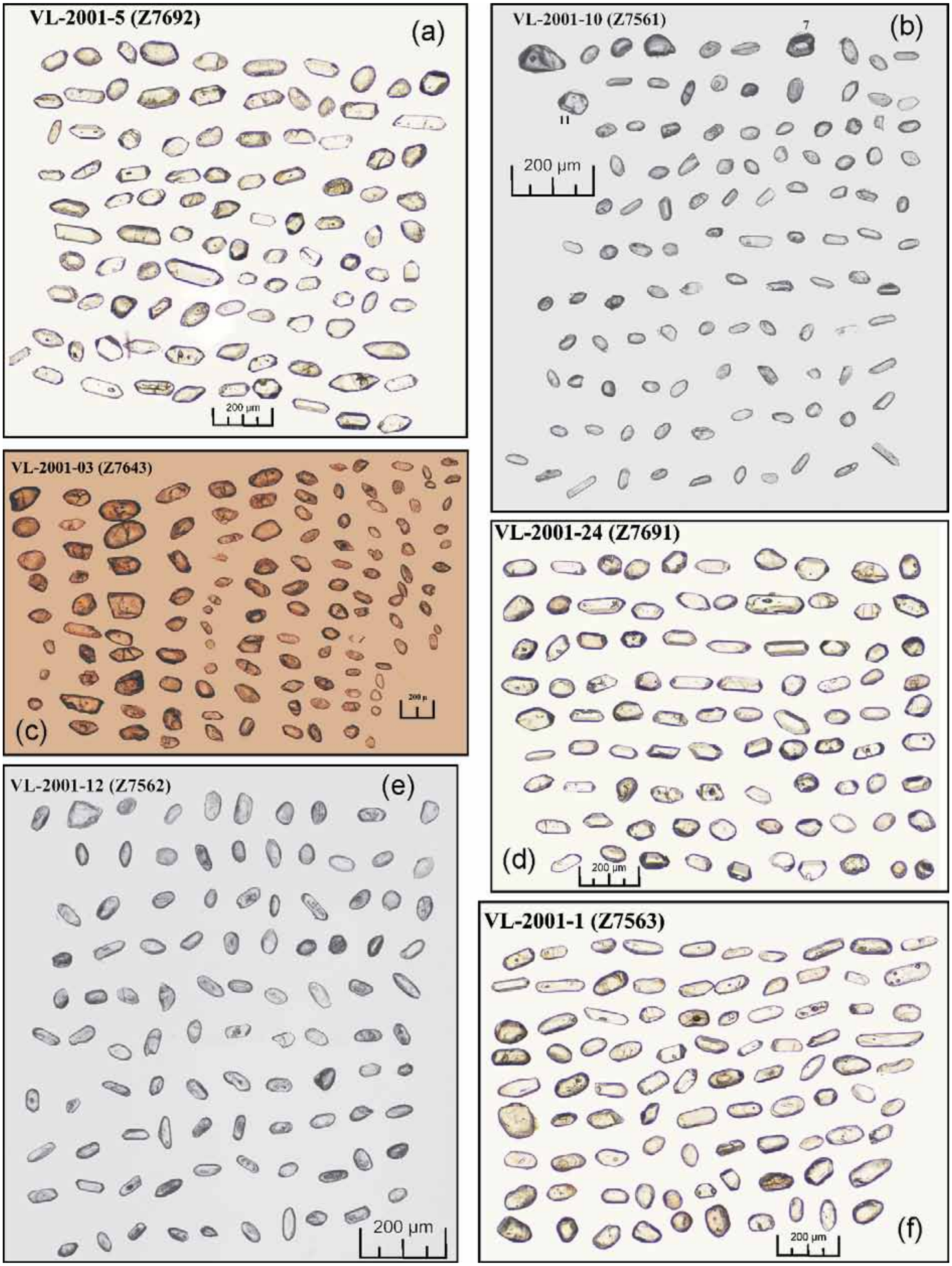

Fig. 5. Transmitted light photograph of the detrital zircons: (a) Martinon Formation (Sample VL-2001-05 on SHRIMP Mount #IP295; (b) Flagg Cove Formation (Sample VL-2001-10 on SHRIMP Mount #IP296); (c) Matthews Lake Formation (Sample VL-2001-03 on SHRIMP Mount #IP286); (d) Ellsworth Formation (Sample VL-2001-24 on SHRIMP Mount #IP295); (e) Calais Formation (Sample VL-2001-12 on SHRIMP Mount #IP296); (f) Baskahegan Lake Formation (Sample VL-2001-01 on SHRIMP Mount #IP295).

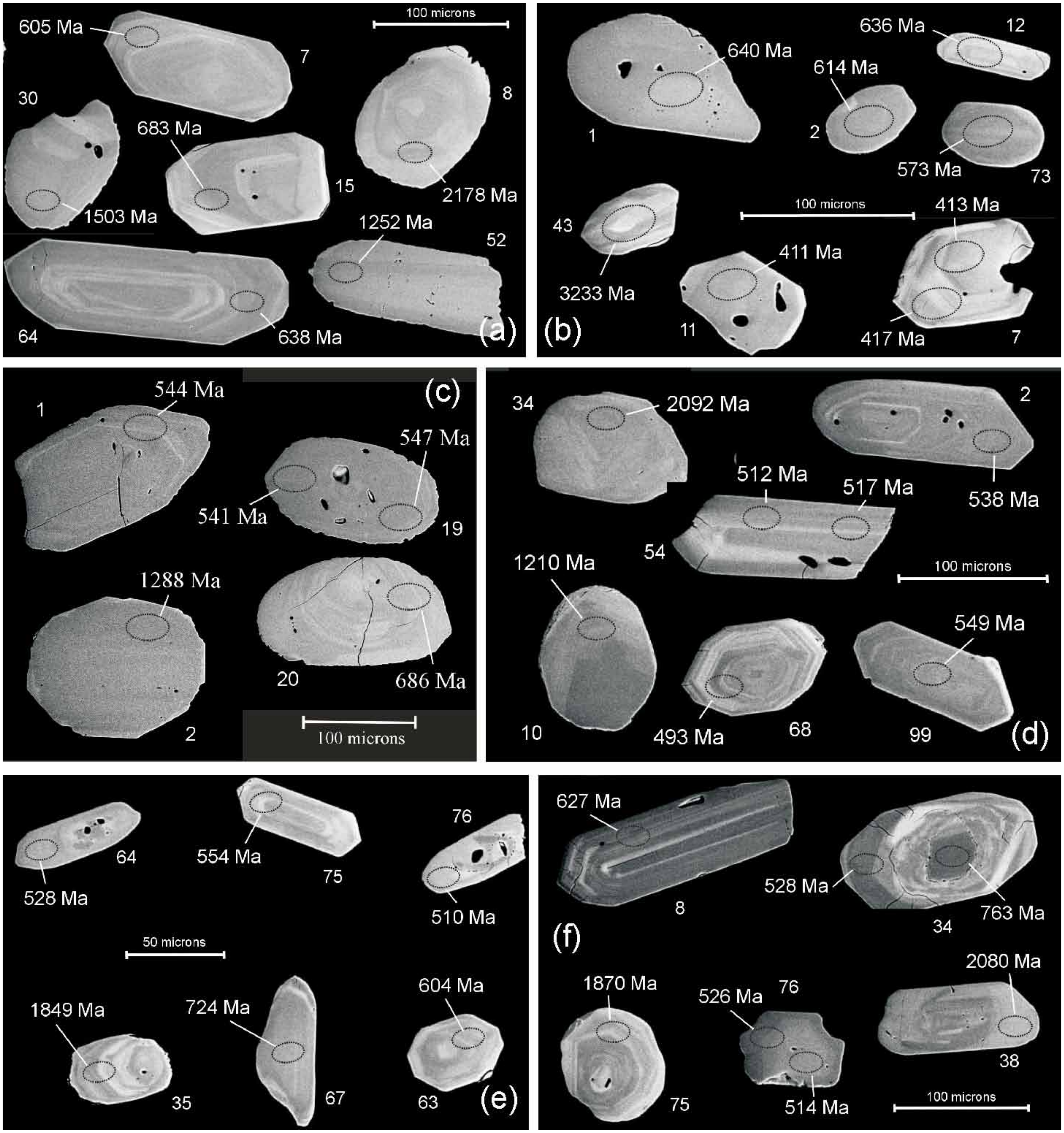

Fig. 6. Representative BSE SEM images of detrital zircons with location of the SHRIMP spots: (a) Martinon Formation (Sample VL-2001-05); (b) Flagg Cove Formation (Sample VL-2001-10); (c) Matthews Lake Formation (Sample VL-2001-03); (d) Ellsworth Formation (Sample VL-2001-24); (e) Calais Formation (Sample VL-2001-12); (f) Baskahegan Lake Formation (Sample VL-2001-01).

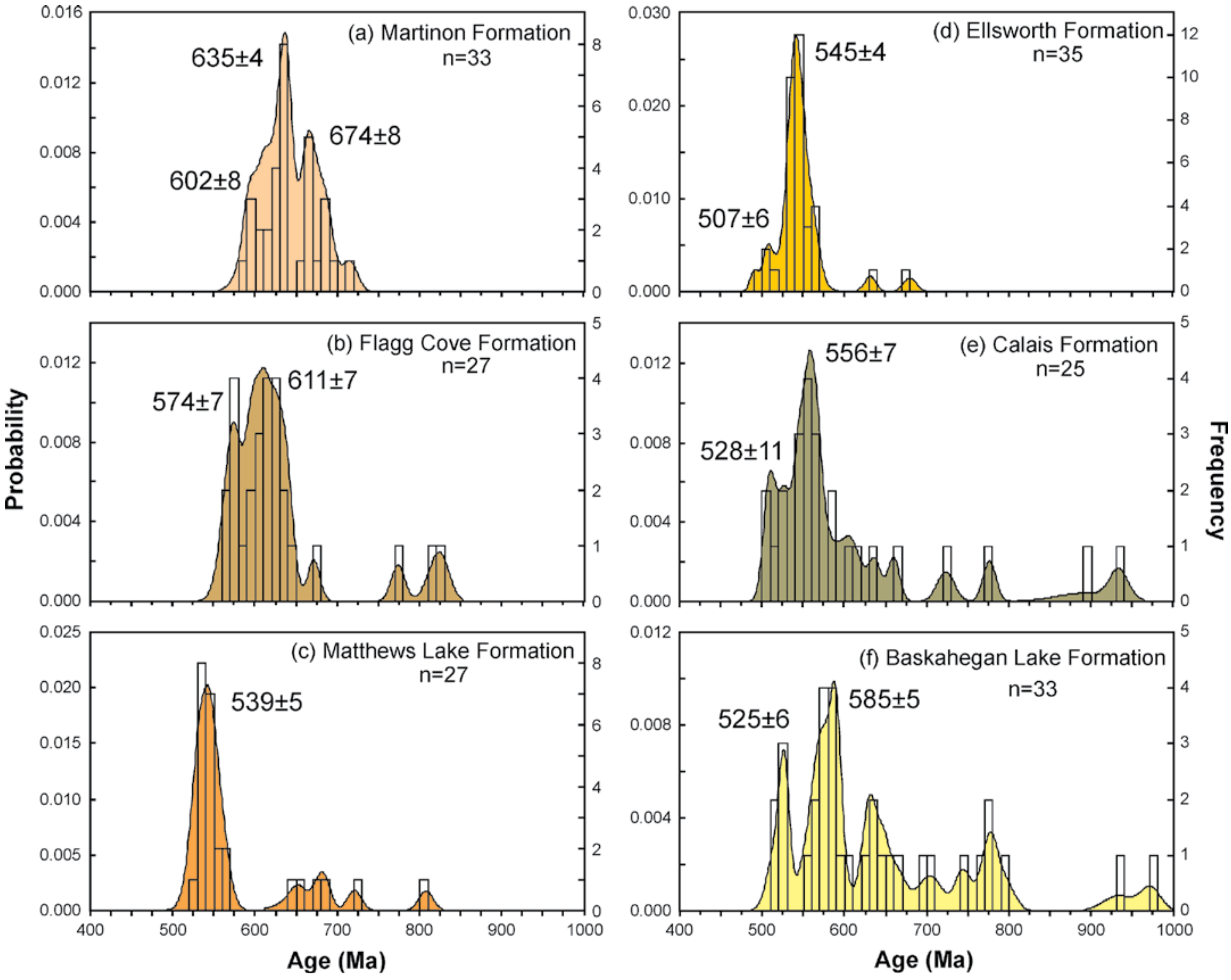

Fig. 7. Cumulative probability plots of the data ranging in age between 400–1000 Ma: (a) Martinon Formation (Sample VL-2001-05); (b) Flagg Cove Formation (Sample VL-2001-10); (c) Matthews Lake Formation (Sample VL-2001-03); (d) Ellsworth Formation (Sample VL-2001-24); (e) Calais Formation (Sample VL-2001-12); (f) Baskahegan Lake Formation (Sample VL-2001-01).

longest dimension, with many ≤ 50 microns in size). Many grains have cores, abundant inclusions, and/or fractures, but also present are high quality, optically clear grains (Fig. 5b).

The dominant statistical age population in the sample (~30% of the analyses) has a Neoproterozoic age of 611 ± 7 Ma (MSWD = 2.2, n = 13 grains). Also present is a younger Neoproterozoic age population of 574 ± 7 Ma (MSWD = 0.69, probability = 0.66, n = 7 grains), which is considered to represent the maximum depositional age of the sandstone (Fig. 7b). Other zircons of Neoproterozoic age range from ~828 to ~672 Ma. Rare detrital zircons of Mesoproterozoic (~1.44 to ~1.34 Ga), Paleoproterozoic (~2.44 to ~1.74 Ga), and Archean (~3.23 to ~2.90 Ga) age are also represented in the sandstone (Fig. 8b; Table A2).

Two analyses at ~507 Ma from a single zircon (grain 91) are not included in the cumulative probability plot as they are slightly discordant, have low U contents, and are from a grain which contains some fractures. These data are not of sufficient quality to evaluate if grains of this age are present in this sample. However, two other zircon grains (grains 7 and 11, Table A2; not plotted) also yielded Paleozoic ages and these two grains contain sufficient U to produce good quality analyses. These two grains are similar in morphology (stubby to equant) and are slightly larger than most of the detrital zircons in the sample (Figs. 5b, 6b). The data include two overlapping reproducible analyses from grain 7, and one analysis from grain 11 (Table A2), all of which are concordant. A weighted average of these analyses has an age of 414 ± 6 Ma (MSWD = 0.36, probability = 0.70, n = 3). Although the data are of good quality, the two grains are interpreted to be contaminants, possibly from

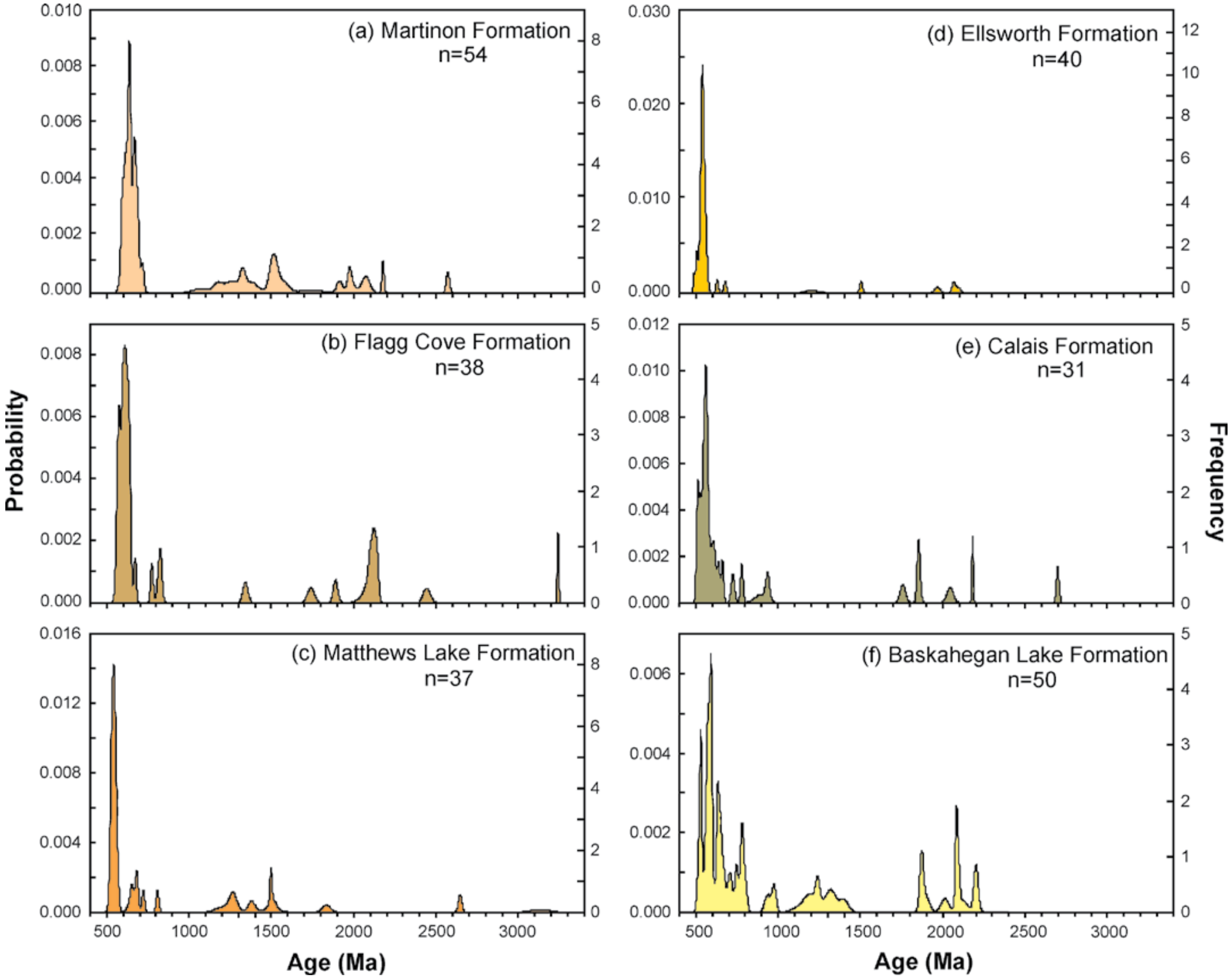

Fig. 8. Cumulative probability plots of all the data: (a) Martinon Formation (Sample VL-2001-05); (b) Flagg Cove Formation (Sample VL-2001-10); (c) Matthews Lake Formation (Sample VL-2001-03); (d) Ellsworth Formation (Sample VL-2001-24); (e) Calais Formation (Sample VL-2001-12); (f) Baskahegan Lake Formation (Sample VL-2001-01).

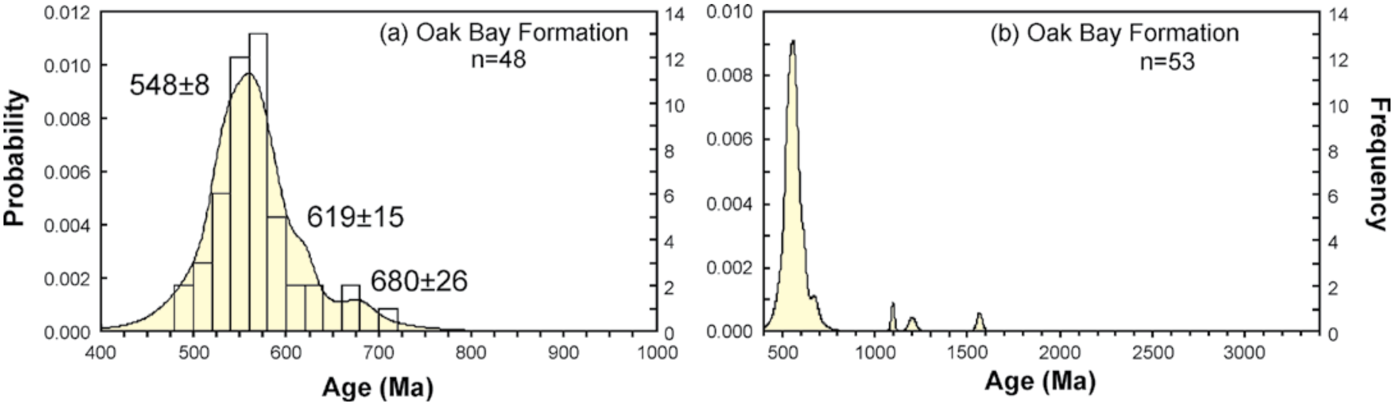

Fig. 9. Cumulative probability plots of the data from the Oak Bay Formation (Sample 21G/3g -1A): (a) data ranging in age between 400–1000 Ma; (b) all the data.

thin glassy quartz veins that are not easy to differentiate from the quartz-rich sedimentary host, as field relationships indicate that the Flagg Cove Formation was intruded by the ~535 Ma Stanley Brook Granite (Miller *et al.* 2007).

Matthews Lake Formation (New River belt)

Sample VL-2001-03 from quartzose sandstone of the Matthews Lake Formation contains detrital zircon grains with a wide range of morphologies from well rounded, frosted and pitted grains to sharply faceted euhedral crystals. Zircon grains selected for SHRIMP analysis vary in size (~75 to 300 μm) and quality and include optically clear grains, those that contain colourless fluid or dark opaque inclusions, grains with abundant fractures, and grains with cores (Figs. 5c, 6c).

A single statistical age population of 539 ± 5 Ma (MSWD = 1.2, probability = 0.25, n = 17), which spans the Neoproterozoic-Paleozoic boundary, dominates the sample (40% of the analyses), and provides a maximum depositional age for the sandstone (Fig. 7c). Other significant contributions include detritus of Mesoproterozoic (~1.50 to ~1.20 Ga) and Neoproterozoic (~808 to ~644 Ma) age. Rare grains of Paleoproterozoic (~1.83 Ga) and Archean (~3.14 to ~2.65 Ga) age were analysed from this sample (Fig. 8c; Table A3).

Ellsworth Formation (Ellsworth belt)

Sample VL-2001-24 from quartzose sandstone of the Ellsworth Formation contains detrital zircon grains dominated by well-faceted grains ranging in morphology from multi-faceted crystals to stubby prismatic grains to elongate crystals. Subround to round, colourless to light brown grains are less common, but were also analyzed. Zircons with a range of quality were analyzed, from grains with abundant inclusions and fractures to high quality, clear, colourless, well faceted crystals. Zircons with cores are also present in the sample. The zircon grains range in length from about 50 to 200 μm (Fig. 5d).

A dominant statistical age population (73% of the analyses) with an age of 545 ± 4 Ma (MSWD = 1.6, n = 28, spans the Neoproterozoic-Paleozoic boundary. Younger Paleozoic grains are also present in the sample and define a statistical age population of 507 ± 6 Ma (MSWD = 1.2, probability = 0.33, n = 6 analyses on four grains). Two of these younger zircons have reproducible analyses: grain 54 has two overlapping analyses with a weighted average of 515 ± 11 Ma (MSWD = 0.21, probability = 0.65; Fig. 6d), and grain 67 has two overlapping analyses with a weighted average of 506 ± 11 Ma (MSWD = 0.59, probability = 0.44; Table A4). These grains likely indicate a maximum depositional age for the Ellsworth Formation of ~507 Ma. Rare detrital zircons of Neoproterozoic (~680 and ~632 Ma), Mesoproterozoic (~1.50 and ~1.21 Ga) and Paleoproterozoic (~2.09 to ~1.97 Ga) age were also analysed from the sample (Fig. 8d; Table A4).

Calais Formation (St. Croix belt)

Sample VL-2001-12 from sandstone of the Calais Formation contains detrital zircon grains that are consistently small, ranging from about 50 to < 100 μm in the longest dimension. The grains exhibit a range of morphologies including subround to round grains, and equant to prismatic euhedral crystals. High quality, clear zircons are common in the sample but grains with abundant fractures, inclusions, and cores are also present (Fig. 5e).

The most dominant statistical age population in the sample (~30% of the analyses) has a Neoproterozoic age of 556 ± 7 Ma (MSWD = 1.6, probability = 0.10, n = 10; Fig. 7e). Younger Paleozoic zircons include three detrital grains defining a statistical population of 510 ± 8 Ma (MSWD = 0.51, probability = 0.60, n = 3) and two grains at 528 ± 11 Ma (MSWD = 0.017, probability = 0.90; Fig. 6e). The analyses from these younger concordant grains contain a sufficient amount of U to produce good quality data, and are likely to provide a maximum depositional age for the Calais Formation. Neoproterozoic (~936 to ~580 Ma), Paleoproterozoic (~2.18 to ~1.76 Ga), and minor Archean (~2.70 and ~2.60 Ga) grains are also present in the sample (Fig. 8e; Table A5).

Baskahegan Lake Formation (Miramichi belt)

Sample VL-2001-01 from quartzose sandstone of the Baskahegan Lake Formation contains detrital zircon grains with a wide range of morphologies from well-rounded, light pink grains to sharply faceted, colourless, euhedral crystals including some delicate elongate grains (Fig. 5f). Grains selected for SHRIMP analysis ranged in length from about 75 to 300 μm. A range of zircon quality was also represented on the mount and includes grains that are optically clear, those that contain colourless fluid or dark opaque inclusions and abundant fractures, and grains with cores (Fig. 6f).

The youngest statistical age population has an Early Cambrian age of 525 ± 6 Ma (MSWD = 0.56, probability = 0.69, n = 5 analyses on four grains; Fig. 7f). Two reproducible spots on one grain (grain 76; Fig. 6f) have an age of 522 ± 11 Ma (MSWD = 1.02, probability = 0.31). A statistical population with a Neoproterozoic age of 585 ± 5 Ma (MSWD = 0.90, probability = 0.53, n = 10) comprises about 20% of the analyses. Older Neoproterozoic zircons, ranging in age between 796 and 627 Ma, comprise about 25% of the analyses. The sandstone also contains detrital grains of Mesoproterozoic (~1.40 to ~1.15 Ga), and Paleoproterozoic (~2.20 to ~1.87 Ga) age (Fig. 8f; Table A6).

Oak Bay Formation (Silurian cover)

Results from 53 detrital zircons from crushed igneous pebbles and matrix of a conglomerate sample (21G/3g -1A) from the Oak Bay Formation are divided into the following populations, although large analytical errors in this particular sample produces considerable overlap at the younger end of the age spectrum (Fig. 9): a dominant Neoproterozoic statistical age population of 548 ± 8 Ma (MSWD = 1.5, probability 0.05, n=35); additional Neoproterozoic populations at 619 ± 15 Ma (MSWD = 0.38, probability 0.77, n= 4) and 680 ± 26 Ma (MSWD = 0.19, probability 0.83, n= 3); and rare Mesoproterozoic grains in the range 1.57 to 1.10 Ga (Table A7). The age of a single granite cobble (21G/3g -1B) was determined to be 549 ± 16 Ma.

IMPLICATIONS FOR DEPOSITIONAL AGES

The minimum detrital zircon age populations in the samples (Table 1) provide maximum absolute ages for the six dated Ganderian units, which were only partly constrained previously by stratigraphic relations and dated cross-cutting plutons (Fig. 3). The time scale followed here is from Gradstein *et al.* (2004).

Martinon Formation

Detrital zircon dates indicate that the maximum age of deposition for the Martinon Formation is 602 ± 8 Ma (Ediacaran), based on the youngest statistical age population in quartzite pebble conglomerate at Ludgate Lake. The minimum age of the conglomerate is 546 ± 2 Ma, the age of the cross-cutting Ludgate Lake Granodiorite of the Golden Grove Plutonic Suite (White *et al.* 2002). Previously, the Martinon Formation was assumed to be much older than Ediacaran, based on its stratigraphic position overlying the Ashburn Formation. The latter has a maximum depositional age of ~1.23 Ga (Table 1) based its detrital zircon content, and a minimum age of ~550 Ma constrained by cross-cutting plutons (Barr *et al.* 2003c). However, the nature of the stratigraphic contact between the two formations is uncertain with Alcock (1938), Leavitt (1963), Nance (1987), and Currie (1991) considering it to be an unconformity, and Wardle (1978) and White (1996) interpreting it as a gradational boundary. The presence of an unconformity between the Martinon and Ashburn formations was based on the interpretation of a carbonate conglomerate as a basal conglomerate in the Martinon Formation, whereas White (1996) and White and Barr (1996) interpreted the conglomerate to be an olistostrome, in which the carbonate clasts were not fully lithified prior to their incorporation in the Martinon sandstone matrix. Such olistostrome lenses occur at several locations in the Martinon Formation, not just at the base, and sandstone similar to the Martinon Formation occurs interbedded with marble of the Ashburn Formation on Green Head Island (White 1996). Therefore, White (1996) and White and Barr (1996) considered a major unconformity between the two formations to be unlikely. Irrespective of the interpreted Ashburn-Martinon relationship, the lack of a Neoproterozoic zircon population in quartzite from the Ashburn Formation and its presence in conglomerate of the Martinon Formation are consistent with Late Neoproterozoic uplift and exhumation of the Brookville belt.

Flagg Cove Formation

The maximum age of deposition of the Flagg Cove Formation is 574 ± 7 Ma based on the youngest statistical age population of detrital zircons in quartzose sandstone sample VL-2001-1 (Table 1). Its minimum age of deposition is 535 ± 3 Ma, the age of the cross-cutting Stanley Brook Granite (Miller *et al.* 2007). The age of the Flagg Cove Formation is, therefore, restricted to between mid-Ediacaran and earliest Cambrian.

The detrital zircon data circumstantially provides some age constraints on the undated Long Island Bay Formation as this formation was likely a source of detritus for the overlying Flagg Cove Formation. Volcanic clasts derived from the Long Island Bay Formation are present in unconformably overlying conglomerate of the Great Duck Island Formation on Long Island. These clasts in turn may have been reworked and incorporated into the overlying sandstone sequence of the Flagg Cove Formation. Abundant small stubby prismatic zircons, typical of volcanic rocks, were retrieved from the Flagg Cove sample and are consistent with the above observation (Fig. 5b). The volcanic rocks of the Long Island Bay Formation, therefore, are likely to be no younger than 574 ± 7 Ma, the youngest statistical detrital zircon age population in the Flagg Cove sample.

Matthews Lake Formation

The youngest and dominant detrital zircon population in the sample from the type area of the Matthews Lake Formation has an age of 539 ± 5 Ma, which provides constraints on its maximum age of deposition. The age range of this population spans the Ediacaran-Cambrian boundary and is consistent with a local basement source that includes the Ragged Falls Granite dated at 553 ± 2 Ma and volcanic rocks of the Simpsons Island Formation dated at 539 ± 4 Ma (Johnson and McLeod 1996; Johnson 2001; Barr *et al.* 2003a; McLeod *et al.* 2003). The absence of younger zircon ages in the sample, the "clean" nature of the sandstone, and observations to the northeast that the quartzose sandstone sequence appears to lie directly on Neoproterozoic basement suggest that the Matthews Lake Formation underlies, rather than overlies, volcanic rocks of the Mosquito Lake Road Formation dated at 514 ± 2 Ma (McLeod *et al.* 2003). If the Matthews Lake sandstone were correlative with the polymictic conglomerate that overlies the Mosquito Lake Road volcanic rocks, it would be likely to contain volcanic detritus and zircon as young as late Early Cambrian.

Ellsworth Formation

The youngest statistical detrital zircon age population in the sandstone sample from the Ellsworth Formation has an age of 507 ± 6 Ma. The source of these Middle Cambrian zircon grains is most likely felsic tuff of the Ellsworth Formation (dated at 509 ± 1 Ma). Abundant sharply faceted prismatic zircons retrieved from the sample are consistent with this interpretation (Fig. 5d). Although complex deformation makes it difficult to determine the exact stratigraphic position of the sandstone beds within the Ellsworth Formation, they are unlikely to be younger than the volcanic rocks of the Castine Formation (dated at 504 ± 3 Ma), which unconformably overlie the Ellsworth Formation in the Penobscot Bay area (Ruitenberg *et al.* 1993; Schultz *et al.* 2008). The dominant population of 545 ± 4 Ma in the Ellsworth sandstone suggests that basement rocks underlying the Middle Cambrian Ellsworth Formation were likely correlative with those of the New River belt but such Neoproterozoic rocks have yet to be identified in Maine.

Calais Formation

The youngest statistical detrital zircon population in the sandstone sample from the Calais Formation indicates that its maximum age of deposition is 510 ± 8 Ma, *i.e.* Middle Cambrian. The minimum age of the sample is early Tremadocian (~479 Ma) based on graptolites found on Cookson Island near the collection site (Fyffe and Riva 1990). The zircon grains were likely derived from reworking of detritus from intraformational tuff beds (503 ± 5 Ma; Tucker *et al.* 2001) found lower in the section in Maine; other possible sources include volcanic rocks of the Ellsworth Formation (509 ± 1 Ma) and Castine Formation (504 ± 3 Ma) (Ruitenberg *et al.* 1993; Schultz *et al.* 2008).

Baskahegan Lake Formation

The youngest statistical detrital zircon population in the sandstone sample from the Baskahegan Lake Formation indicates that the maximum age of deposition is 525 ± 6 Ma, *i.e.* Early Cambrian. The minimum age of deposition is early Tremadocian (~488 Ma) based on the presence of graptolites in the conformably overlying Bright Eye Brook Formation. The sampled part of this formation is either older than the Calais Formation, or did not have access to detritus from the same ~509 to 504 Ma volcanic units.

IMPLICATIONS FOR SEDIMENT PROVENANCE

In addition to the minimum detrital age populations discussed above, all of the samples contain a range of older zircon grains, a few as old as Archean (Table 1). Previously published zircon data from the Ganderian belts including detrital zircon ages from the Ashburn Formation of the Green Head Group (Barr *et. al.* 2003c); xenocrystic zircon ages from diabasic dykes that intrude the Woodstock Group (David *et al.* 1991); xenocrystic zircon data from the Meridian Brook Granite, which intrudes the Miramichi Group in north-central New Brunswick (Roddick and Bevier 1995); and xenocrystic zircon data from the Middle River Rhyolite, which is interbedded with sedimentary rocks of the Patrick Brook Formation near the top of the Miramichi Group in northeastern New Brunswick (McNicoll *et al*. 2002), all contain essentially the same range of age populations as determined in this study.

Neoproterozoic to Ordovician populations

Although all of the samples are dominated by Neoproterozoic zircon populations, these populations differ in detail (Fig. 7). The Martinon Formation is dominated by populations with ages of 635 ± 4 Ma, 674 ± 8 Ma, and 602 ± 8 Ma, whereas the likely somewhat younger Flagg Cove Formation is dominated by populations at 611 ± 7 Ma and 574 ± 7 Ma, and also contain a few grains with ages of 828 to 752 Ma not seen in the Martinon sample. Basement rocks such as the gneiss dated at ~675 Ma in the Ganderian Hermitage Flexure of Newfoundland (Valverde-Vaquero *et al.* 2006) are possible sources of the 674 ± 8 Ma zircons in the Martinon Formation. Possible sources for the 635 ± 4 and 602 ± 8 Ma zircon grains are the ~629 to ~611 Ma volcanic and plutonic rocks in the Grand Manan Island and New River belts. Arc-related comagmatic volcanic and plutonic complexes dated at ~685 to ~670 Ma and ~635 to ~575 Ma in Avalonia of Nova Scotia and Newfoundland (Bevier *et al.* 1993; O'Brien *et al.* 1996; Keppie *et al.* 1998) are also possible regional sources if Avalonia was close to Ganderia in the Late Neoproterozoic-Early Paleozoic. Volcanic rocks of the Ingalls Head Formation dated at 618 ± 3 Ma and intrusive rocks of the Three Islands Granite dated at 611 ± 2 Ma (Miller *et al*. 2007) are likely local sources for the 611 ± 7 Ma detrital zircons in the Flagg Cove Formation.

Zircon age populations that are close to the Ediacaran-Cambrian boundary dominate in the Matthews Lake Formation (539 ± 5 Ma), Ellsworth Formation (545 ± 4 Ma), Calais Formation (556 ± 7 Ma and 528 ± 11 Ma), and Oak Bay Formation (548 ± 8 Ma and 549 ± 16 Ma). These dominant populations were likely derived from detritus present in igneous units from the Brookville, Grand Manan Island and New River belts of southern New Brunswick (Johnson and McLeod 1996; Currie and McNicoll 1999; Johnson 2001; White *et al.* 2002; Bartsch and Barr 2005). The presence of abundant large Neoproterozoic igneous clasts in the Oak Bay Formation indicates that the basement rocks of southern New Brunswick underwent significant uplift in the Early Silurian.

The Matthews Lake, Calais, and Oak Bay formations have a scattering of older Neoproterozoic ages in the 934 to 630 Ma range, whereas only two zircon grains in that range were analysed in the Ellsworth sandstone. The Baskahegan Lake Formation is dominated by zircon grains with an Ediacaran age of 585 ± 5 Ma, but also contains a relatively large population in the range 973 to 627 Ma, similar to the Matthew Lakes, Calais and Oak Bay formations. However, no igneous units older than 629 ± 1 Ma have yet to be identified in these belts, so the sources of the older grains are uncertain. Plutonic rocks such as those dated at ~584 Ma in the Ganderian Hermitage Flexure of Newfoundland (Valverde-Vaquero *et al.* 2006) could be a source for dominant age population in the Baskahegan

Lake Formation. Igneous units with ages of ~685-670 Ma, and 760 Ma are known in Avalonia (Bevier *et al.* 1993; O'Brien *et al.* 1996; Keppie *et al.* 1998) and are potential sources if Avalonia were nearby.

Mesoproterozoic and older populations

Except for the sample from the Calais Formation, all other samples contain small populations of Mesoproterozoic detrital zircon grains in the range from 1.61 to 1.07 Ga and lack Paleoproterozoic detrital zircons in the range 2.5 to 2.3 Ga (Fig. 8). Such age populations suggest that the various fault-bounded belts had their origins along the northern or western margin of the Amazonian craton rather than West Africa (van Staal *et al.* 1996; Keppie *et al.*1998). Previously published data on detrital zircons from the Ashburn Formation of the Brookville belt; and on the ages of granodiorite cobbles from the basal part of the Tetagouche Group and on xenocrystic zircons from intrusive rocks of the Miramichi belt, are also consistent with an Amazonian provenance (Roddick and Bevier 1995; van Staal *et al*. 1996; Barr *et al.* 2003c).

DISCUSSION

Global plate tectonic reconstructions based on paleomagnetic, isotopic, and detrital zircon studies (including the new zircon data presented above) place Ganderia and Avalonia along the periphery of the Amazonian craton in the Neoproterozoic. These reconstructions either treat Ganderia and Avalonia as a single microcontinent (Murphy and Nance 1989; Nance and Murphy 1994; Keppie *et al.* 1996, 1998; Murphy *et al.* 2000; Nance *et al.* 2002), or as two distinct microcontinents that were brought into juxtaposition by strike-slip faults with Avalonia originally positioned further east, possibly bridging the gap that separated Amazonia from West Africa (van Staal *et al.* 1996; 1998; Rogers *et al.* 2006). The latter interpretation is adopted herein. Although Ganderia and Avalonia may have shared a common cover sequence by the Early Cambrian (Johnson 2001; Landing *et al.* 2008), it should be pointed out that this supposed 'cover sequence' occurs in separate faulted basins and cannot be proven to have been continuous between Ganderia and Avalonia. Furthermore, the assumption that Ganderia and Avalonia formed a single microcontinent with the more juvenile part of an arc lying outboard of the Amazonian craton requires the microcontinent to make a 180° rotation prior to its accretion to Laurentia (Keppie *et al.* 1996). Such a rotation is unnecessary if these microcontinents rifted from the Gondwanan margin as separate entities.

Reconstruction of the paleogeographic relationships between fault-bounded belts is a difficult problem because evidence of linkages between ancient oceanic tracts and continental margins have largely been destroyed, particularly so if the region have been involved in multiple orogenic cycles. The global plate tectonic model of Nance *et al.* (2002) that places a southward-dipping subduction zone along the northern margin for Gondwana during the Neoproterozoic is accepted here as the basic framework in which to discuss possible inter-relationships among the various belts that make up Ganderia in New Brunswick and coastal Maine. Similarities and differences in the stratigraphy, magmatic history, isotopic signatures, and detrital zircon populations of these belts are examined below in order to determine the possible paleotectonic evolution of the region during the period from the late Neoproterozoic to Early Paleozoic.

The presence of xenocrystic zircons and overlapping mainly negative ε_{Nd} signatures in Neoproterozoic igneous rocks of the Brookville, Grand Manan Island, and New River belts suggests that the volcanic and plutonic rocks in these belts were derived from a similar source containing a component of highly evolved continental crust (Hodgins 1994; Samson *et al.* 2000). It is noteworthy that the > 600 Ma magmatic activity that affected the platformal carbonate rocks of the Kent Island Formation of the Grand Manan Group is absent from similar carbonates of the Ashburn Formation of the Green Head Group. This relationship suggests that during this period, the Brookville belt represented a more stable inboard position within the Ganderian segment of the Amazonian upper-plate hinterland relative to the active outboard margin represented by the Grand Manan Island and New River belts. This same relationship is also evident in the Ganderian belts of Cape Breton Island where > 600 Ma plutons occur in the western Aspy (= New River) belt in northwestern Cape Breton Island but are absent in the Bras d'Or (= Brookville) belt to the southeast (Barr and Raeside 1989; Lin *et al.* 2007).

The Grand Manan Island and New River belts have a similar episodic magmatic history, respectively spanning the time intervals from ~618 to ~535 Ma and ~629 to ~539 Ma (Currie and Hunt 1991; Currie and McNicoll 1999; Barr *et al.* 2003a,b; Black *et al*. 2004; McLeod *et al.* 2003; Miller *et al*. 2007), consistent with their being proximal components of a single, structurally telescoped Ganderian continental margin rather than representing far-travelled exotic terranes. Although data are somewhat limited, the difference in the age of > 600 Ma plutonism in the New River belt (~622 to ~629 Ma) compared to that on Grand Manan Island (~611 Ma) suggests that the magmatic activity in the latter belt may have been related to extension in a back-arc basin and/or the onset of rifting of Ganderia from the Amazonian craton. Under this scenario, volcanic rocks > 630 Ma in the New River belt are expected to have an arc signature but as yet no supracrustal rocks have yet been identified that are intruded by the older plutonic suite.

A significant time gap exists between the older ~629 to ~611 Ma and younger ~553 to ~535 Ma magmatic events documented in both the Grand Manan Island and New River belts (Fig. 3). It was during this gap in volcanic activity that the carbonate breccia, clastic siltstone, and quartz-pebble conglomerate of the Martinon Formation were deposited, possibly unconformably on the platformal stromatolitic carbonates and quartzose sandstone of the Ashburn Formation. If correct, this unconformable relationship appears to be a unique feature restricted to the Ganderian basement rocks of southern New

Brunswick and may be related to a tectonic event localized along this segment of the Proterozoic Amazonian continental margin. The extensional or compressional nature of subduction along a plate boundary is controlled by a number of factors including relative convergent rate, age of the subducting slab, absolute motion of the overriding plate, and ridge-trench collision (Dewey 1980).

Localized collision of an aseismic ridge with the Ganderian segment of the Amazonian margin offers a mechanism to account for the cessation of the > 600 Ma period in the Grand Manan Island and New River belts. Under-thrusting of a buoyant oceanic ridge following such a collision will shallow the angle of subduction and arc activity may temporarily shut down above the flattened slab (Thorkelson and Taylor 1989; Gutscher *et al.* 1999). Ridge subduction under this part of Ganderia is also an attractive mechanism to explain the formation of the igneous protolith of the Brookville orthogneiss at 605 ± 3 Ma and subsequent metamorphism at 564 ± 6 Ma in the Brookville belt (Bevier *et al.* 1990; Collins 2002). Under-thrusting of a ridge may lead to partial melting in the overlying rocks and is commonly accompanied by arching and deformation in the retroarc region of the hinterland (Espurt *et al.* 2007).

Arching in part of the Brookville belt thus could account for uplift of the Ashburn platformal carbonate sequence and formation of a deep-water retroarc basin off its flank into which clastic sedimentary rocks of the Martinon Formation were deposited. Erosion of volcanic and plutonic rocks in the inactive but uplifted arc or back-arc areas could have provided a source for the dominant 635 ± 4 Ma and 602 ± 8 Ma detrital zircon populations in the Martinon Formation. The significantly more juvenile ε_{Nd} signature of the sedimentary rocks of the Martinon Formation, compared to those of the underlying Ashburn Formation (Samson *et al.* 2000), can be explained by this model – the Martinon sediments contain a significant detrital component derived from erosion of the continental-margin volcanic and plutonic rocks, whereas the older Ashburn sediments were sourced entirely from evolved continental basement of the Amazonian hinterland. Outboard of the Brookville belt, sandstone of The Thoroughfare and Flagg Cove formations on Grand Manan Island, respectively exhibit evolved and more juvenile ε_{Nd} signatures (Hodgins 1994), suggesting that the Flagg Cove sandstone and underlying conglomerate of the Great Duck Island Formation may represent a coarser retoarc facies that overstepped the passive margin of the back-arc area bordering the Martinon basin.

Magmatic arc activity resumed in coastal New Brunswick in the later part of the Ediacaran and continued into the early part of the Early Cambrian. In the New River belt magmatic activity lasted from ~553 to ~539 Ma and on Grand Manan Island from ~547 to ~535 Ma; magmatic activity was particularly long-lived in the Brookville belt where voluminous calc-alkaline plutons were emplaced into the hinterland region from ~553 to ~528 Ma (Eby and Currie 1996; White and Barr 1996; Currie and McNicoll 1999; White *et al.* 2002; Barr *et al.* 2003a). This inboard onset of calc-alkaline plutonic activity can be attributed to the continued presence of a relatively shallow subduction angle that caused the marginal arc to become compressive and encroach inboard onto thickened continental crust (Collins 2002; Kay *et al.* 2005). Hinterland-vergent (southward) thrusting documented in volcanic rocks of the Ingalls Head Formation on Grand Manan Island by Fyffe and Grant (2005) may be a consequence of this arc migration. This overall change in tectonic regime of the Ediacaran to Early Cambrian Ganderian arc system from extensional (~629 to ~611 Ma) to compressional (~553 to ~528 Ma) is a typical feature in the geodynamic evoution of a convergent plate boundary with time (Dewey 1980).

Oblique subduction and eventual collision of a spreading oceanic ridge with the continental margin may have terminated this younger period of arc magmatism at ~528 Ma, as proposed by Murphy and Nance (1989) for similar but older events in Avalonia, because the subducting slab will break off and transform motion will then become dominant (Michaud *et al.* 2006). This change from a convergent to a transform plate boundary along the northern Gondwanan continental margin may have led to the transfer of the Ganderian and Avalonian microcontinents from the Pacific Ocean to the opening Paleozoic Iapetus Ocean (Murphy and Nance 1989; van Staal *et al.* 1996; Nance *et al.* 2002; Rogers *et al.* 2006).

The overstepping of the platformal sequence of the Buckmans Creek "group" onto basement rocks of the New River belt suggests that the encroachment of Ganderia into the Iapetan ocean tract had occurred by the Early Cambrian (Fig. 10). The presence of a thick volcanic section of continental tholeiites in the middle part of the Buckmans Creek

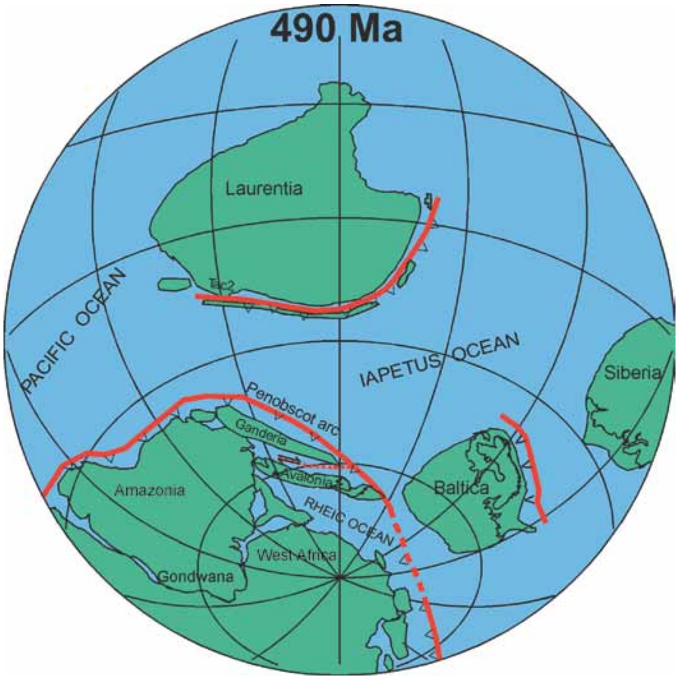

Fig. 10. Late Cambrian paleogeographic setting of Ganderia within the Iapetus Ocean (modified after van Staal *et al.* 1998).

"group" indicates that extensive rifting had started along this margin by the late Early Cambrian at ~520 Ma (Greenough *et al.* 1985; Landing *et al.* 1998, 2008). The quartzose sandstone and conglomerate of the Matthews Lake Formation, shown above to overlie Neoproterozoic rocks of the New River belt and underlie volcanic rocks of the Mosquito Lake Road Formation dated at 514 ± 2 Ma, may represent a more outboard facies of the quartzose sandstone found near the base of the Buckmans Creek "group" farther to the southwest. If correct, southern New Brunswick appears to be the only region in the Appalachian Orogen that preserves remnants of the inner and outer Paleozoic platform of Ganderia.

Neoproterozoic rocks similar to the Ragged Falls Granite (dated at 553 ± 2 Ma) and associated volcanic rocks underlie the late Early Cambrian volcanic rocks of the Mosquito Lake Road Formation in the New River belt. Similar basement rocks are inferred to underlie the Middle Cambrian volcanic rocks of the Ellsworth Formation in coastal Maine on the basis of the dominant detrital zircon population (545 ± 4 Ma) recovered from the sample of intraformational sandstone. These late Early Cambrian volcanic sequences in New Brunswick and Maine occupy the same inboard position along the southeastern Iapetan margin as the volcanic rocks of the Bay du Nord Formation on the southern coast of Newfoundland (Dunning and O'Brien 1989; O'Brien *et al.* 1991; Tucker *et al.* 1994). All can be interpreted to have been generated in a Cambrian back-arc basin that opened behind a northwesterly facing Penobscot arc represented by the 513-510 Ma Tally Pond Group in central Newfoundland (Rogers *et al.* 2006; Zagorevski *et al.* 2007; Hibbard *et al.* 2007).

The St. Croix belt displays stratigraphic characteristics that are for the most part quite distinct from the nearby Ellsworth, New River, and Brookville belts. Basement to the St. Croix belt, as reconstructed by Tucker *et al.* (2001), is likely represented by marble and quartzite of the Seven Hundred Acre Island Formation, which lithologically resembles the Ashburn Formation of the Brookville belt. However, as noted above, the Seven Hundred Acre sequence lacks evidence of having been involved in the ~553 to ~528 Ma magmatic event that affected the Brookville belt. The St. Croix belt contains a thick succession of quartzose sandstone (Crocker Hill Formation in New Brunswick = Megunticook Formation in Maine) that were presumably deposited on an inactive segment of the continental margin during the rifting of Ganderia from Amazonia in the Cambrian. In contrast, the presently adjoining Ellsworth and New River belts was apparently formed along an active part of this same margin as indicated by the presence of a late Early to Middle Cambrian volcanic arc. However, the inactive and active segments of the margin were also apparently proximal enough to each other for erosion of the Neoproterozoic arc system of the Ellsworth and New River belts to provide detritus to the Calais black shale sequence of the St. Croix belt.

The proximal nature of the of the St. Croix belt to the Ellsworth and New River belts is supported by some notable lithological similarities. Mafic volcanic flows and tuff dated at 503 ± 4 Ma (Tucker *et al.* 2001), which occur at the base of the black shale sequence that defines the Calais Formation of the St. Croix belt, have MORB-like geochemistry similar to that of mafic volcanic rocks of the Castine Formation dated at 502 ± 4 Ma in the adjacent Ellsworth belt (Schultz *et al.* 2008). Moreover, Middle Cambrian black shale at the top of the stratigraphic section of the Buckmans Creek "group" is consistent with the New River and St. Croix belts being located along the same transgressive oceanic margin at that time.

Juxtaposition of the St. Croix belt against the Ellsworth and New River belts likely took place by dextral displacement along the Turtle Head fault as a result of the oblique collision between Ganderia and Laurentia in the Silurian (Stewart *et al.* 1995; van Staal 2007; Wintsch *et al.* 2007; van Staal *et al.* 2008). Dextral displacement appears to have also resulted in the removal of much of the arc and all the forearc region of the Penobscot arc in southern New Brunswick and coastal Maine. It is interesting to note that the evolution of Cambrian volcanic arc system in the New River and Ellsworth belts is more closely related in time to development of the Tally Pond arc in central Newfoundland than to the adjacent St. Croix and Miramichi belts.

Evidence for some Penobcot arc activity does exist in the Miramichi belt near Bathurst in northern New Brunswick, where volcanic clasts and a rhyolite flow dated at 479 ± 6 Ma are present in sandstone of the Patrick Brook Formation in the uppermost part of the Miramichi Group (Fyffe *et al*. 1997; McNicoll *et al*. 2002). Conglomerate of Vallée Lourdes Formation overlying the Patrick Brook Formation marks the Penobcsot unconformity at the base of the Tetagouche Group. No such unconformity is apparent in the southern part of the Miramichi belt where post-Penobscot arc volcanics of the Meductic Group appear to lie conformably above Cambrian to Early Ordovician sedimentary rocks of the Woodstock Group (Fyffe *et al*. 1983; Fyffe 2001). Therefore, it is likely that the Meductic arc and Tetagouche back-arc volcanic activity is related to the extensional evolution of the northwest-facing post-Penobscot Popelogan arc in northwestern New Brunwick (van Staal and Fyffe 1995a, b; van Staal *et al.* 1996, 1998, 2008).

CONCLUSIONS

The possible age range of deposition for sampled conglomerate and sandstone units from New Brunswick and coastal Maine - based on a maximum limit constrained by the youngest statistical detrital zircon age populations and on a minimum limit constrained by stratigraphic, paleontological, and cross-cutting intrusive relationships - are as follows: Martinon Formation from 602 ± 8 to 546 ± 2 Ma, the age of the cross-cutting Ludgate Lake Granodiorite; Flagg Cove Formation from 574 ± 7 to 535 ± 3 Ma, the age of the cross-cutting Stanley Brook Granite; Matthews Lake Formation from 539 ± 5 to 514 ± 2 Ma, the age of overlying volcanic rocks in the Mosquito Lake Road Formation; Ellsworth Formation from 507 ± 6 to 509 ± 1 Ma, the age of magmatic zircons from intraformational felsic tuff; Calais Formation from 510 ± 8 to 479 ± 2 Ma, based on contained Arenigian graptolites; and Baskahegan Lake Formation from 525 ± 6 to 488 ± 2 Ma, based on Tremadocian graptolites in overlying black shale of the Bright Eye Brook Formation (Fig. 3).

The relatively young Neoproterozoic age indicated for Martinon Formation of the Brookville belt is consistent with the earlier interpretation that it lies unconformably on platformal carbonates of the Ashburn Formation, which could be as old as Mesoproterozoic based on the presence of stomatolites and previous detrital zircon results. The progressive younger depositional ages of the quartzose sandstone sequences of the Brookville belt (Martinon Formation), Grand Manan Island belt (Flagg Cove Formation) and New River belt (Matthews Lake Formation) can be attributed to episodic periods of quiescence and arc activity along the convergent margin of Ganderia.

The dominant zircon age population in the Ellsworth sample has an age of 545 ± 4 Ma indicating that Middle Cambrian volcanic rocks of the Ellsworth and Castine formations in coastal Maine likely lie on the same Neoproterozoic volcanic and plutonic basement rocks as the late Early Cambrian volcanic rocks of the Mosquito Lake Road Formation in the New River belts of New Brunswick. The quartzose sandstone and conglomerate of the Matthews Lake Formation, shown to directly overlie New River basement on the basis of detrital zircon content, apparently represent a deeper water facies of the platformal quartzose sandstone found near the base of the Cambrian Buckmans Creek "group" lying with faulted unconformity on New River basement farther to the southwest. Southern New Brunswick may, therefore, be the only region in the Appalachian Orogen where the transition from platformal to deeper water sedimentary facies characteristic of Ganderia is preserved.

The igneous rocks of the Brookville, Grand Manan Island, and New River belts possess similar negative ε_{Nd} signatures suggesting that the volcanic and plutonic rocks in these belts were derived from a similar source containing a component of highly evolved continental crust. Mesoproterozoic detrital zircon grains in the range from 1.6 to 1.2 Ga and lack of Paleoproterozoic grains in the range 2.5 to 2.3 Ga in sedimentary samples from these Ganderian belts is consistent with an origin along the peri-Gondwanan margin of the Amazonia rather than West Africa. The Grand Manan and New River belts both record two distinct periods of Neoproterozoic arc magmatism along this margin at ~629 to ~611 Ma and at ~553 to ~535 Ma.

The carbonate succession of the Brookville belt is interpreted to represent the hinterland interior of the Amazonian craton lying inboard of the Grand Manan back-arc basin and New River arc system. Uplift of the Brookville carbonate platform and development of the Martinon retroarc basin may have been related to subduction of an aseismic oceanic ridge that resulted in shallowing of the subduction angle and temporary cessation of the older period of arc activity. Migration of younger arc magmatism toward the hinterland region of the Brookville belt suggests that the angle of subduction angle remained shallow into the later part of the Neoproterozoic. Termination of this younger period of arc activity is attributed to collision of a spreading oceanic ridge with the continental margin in the Early Cambrian.

Back-arc volcanic activity related to development of a Cambrian Penobscot arc system occurred along the peri-Gondwanan margin of Iapetus between the late Early to Middle Cambrian in the New River and Ellsworth belts of southern New Brunswick and coastal Maine. Rifting of the Meductic-Popelogan arc along the outboard margin of Ganderia led to a period of Ordovician back-arc volcanic activity in the Miramichi belt of central and northern New Brunswick.

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Table A1. U/Pb SHRIMP analytical data for the Martinon Formation (VL-2001-05)*.

									Isotopic ratios									Ages (Ma)					
Spot name	U (ppm)	Th (ppm)	$\frac{Th}{U}$	Pb (ppm)	^{204}Pb (ppb)	$\frac{^{204}Pb}{^{206}Pb}$	$\pm\frac{^{204}Pb}{^{206}Pb}$	f(206)^{204}	$\frac{^{208}Pb}{^{206}Pb}$	$\pm\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{207}Pb}{^{235}U}$	$\pm\frac{^{207}Pb}{^{235}U}$	$\frac{^{206}Pb}{^{238}U}$	$\pm\frac{^{206}Pb}{^{238}U}$	Corr Coeff	$\frac{^{207}Pb}{^{206}Pb}$	$\pm\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{206}Pb^1}{^{238}U}$	$\pm\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{206}Pb}$	$\pm\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{206}Pb^2}{^{238}U}$	$\pm\frac{^{206}Pb}{^{238}U}$
7692-43.2	235	115	0.506	18	6	0.000010	0.000010	0.0002	0.1474	0.0065	0.6554	0.0176	0.0768	0.0014	0.774	0.0619	0.0011	477	9	670	37	474	9
7692-43.1	284	160	0.580	25	4	0.000112	0.000097	0.0019	0.1782	0.0054	0.6892	0.0221	0.0843	0.0011	0.496	0.0593	0.0017	522	6	578	62	521	6
7692-34.1	216	148	0.707	21	2	0.000186	0.000095	0.0032	0.2141	0.0105	0.6923	0.0246	0.0873	0.0015	0.572	0.0575	0.0017	540	9	511	66	540	9
7692-34.2	81	27	0.351	7	2	0.000304	0.000220	0.0053	0.1025	0.0096	0.7219	0.0490	0.0900	0.0017	0.388	0.0582	0.0037	556	10	536	144	556	10
7692-19.1	71	67	0.979	8	1	0.000265	0.000237	0.0046	0.3074	0.0121	0.7713	0.0560	0.0949	0.0021	0.422	0.0590	0.0039	584	12	566	151	584	12
7692-57.1	224	158	0.732	24	4	0.000195	0.000091	0.0034	0.2236	0.0069	0.7980	0.0293	0.0964	0.0013	0.469	0.0601	0.0020	593	7	606	72	593	7
7692-84.1	152	46	0.315	15	3	0.000010	0.000010	0.0002	0.0990	0.0035	0.8379	0.0188	0.0971	0.0013	0.683	0.0626	0.0010	597	8	695	36	595	8
7692-46.1	238	422	1.834	32	1	0.000010	0.000010	0.0002	0.5745	0.0095	0.8051	0.0203	0.0969	0.0016	0.747	0.0602	0.0010	596	10	612	37	596	10
7692-7.1	260	115	0.457	26	4	0.000185	0.000115	0.0032	0.1367	0.0063	0.8115	0.0329	0.0984	0.0020	0.606	0.0598	0.0019	605	12	597	72	605	12
7692-35.1	343	340	1.026	41	2	0.000046	0.000104	0.0008	0.3262	0.0094	0.8304	0.0276	0.0992	0.0012	0.471	0.0607	0.0018	610	7	629	65	609	7
7692-96.1	271	251	0.958	31	2	0.000109	0.000090	0.0019	0.2955	0.0054	0.8165	0.0245	0.0993	0.0012	0.516	0.0596	0.0016	610	7	590	57	611	7
7692-85.1	218	161	0.763	24	0	0.000125	0.000072	0.0022	0.2366	0.0075	0.8097	0.0240	0.1001	0.0016	0.640	0.0587	0.0014	615	9	556	51	616	9
7692-55.2	90	89	1.021	11	0	0.000033	0.000337	0.0006	0.3243	0.0176	0.8385	0.0784	0.1012	0.0016	0.287	0.0601	0.0054	621	9	607	208	622	9
7692-97.1	107	107	1.028	13	1	0.000010	0.000010	0.0002	0.3414	0.0070	0.8684	0.0195	0.1016	0.0013	0.669	0.0620	0.0010	624	8	674	36	623	8
7692-42.1	172	130	0.783	19	1	0.000145	0.000148	0.0025	0.2243	0.0087	0.8314	0.0606	0.1020	0.0032	0.541	0.0591	0.0037	626	19	572	141	627	19
7692-16.1	164	110	0.691	18	2	0.000167	0.000087	0.0029	0.2102	0.0053	0.8495	0.0258	0.1023	0.0013	0.525	0.0602	0.0016	628	8	612	57	628	8
7692-83.1	117	86	0.765	13	3	0.000010	0.000010	0.0002	0.2460	0.0059	0.9232	0.0248	0.1039	0.0016	0.668	0.0644	0.0013	637	9	756	43	635	9
7692-62.1	222	151	0.704	25	3	0.000190	0.000063	0.0033	0.2197	0.0049	0.8665	0.0215	0.1036	0.0013	0.599	0.0607	0.0012	635	7	627	44	636	7
7692-33.1	126	108	0.886	15	2	0.000442	0.000188	0.0077	0.2636	0.0101	0.8062	0.0482	0.1034	0.0016	0.378	0.0566	0.0032	634	9	474	128	637	9
7692-64.1	156	57	0.377	16	1	0.000217	0.000149	0.0038	0.1054	0.0064	0.8418	0.0396	0.1037	0.0013	0.381	0.0589	0.0026	636	8	563	98	638	7
7692-56.2	562	143	0.262	58	0	0.000033	0.000061	0.0006	0.0837	0.0034	0.8678	0.0194	0.1040	0.0011	0.588	0.0605	0.0011	638	7	622	40	638	7
7692-32.1	365	660	1.867	53	2	0.000010	0.000010	0.0002	0.5655	0.0050	0.8833	0.0135	0.1042	0.0011	0.796	0.0615	0.0006	639	7	657	20	638	7
7692-27.1	129	91	0.730	15	1	0.000071	0.000174	0.0012	0.2251	0.0087	0.8865	0.0442	0.1042	0.0014	0.382	0.0617	0.0029	639	8	663	103	639	8
7692-94.1	265	189	0.738	30	2	0.000218	0.000063	0.0038	0.2125	0.0048	0.8442	0.0227	0.1040	0.0014	0.613	0.0589	0.0013	638	8	563	47	639	8
7692-37.1	169	80	0.490	19	2	0.000382	0.000113	0.0066	0.1361	0.0058	0.8401	0.0331	0.1062	0.0014	0.441	0.0574	0.0020	651	8	506	80	654	8
7692-100.1	183	159	0.897	23	0	0.000116	0.000151	0.0020	0.2703	0.0077	0.8885	0.0405	0.1080	0.0014	0.404	0.0597	0.0025	661	8	592	94	663	8
7692-90.1	171	106	0.643	20	2	0.000189	0.000110	0.0033	0.1953	0.0058	0.9178	0.0334	0.1087	0.0016	0.501	0.0613	0.0020	665	9	648	70	665	9
7692-49.1	489	271	0.573	57	1	0.000024	0.000028	0.0004	0.1784	0.0028	0.9237	0.0162	0.1088	0.0013	0.764	0.0616	0.0007	665	8	660	25	666	8
7692-92.1	508	267	0.543	59	7	0.000089	0.000035	0.0016	0.1765	0.0029	0.9427	0.0186	0.1091	0.0014	0.747	0.0627	0.0008	667	8	698	28	667	8
7692-31.1	691	180	0.269	74	2	0.000038	0.000025	0.0007	0.0856	0.0058	0.9283	0.0177	0.1091	0.0015	0.813	0.0617	0.0007	667	9	665	24	667	9
7692-29.1	49	28	0.588	6	1	0.001078	0.000874	0.0187	0.1331	0.0334	0.7583	0.2105	0.1089	0.0026	0.210	0.0505	0.0138	666	15	219	798	675	12
7692-28.1	147	98	0.692	18	1	0.000523	0.000231	0.0091	0.1915	0.0106	0.8452	0.0597	0.1105	0.0015	0.315	0.0555	0.0038	676	9	431	158	681	9
7692-15.1	259	83	0.332	29	1	0.000155	0.000066	0.0027	0.0933	0.0035	0.9319	0.0251	0.1115	0.0015	0.589	0.0606	0.0013	682	8	625	48	683	9
7692-98.1	261	115	0.457	31	-1	0.000096	0.000042	0.0017	0.1492	0.0037	0.9324	0.0289	0.1123	0.0013	0.487	0.0602	0.0016	686	8	611	60	688	8
7692-70.1	38	38	1.043	5	1	0.000764	0.000471	0.0133	0.3029	0.0258	0.8508	0.1222	0.1131	0.0024	0.267	0.0545	0.0076	691	14	393	348	697	13
7692-22.1	188	248	1.365	28	2	0.000089	0.000133	0.0016	0.4227	0.0108	1.0336	0.0419	0.1177	0.0015	0.426	0.0637	0.0024	717	9	731	80	717	8
7692-80.1	130	45	0.353	23	2	0.000118	0.000105	0.0021	0.1128	0.0047	1.7124	0.0672	0.1736	0.0021	0.422	0.0716	0.0026	1032	12	973	75		
7692-73.1	215	51	0.246	39	5	0.000157	0.000103	0.0027	0.0869	0.0044	1.8622	0.0535	0.1800	0.0025	0.588	0.0750	0.0018	1067	14	1070	48		
7692-66.1	423	160	0.390	89	0	0.000001	0.000015	0.0000	0.1180	0.0016	2.2227	0.0414	0.2040	0.0025	0.738	0.0790	0.0010	1197	13	1173	25		
7692-52.1	97	135	1.439	26	3	0.000163	0.000118	0.0028	0.4179	0.0073	2.3303	0.0752	0.2054	0.0030	0.558	0.0823	0.0022	1204	16	1252	54		
7692-74.1	319	166	0.538	73	2	0.000038	0.000024	0.0007	0.1918	0.0026	2.4362	0.0345	0.2069	0.0023	0.846	0.0854	0.0007	1212	12	1325	15		
7692-93.1	326	490	1.551	92	6	0.000095	0.000060	0.0017	0.4640	0.0047	2.3871	0.0533	0.2108	0.0024	0.603	0.0821	0.0015	1233	13	1249	36		
7692-75.1	114	82	0.748	29	2	0.000100	0.000183	0.0017	0.2335	0.0082	2.6583	0.1100	0.2253	0.0028	0.416	0.0856	0.0033	1310	15	1329	75		
7692-60.1	342	116	0.351	79	3	0.000039	0.000025	0.0007	0.1060	0.0017	2.6669	0.0582	0.2255	0.0027	0.642	0.0858	0.0015	1311	14	1333	33		
7692-50.1	103	63	0.627	26	1	0.000046	0.000078	0.0008	0.1844	0.0076	2.7889	0.0650	0.2285	0.0033	0.702	0.0885	0.0015	1327	17	1394	32		
7692-30.1	188	82	0.451	51	0	0.000010	0.000010	0.0002	0.1359	0.0021	3.2806	0.0517	0.2538	0.0033	0.874	0.0938	0.0007	1458	17	1503	15		
7692-26.1	135	80	0.609	38	1	0.000047	0.000035	0.0008	0.1807	0.0030	3.3299	0.0542	0.2593	0.0030	0.794	0.0932	0.0009	1486	16	1491	19		
7692-76.1	347	106	0.314	95	2	0.000030	0.000060	0.0005	0.0940	0.0029	3.4864	0.0588	0.2661	0.0030	0.750	0.0950	0.0011	1521	15	1528	21		
7692-1.1	126	90	0.741	38	0	0.000010	0.000010	0.0002	0.2293	0.0039	3.5656	0.0895	0.2681	0.0032	0.578	0.0965	0.0020	1531	16	1557	39		
7692-79.1	713	343	0.497	209	0	0.000002	0.000009	0.0000	0.1439	0.0016	3.5988	0.0509	0.2754	0.0030	0.827	0.0948	0.0008	1568	15	1524	15		
7692-51.1	83	72	0.895	27	0	0.000012	0.000072	0.0002	0.2625	0.0051	3.7237	0.0834	0.2769	0.0037	0.684	0.0975	0.0016	1576	19	1578	31		
7692-9.1	387	223	0.594	121	3	0.000036	0.000021	0.0006	0.1747	0.0019	4.3659	0.0870	0.2825	0.0052	0.962	0.1121	0.0006	1604	26	1834	10		
7692-20.1	48	23	0.493	16	2	0.000157	0.000227	0.0027	0.1430	0.0093	4.5439	0.1864	0.3094	0.0049	0.498	0.1065	0.0038	1738	24	1740	67		
7692-54.1	212	139	0.678	83	3	0.000052	0.000054	0.0009	0.1935	0.0033	5.6321	0.1010	0.3484	0.0048	0.839	0.1172	0.0012	1927	23	1915	18		
7692-6.1	270	267	1.023	115	3	0.000031	0.000017	0.0005	0.2900	0.0025	5.8559	0.0819	0.3504	0.0041	0.888	0.1212	0.0008	1937	19	1974	12		
7692-4.1	111	47	0.434	42	0	0.000010	0.000074	0.0002	0.1226	0.0036	5.9344	0.1068	0.3524	0.0042	0.748	0.1221	0.0015	1946	20	1988	22		
7692-95.1	49	36	0.764	20	1	0.000070	0.000070	0.0012	0.2115	0.0050	6.4189	0.1298	0.3628	0.0050	0.768	0.1283	0.0017	1996	24	2075	23		
7692-78.1	227	101	0.457	94	1	0.000008	0.000016	0.0001	0.1329	0.0026	6.7115	0.1648	0.3802	0.0066	0.783	0.1280	0.0020	2077	31	2071	27		
7692-8.1	338	168	0.514	144	1	0.000010	0.000010	0.0002	0.1463	0.0013	7.2686	0.0922	0.3874	0.0045	0.957	0.1361	0.0005	2111	21	2178	6		
7692-61.1	168	151	0.929	102	2	0.000022	0.000020	0.0004	0.2605	0.0042	11.5710	0.1813	0.4895	0.0067	0.927	0.1715	0.0010	2568	29	2572	10		

Uncertainties reported at 1σ (absolute) and are calculated by numerical propagation of all known sources of error; f(206)^{204} refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb-method; common Pb composition used is the surface blank; [1] 204-corrected ages; [2] 207-corrected ages (Stern 1997); * GSC grain mount IP295.

Table A2. U/Pb SHRIMP analytical data for the Flagg Cove Formation (VL-2001-10)*.

									Isotopic ratios									Ages (Ma)					
Spot name	U (ppm)	Th (ppm)	$\frac{\text{Th}}{\text{U}}$	Pb (ppm)	^{204}Pb (ppb)	$\frac{^{204}\text{Pb}}{^{206}\text{Pb}}$	$\pm\frac{^{204}\text{Pb}}{^{206}\text{Pb}}$	f(206)^{204}	$\frac{^{208}\text{Pb}}{^{206}\text{Pb}}$	$\pm\frac{^{208}\text{Pb}}{^{206}\text{Pb}}$	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$	$\pm\frac{^{207}\text{Pb}}{^{235}\text{U}}$	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\pm\frac{^{206}\text{Pb}}{^{238}\text{U}}$	Corr Coeff	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\pm\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\frac{^{206}\text{Pb}^{1}}{^{238}\text{U}}$	$\pm\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\pm\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\frac{^{206}\text{Pb}^{2}}{^{238}\text{U}}$	$\pm\frac{^{206}\text{Pb}}{^{238}\text{U}}$
7561-11.1	157	73	0.479	11	6	0.000905	0.000361	0.0157	0.1481	0.0183	0.4625	0.0543	0.0655	0.0011	0.263	0.0512	0.0058	409	7	250	250	411	6
7561-7.1	619	279	0.466	42	0	0.000022	0.000056	0.0004	0.1423	0.0056	0.4972	0.0194	0.0661	0.0008	0.416	0.0546	0.0020	412	5	395	82	413	5
7561-7.2	753	330	0.453	52	9	0.000242	0.000075	0.0042	0.1395	0.0055	0.5019	0.0169	0.0667	0.0008	0.445	0.0545	0.0017	416	5	394	70	417	5
7561-91.1	86	67	0.814	8	13	0.001897	0.000463	0.0329	0.2432	0.0204	0.6635	0.0904	0.0804	0.0026	0.355	0.0599	0.0077	498	15	599	306	496	15
7561-91.2	202	102	0.522	17	23	0.001536	0.000292	0.0266	0.1633	0.0128	0.6538	0.0567	0.0822	0.0012	0.287	0.0577	0.0048	509	7	518	195	509	7
7561-88.1	95	381	4.157	18	2	0.000479	0.000206	0.0083	1.3021	0.0229	0.6923	0.0465	0.0909	0.0015	0.360	0.0552	0.0035	561	9	422	147	563	9
7561-33.1	204	98	0.496	19	7	0.000317	0.000152	0.0055	0.1509	0.0074	0.7715	0.0389	0.0918	0.0020	0.534	0.0610	0.0026	566	12	639	95	564	12
7561-73.1	109	131	1.236	13	1	0.000207	0.000327	0.0036	0.3789	0.0229	0.7426	0.0706	0.0928	0.0016	0.302	0.0580	0.0053	572	10	530	214	573	9
7561-26.1	470	476	1.046	52	31	0.000736	0.000107	0.0128	0.3259	0.0059	0.7750	0.0272	0.0932	0.0013	0.492	0.0603	0.0019	575	7	614	68	574	7
7561-96.1	434	13	0.032	37	4	0.000101	0.000131	0.0018	0.0115	0.0052	0.7703	0.0418	0.0937	0.0017	0.439	0.0597	0.0029	577	10	591	110	577	10
7561-49.1	209	83	0.410	20	1	0.000260	0.000122	0.0045	0.1153	0.0058	0.7330	0.0322	0.0937	0.0017	0.512	0.0568	0.0022	577	10	482	86	579	10
7561-72.1	124	3	0.025	11	0	0.000388	0.000299	0.0067	-0.0034	0.0112	0.7039	0.0656	0.0945	0.0017	0.307	0.0540	0.0048	582	10	372	215	586	9
7561-69.1	57	0	0.004	5	2	0.001181	0.000477	0.0205	-0.0167	0.0182	0.6292	0.1069	0.0951	0.0030	0.304	0.0480	0.0078	585	17	99	346	593	17
7561-23.1	160	134	0.866	18	3	0.000221	0.000148	0.0038	0.2797	0.0091	0.8029	0.0371	0.0965	0.0013	0.399	0.0603	0.0026	594	7	616	95	593	7
7561-97.1	1014	484	0.493	103	-2	0.000098	0.000030	0.0017	0.1552	0.0021	0.7743	0.0132	0.0967	0.0011	0.762	0.0581	0.0006	595	7	532	25	596	7
7561-41.1	162	264	1.679	22	7	0.000053	0.000162	0.0009	0.5233	0.0106	0.9038	0.0411	0.0989	0.0015	0.442	0.0663	0.0027	608	9	815	88	603	9
7561-55.1	176	207	1.211	22	4	0.000357	0.000233	0.0062	0.3816	0.0124	0.7946	0.0548	0.0982	0.0016	0.351	0.0587	0.0038	604	9	557	149	604	9
7561-66.1	476	2	0.004	43	1	0.000058	0.000146	0.0010	0.0006	0.0054	0.8199	0.0377	0.0995	0.0012	0.371	0.0598	0.0026	611	7	596	96	612	7
7561-51.1	127	152	1.231	16	2	0.000010	0.000010	0.0002	0.4006	0.0091	0.8683	0.0241	0.1000	0.0016	0.679	0.0630	0.0013	615	10	706	44	613	10
7561-2.1	45	47	1.076	5	3	0.001202	0.000470	0.0208	0.3244	0.0218	0.7096	0.1065	0.0990	0.0019	0.247	0.0520	0.0076	608	11	286	304	614	10
7561-90.1	393	275	0.721	44	7	0.000233	0.000085	0.0040	0.2291	0.0052	0.8286	0.0285	0.1004	0.0014	0.518	0.0599	0.0018	617	8	598	66	617	8
7561-37.1	998	383	0.396	103	27	0.000298	0.000057	0.0052	0.1234	0.0105	0.8451	0.0445	0.1011	0.0034	0.717	0.0607	0.0022	621	20	627	82	620	20
7561-14.1	344	10	0.030	32	4	0.000229	0.000085	0.0040	0.0111	0.0034	0.8269	0.0244	0.1016	0.0012	0.512	0.0590	0.0015	624	7	567	57	625	7
7561-50.1	429	58	0.139	42	5	0.000205	0.000097	0.0036	0.0404	0.0043	0.8389	0.0288	0.1021	0.0016	0.553	0.0596	0.0017	627	9	588	64	628	9
7561-21.1	178	142	0.829	21	3	0.000432	0.000153	0.0075	0.2518	0.0087	0.8045	0.0393	0.1020	0.0014	0.396	0.0572	0.0026	626	8	499	103	629	8
7561-12.1	567	439	0.800	66	19	0.000469	0.000291	0.0081	0.2388	0.0116	0.8486	0.0688	0.1035	0.0016	0.312	0.0595	0.0046	635	9	584	178	636	9
7561-59.1	354	304	0.885	42	9	0.000655	0.000203	0.0114	0.2619	0.0087	0.7897	0.0488	0.1036	0.0014	0.336	0.0553	0.0033	635	8	425	137	639	8
7561-1.1	183	390	2.205	29	5	0.000274	0.000142	0.0048	0.6841	0.0166	0.8895	0.0390	0.1045	0.0014	0.418	0.0617	0.0025	641	8	665	88	640	8
7561-79.1	561	541	0.996	74	7	0.000131	0.000050	0.0023	0.3332	0.0043	0.9403	0.0187	0.1099	0.0013	0.666	0.0621	0.0009	672	7	677	32	672	7
7561-84.1	541	36	0.069	62	59	0.000037	0.000031	0.0006	0.0494	0.0017	1.3664	0.0251	0.1259	0.0016	0.783	0.0787	0.0009	764	9	1165	23	752	9
7561-22.1	379	182	0.496	51	4	0.000098	0.000047	0.0017	0.1523	0.0031	1.1426	0.0221	0.1276	0.0014	0.669	0.0649	0.0009	774	8	772	31	774	8
7561-60.1	242	340	1.454	43	5	0.000242	0.000092	0.0042	0.4460	0.0068	1.2149	0.0371	0.1351	0.0020	0.582	0.0652	0.0016	817	11	782	53	818	11
7561-10.1	401	197	0.509	58	7	0.000143	0.000060	0.0025	0.1552	0.0037	1.2629	0.0292	0.1372	0.0018	0.653	0.0668	0.0012	829	10	831	37	828	10
7561-45.1	457	55	0.124	101	7	0.000075	0.000056	0.0013	0.0404	0.0024	2.8403	0.0539	0.2277	0.0031	0.786	0.0905	0.0011	1322	16	1436	23		
7561-35.1	431	303	0.727	111	2	0.000026	0.000026	0.0005	0.2228	0.0027	2.7075	0.0389	0.2279	0.0025	0.835	0.0862	0.0007	1324	13	1342	16		
7561-3.1	45	42	0.963	13	7	0.000693	0.000239	0.0120	0.2657	0.0115	3.4754	0.1677	0.2429	0.0054	0.561	0.1038	0.0042	1402	28	1693	76		
7561-82.1	119	72	0.624	40	0	0.000016	0.000042	0.0003	0.1847	0.0077	4.4378	0.0859	0.3022	0.0043	0.809	0.1065	0.0012	1702	21	1741	21		
7561-18.1	259	17	0.068	79	3	0.000040	0.000030	0.0007	0.0181	0.0016	5.2696	0.0748	0.3116	0.0035	0.857	0.1227	0.0009	1749	17	1995	13		
7561-32.1	714	8	0.011	219	8	0.000041	0.000014	0.0007	0.0030	0.0005	5.0922	0.0869	0.3193	0.0045	0.889	0.1157	0.0009	1786	22	1890	14		
7561-74.1	378	284	0.775	155	3	0.000022	0.000040	0.0004	0.2127	0.0032	6.2918	0.1170	0.3534	0.0044	0.749	0.1291	0.0016	1951	21	2086	22		
7561-29.1	82	36	0.448	31	5	0.000209	0.000160	0.0036	0.1251	0.0076	6.2609	0.1936	0.3534	0.0062	0.658	0.1285	0.0030	1951	29	2077	42		
7561-81.1	252	75	0.305	96	2	0.000026	0.000020	0.0004	0.0875	0.0017	6.7178	0.1500	0.3628	0.0060	0.819	0.1343	0.0017	1995	29	2155	23		
7561-62.1	314	165	0.543	129	5	0.000055	0.000019	0.0001	0.1714	0.0029	6.6744	0.0861	0.3670	0.0040	0.905	0.1319	0.0007	2015	19	2123	10		
7561-75.1	257	123	0.496	104	2	0.000026	0.000026	0.0004	0.1382	0.0021	6.7447	0.0987	0.3701	0.0044	0.875	0.1322	0.0009	2030	21	2127	13		
7561-13.1	159	39	0.252	61	4	0.000088	0.000076	0.0015	0.0715	0.0041	6.6643	0.1228	0.3728	0.0045	0.742	0.1297	0.0016	2043	21	2093	22		
7561-93.1	286	119	0.431	119	5	0.000051	0.000024	0.0009	0.1175	0.0020	6.9672	0.0915	0.3876	0.0043	0.902	0.1304	0.0008	2112	20	2103	10		
7561-89.1	378	39	0.108	153	6	0.000049	0.000018	0.0009	0.0309	0.0012	7.4279	0.0948	0.4039	0.0045	0.924	0.1334	0.0007	2187	21	2143	9		
7561-78.1	153	55	0.372	74	44	0.000746	0.000088	0.0129	0.1000	0.0039	9.8204	0.1995	0.4489	0.0063	0.768	0.1587	0.0021	2390	28	2442	22		
7561-80.1	317	143	0.466	188	6	0.000043	0.000019	0.0008	0.1230	0.0014	14.9154	0.1897	0.5182	0.0057	0.913	0.2088	0.0011	2691	24	2896	9		
7561-43.1	423	32	0.077	289	3	0.000013	0.000020	0.0002	0.0212	0.0009	22.1048	0.2748	0.6220	0.0073	0.972	0.2578	0.0008	3118	29	3233	5		

Uncertainties reported at 1σ (absolute) and are calculated by numerical propagation of all known sources of error; f(206)^{204} refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb-method; common Pb composition used is the surface blank; [1] 204-corrected ages; [2] 207-corrected ages (Stern 1997); * GSC grain mount IP296.

Table A3. U/Pb SHRIMP analytical data for the Matthew Lake Formation (VL-2001-03)*.

									Isotopic ratios									Ages (Ma)					
Spot name	U (ppm)	Th (ppm)	$\frac{\text{Th}}{\text{U}}$	Pb (ppm)	^{204}Pb (ppb)	$\frac{^{204}\text{Pb}}{^{206}\text{Pb}}$	$\pm\frac{^{204}\text{Pb}}{^{206}\text{Pb}}$	$f(206)^{204}$	$\frac{^{208}\text{Pb}}{^{206}\text{Pb}}$	$\pm\frac{^{208}\text{Pb}}{^{206}\text{Pb}}$	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$	$\pm\frac{^{207}\text{Pb}}{^{235}\text{U}}$	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\pm\frac{^{206}\text{Pb}}{^{238}\text{U}}$	Corr Coeff	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\pm\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\frac{^{206}\text{Pb}^{1}}{^{238}\text{U}}$	$\pm\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\pm\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\frac{^{206}\text{Pb}^{2}}{^{238}\text{U}}$	$\pm\frac{^{206}\text{Pb}}{^{238}\text{U}}$
7643-19.1	143	85	0.614	13	4	0.000061	0.000545	0.0011	0.1914	0.0207	0.7333	0.1026	0.0848	0.0015	0.251	0.0627	0.0086	525	9	698	321	522	8
7643-61.1	76	41	0.558	7	2	0.000010	0.000010	0.0002	0.1753	0.0089	0.7494	0.0255	0.0863	0.0019	0.720	0.0630	0.0015	533	11	709	52	530	11
7643-28.1	230	121	0.543	21	1	0.000216	0.000095	0.0037	0.1714	0.0046	0.6602	0.0292	0.0857	0.0011	0.409	0.0559	0.0023	530	7	447	93	531	7
7643-12.1	155	74	0.495	14	1	0.000458	0.000154	0.0079	0.1512	0.0083	0.6132	0.0383	0.0854	0.0021	0.505	0.0521	0.0028	528	13	290	129	532	13
7643-60.1	220	135	0.635	20	2	0.000250	0.000211	0.0043	0.1951	0.0087	0.6657	0.0418	0.0858	0.0011	0.326	0.0563	0.0034	531	7	463	138	532	6
7643-22.1	93	83	0.926	9	2	0.000496	0.000444	0.0086	0.2849	0.0187	0.6584	0.0869	0.0858	0.0019	0.285	0.0556	0.0071	531	11	438	312	532	10
7643-9.1	164	103	0.652	15	0	0.000166	0.000154	0.0029	0.1900	0.0070	0.6521	0.0389	0.0859	0.0015	0.409	0.0551	0.0030	531	9	416	128	533	9
7643-17.1	111	60	0.561	10	1	0.000010	0.000010	0.0002	0.1765	0.0124	0.7093	0.0191	0.0869	0.0012	0.602	0.0592	0.0013	537	7	574	48	537	7
7643-13.1	64	43	0.691	6	1	0.000176	0.000423	0.0031	0.2426	0.0209	0.7078	0.0853	0.0871	0.0020	0.308	0.0590	0.0068	538	12	566	274	538	11
7643-29.1	120	79	0.678	11	1	0.000228	0.000282	0.0039	0.1807	0.0120	0.6799	0.0597	0.0876	0.0013	0.289	0.0563	0.0048	541	8	465	199	542	7
7643-19.2	204	142	0.720	20	1	0.000234	0.000396	0.0041	0.2210	0.0154	0.6790	0.0768	0.0876	0.0013	0.249	0.0562	0.0062	541	7	461	266	543	7
7643-1.1	145	77	0.545	13	2	0.000010	0.000010	0.0002	0.1731	0.0085	0.7408	0.0367	0.0884	0.0037	0.897	0.0608	0.0013	546	22	632	48	544	22
7643-14.1	711	320	0.466	65	7	0.000039	0.000030	0.0007	0.1432	0.0028	0.7291	0.0129	0.0886	0.0011	0.761	0.0597	0.0007	547	6	593	25	546	6
7643-19.3	156	92	0.613	15	1	0.000110	0.000227	0.0019	0.1780	0.0097	0.7109	0.0484	0.0886	0.0013	0.337	0.0582	0.0038	547	8	537	148	547	8
7643-10.1	404	317	0.811	40	0	0.000010	0.000010	0.0002	0.2483	0.0046	0.7156	0.0120	0.0887	0.0011	0.806	0.0585	0.0006	548	6	550	22	548	6
7643-3.1	267	223	0.860	27	2	0.000094	0.000092	0.0016	0.2709	0.0067	0.7178	0.0265	0.0890	0.0016	0.598	0.0585	0.0018	549	10	550	67	549	10
7643-77.1	560	250	0.461	52	1	0.000000	0.000053	0.0000	0.1418	0.0035	0.7290	0.0201	0.0896	0.0012	0.593	0.0590	0.0013	553	7	567	49	553	7
7643-21.1	499	178	0.367	46	0	0.000202	0.000087	0.0035	0.1120	0.0039	0.6897	0.0205	0.0900	0.0011	0.505	0.0556	0.0014	555	6	436	58	557	6
7643-62.3	151	59	0.401	14	1	0.000205	0.000163	0.0036	0.1221	0.0094	0.7094	0.0362	0.0906	0.0013	0.387	0.0568	0.0027	559	7	483	108	561	7
7643-16.1	821	457	0.575	81	3	0.000061	0.000034	0.0011	0.1801	0.0043	0.7472	0.0150	0.0920	0.0013	0.768	0.0589	0.0008	567	8	564	28	567	8
7643-50.1	168	158	0.975	21	0	0.000010	0.000010	0.0002	0.3046	0.0099	0.8852	0.0470	0.1051	0.0032	0.661	0.0611	0.0025	644	18	642	89	644	19
7643-87.1	212	147	0.717	25	-1	0.000215	0.000094	0.0037	0.2149	0.0057	0.8426	0.0296	0.1061	0.0017	0.557	0.0576	0.0017	650	10	514	66	653	10
7643-82.1	616	16	0.028	63	0	0.000010	0.000010	0.0002	0.0093	0.0006	0.9446	0.0202	0.1107	0.0013	0.659	0.0619	0.0010	677	8	670	35	677	8
7643-20.1	570	5	0.008	59	-1	0.000055	0.000028	0.0010	0.0009	0.0011	0.9494	0.0158	0.1122	0.0013	0.776	0.0614	0.0007	686	8	652	23	686	8
7643-23.1	356	20	0.057	39	5	0.000010	0.000010	0.0002	0.0248	0.0013	1.0696	0.0171	0.1187	0.0015	0.834	0.0654	0.0006	723	8	787	19	721	8
7643-98.1	475	31	0.068	59	0	0.000064	0.000035	0.0011	0.0200	0.0016	1.1967	0.0194	0.1334	0.0015	0.781	0.0651	0.0007	807	9	776	22	808	9
7643-69.1	435	90	0.215	63	29	0.000032	0.000024	0.0006	0.0785	0.0016	1.5880	0.0254	0.1512	0.0018	0.828	0.0762	0.0007	908	10	1100	18	900	10
7643-110.1	168	95	0.583	36	2	0.000066	0.000102	0.0011	0.1811	0.0066	2.1910	0.0626	0.1980	0.0031	0.636	0.0803	0.0018	1164	16	1204	44		
7643-2.1	81	52	0.659	19	2	0.000148	0.000241	0.0026	0.2049	0.0096	2.4093	0.1240	0.2085	0.0035	0.435	0.0838	0.0039	1221	18	1288	94		
7643-78.1	353	172	0.504	82	1	0.000010	0.000010	0.0002	0.1508	0.0017	2.4925	0.0409	0.2180	0.0026	0.813	0.0829	0.0008	1271	14	1268	19		
7643-101.1	447	125	0.289	99	2	0.000018	0.000014	0.0003	0.0848	0.0017	2.5074	0.0589	0.2196	0.0039	0.828	0.0828	0.0011	1280	21	1265	26		
7643-109.1	285	90	0.325	69	4	0.000065	0.000056	0.0011	0.1238	0.0025	3.0402	0.0566	0.2310	0.0030	0.769	0.0955	0.0012	1339	16	1537	23		
7643-36.1	207	86	0.429	51	2	0.000053	0.000032	0.0009	0.1271	0.0023	2.8509	0.0477	0.2353	0.0030	0.840	0.0879	0.0008	1362	16	1380	18		
7643-47.1	556	229	0.426	148	1	0.000010	0.000014	0.0002	0.1287	0.0017	3.2803	0.0617	0.2533	0.0036	0.833	0.0939	0.0010	1456	19	1507	20		
7643-37.1	1225	421	0.355	339	4	0.000015	0.000006	0.0003	0.1051	0.0007	3.4612	0.0421	0.2686	0.0031	0.968	0.0935	0.0003	1534	16	1497	6		
7643-70.1	340	174	0.529	100	17	0.000215	0.000046	0.0037	0.1553	0.0048	3.5229	0.1425	0.2731	0.0074	0.753	0.0935	0.0025	1557	38	1499	52		
7643-73.1	129	41	0.325	43	4	0.000111	0.000046	0.0019	0.0896	0.0027	4.9225	0.1031	0.3187	0.0044	0.743	0.1120	0.0016	1783	22	1833	26		
7643-86.1	170	223	1.355	116	3	0.000041	0.000040	0.0007	0.3803	0.0030	12.5524	0.2128	0.5078	0.0076	0.927	0.1793	0.0012	2647	32	2646	11		
7643-100.1	46	17	0.392	33	2	0.000087	0.000104	0.0015	0.1060	0.0056	20.8613	0.8428	0.6245	0.0087	0.458	0.2423	0.0088	3128	35	3135	59		

Uncertainties reported at 1σ (absolute) and are calculated by numerical propagation of all known sources of error; $f(206)^{204}$ refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb-method; common Pb composition used is the surface blank; [1] 204-corrected ages; [2] 207-corrected ages (Stern 1997); * GSC grain mount IP286.

Table A4. U/Pb SHRIMP analytical data for the Ellsworth Formation (VL-2001-24)*.

									Isotopic ratios									Ages (Ma)					
Spot name	U (ppm)	Th (ppm)	Th/U	Pb (ppm)	^{204}Pb (ppb)	^{204}Pb/^{206}Pb	± ^{204}Pb/^{206}Pb	f(206)^{204}	^{208}Pb/^{206}Pb	± ^{208}Pb/^{206}Pb	^{207}Pb/^{235}U	± ^{207}Pb/^{235}U	^{206}Pb/^{238}U	± ^{206}Pb/^{238}U	Corr Coeff	^{207}Pb/^{206}Pb	± ^{207}Pb/^{206}Pb	^{206}Pb^{1}/^{238}U	± ^{206}Pb/^{238}U	^{207}Pb/^{206}Pb	± ^{207}Pb/^{206}Pb	^{206}Pb^{2}/^{238}U	± ^{206}Pb/^{238}U
7691-68.1	389	330	0.875	35	3	0.000062	0.000059	0.0011	0.2726	0.0116	0.6334	0.0248	0.0795	0.0014	0.567	0.0578	0.0019	493	9	521	73	493	9
7691-67.1	147	87	0.612	13	2	0.000115	0.000094	0.0020	0.1886	0.0065	0.6573	0.0296	0.0812	0.0013	0.472	0.0587	0.0024	503	8	558	90	502	8
7691-55.1	309	220	0.736	28	7	0.000213	0.000110	0.0037	0.2223	0.0094	0.6673	0.0238	0.0819	0.0009	0.433	0.0591	0.0019	507	6	571	72	506	5
7691-67.2	137	79	0.594	12	3	0.000352	0.000300	0.0061	0.1728	0.0123	0.6420	0.0570	0.0824	0.0015	0.321	0.0565	0.0048	510	9	472	199	511	8
7691-54.2	287	347	1.249	30	2	0.000103	0.000067	0.0018	0.3860	0.0062	0.6542	0.0206	0.0827	0.0015	0.684	0.0574	0.0013	512	9	507	52	512	9
7691-91.1	124	50	0.417	10	1	0.000195	0.000201	0.0034	0.1261	0.0089	0.6451	0.0486	0.0826	0.0012	0.309	0.0566	0.0041	512	7	477	168	512	7
7691-6.1	152	205	1.397	16	4	0.000326	0.000264	0.0057	0.4509	0.0139	0.6676	0.0552	0.0832	0.0021	0.417	0.0582	0.0044	515	12	536	175	515	12
7691-54.1	335	396	1.223	35	2	0.000246	0.000303	0.0043	0.3769	0.0128	0.6322	0.0582	0.0833	0.0013	0.286	0.0550	0.0049	516	8	413	212	517	7
7691-14.1	230	210	0.943	22	3	0.000345	0.000160	0.0060	0.2870	0.0117	0.6324	0.0355	0.0835	0.0016	0.452	0.0549	0.0028	517	9	409	117	519	9
7691-13.1	86	90	1.074	9	3	0.000343	0.000556	0.0060	0.3385	0.0235	0.7225	0.1078	0.0861	0.0019	0.267	0.0609	0.0088	532	11	634	347	531	10
7691-15.1	323	55	0.176	26	4	0.000391	0.000477	0.0068	0.0402	0.0179	0.6455	0.0907	0.0857	0.0013	0.229	0.0546	0.0075	530	8	397	343	532	6
7691-100.1	145	34	0.244	12	2	0.000010	0.000010	0.0002	0.0792	0.0035	0.7318	0.0289	0.0865	0.0012	0.463	0.0614	0.0022	535	7	652	78	533	7
7691-6.2	96	109	1.176	10	1	0.000310	0.000233	0.0054	0.3270	0.0140	0.6642	0.0495	0.0860	0.0016	0.365	0.0560	0.0039	532	9	452	163	533	9
7691-91.2	140	68	0.501	13	3	0.000445	0.000176	0.0077	0.1544	0.0081	0.6564	0.0400	0.0863	0.0013	0.369	0.0552	0.0032	533	8	420	133	535	8
7691-66.1	217	205	0.972	22	2	0.000203	0.000294	0.0035	0.3102	0.0124	0.6777	0.0576	0.0865	0.0012	0.286	0.0568	0.0047	535	7	484	192	536	7
7691-2.1	90	57	0.653	8	3	0.000010	0.000010	0.0002	0.2139	0.0099	0.7957	0.0241	0.0879	0.0013	0.599	0.0657	0.0016	543	8	795	52	538	8
7691-5.1	327	246	0.777	32	1	0.000053	0.000038	0.0009	0.2402	0.0085	0.6986	0.0237	0.0872	0.0012	0.508	0.0581	0.0017	539	7	534	66	539	7
7691-28.1	202	127	0.651	19	1	0.000390	0.000229	0.0068	0.1908	0.0099	0.6370	0.0482	0.0868	0.0013	0.324	0.0532	0.0038	537	8	338	172	540	8
7691-7.1	121	49	0.418	11	1	0.000010	0.000010	0.0002	0.1393	0.0050	0.7306	0.0320	0.0876	0.0031	0.865	0.0605	0.0013	541	18	621	49	540	18
7691-51.1	244	241	1.021	25	2	0.000051	0.000231	0.0009	0.3201	0.0103	0.7118	0.0470	0.0875	0.0012	0.328	0.0590	0.0037	541	7	567	143	540	7
7691-42.1	184	166	0.932	19	-1	0.000010	0.000010	0.0002	0.3031	0.0062	0.6900	0.0164	0.0874	0.0011	0.624	0.0573	0.0011	540	6	503	42	540	7
7691-86.1	140	156	1.154	15	1	0.000049	0.000167	0.0009	0.3488	0.0239	0.7167	0.0367	0.0878	0.0012	0.380	0.0592	0.0028	542	7	576	107	542	7
7691-31.1	265	213	0.830	26	2	0.000027	0.000072	0.0005	0.2509	0.0062	0.7157	0.0236	0.0878	0.0015	0.616	0.0592	0.0016	542	9	572	58	542	9
7691-14.2	246	224	0.942	25	3	0.000324	0.000124	0.0056	0.2911	0.0160	0.6705	0.0285	0.0874	0.0012	0.444	0.0556	0.0021	540	7	437	88	542	7
7691-17.1	102	66	0.666	10	4	0.000224	0.000403	0.0039	0.2096	0.0165	0.7592	0.0815	0.0882	0.0014	0.271	0.0625	0.0065	545	8	690	239	542	8
7691-29.1	356	351	1.019	37	-1	0.000007	0.000072	0.0001	0.3177	0.0058	0.6995	0.0186	0.0877	0.0010	0.545	0.0578	0.0013	542	6	523	50	542	6
7691-98.1	142	112	0.814	14	0	0.000045	0.000454	0.0008	0.2449	0.0183	0.7123	0.0899	0.0884	0.0016	0.265	0.0585	0.0072	546	10	547	293	546	9
7691-84.1	170	104	0.636	16	2	0.000194	0.000115	0.0034	0.1821	0.0064	0.7043	0.0280	0.0885	0.0013	0.481	0.0577	0.0020	547	8	519	79	547	8
7691-95.1	625	477	0.788	62	3	0.000053	0.000048	0.0009	0.2448	0.0033	0.7177	0.0146	0.0887	0.0010	0.673	0.0587	0.0009	548	6	555	33	548	6
7691-99.1	146	99	0.705	14	0	0.000094	0.000283	0.0016	0.2122	0.0120	0.7046	0.0583	0.0889	0.0013	0.298	0.0575	0.0046	549	8	511	185	549	7
7691-96.1	319	206	0.666	31	1	0.000107	0.000063	0.0019	0.2117	0.0048	0.7099	0.0306	0.0890	0.0011	0.394	0.0579	0.0023	550	6	524	90	550	6
7691-27.1	214	240	1.157	23	4	0.000070	0.000148	0.0012	0.3589	0.0085	0.7528	0.0338	0.0896	0.0012	0.407	0.0609	0.0025	553	7	636	92	552	7
7691-35.1	102	73	0.739	10	2	0.000382	0.000224	0.0066	0.2125	0.0118	0.6997	0.0513	0.0893	0.0018	0.392	0.0569	0.0039	551	11	486	157	552	11
7691-92.1	255	86	0.350	23	1	0.000071	0.000098	0.0012	0.0987	0.0050	0.7327	0.0255	0.0904	0.0013	0.504	0.0588	0.0018	558	7	558	67	558	7
7691-87.1	181	163	0.934	19	1	0.000142	0.000133	0.0025	0.2877	0.0086	0.7268	0.0312	0.0907	0.0012	0.415	0.0581	0.0023	560	7	534	89	560	7
7691-24.1	263	265	1.041	28	2	0.000001	0.000066	0.0000	0.3244	0.0095	0.7591	0.0212	0.0910	0.0013	0.612	0.0605	0.0014	561	8	622	49	560	8
7691-41.1	203	131	0.668	20	2	0.000010	0.000010	0.0002	0.2072	0.0047	0.7747	0.0178	0.0920	0.0011	0.638	0.0611	0.0011	567	7	641	39	566	7
7691-26.1	299	55	0.188	27	0	0.000061	0.000242	0.0011	0.0584	0.0092	0.7405	0.0531	0.0922	0.0017	0.378	0.0583	0.0039	569	10	539	154	569	10
7691-38.1	300	134	0.461	32	0	0.000188	0.000059	0.0033	0.1350	0.0036	0.8239	0.0198	0.1027	0.0012	0.575	0.0582	0.0012	630	7	538	44	632	7
7691-36.1	417	156	0.388	47	-2	0.000068	0.000065	0.0012	0.1170	0.0038	0.9274	0.0229	0.1110	0.0014	0.602	0.0606	0.0012	679	8	624	43	680	8
7691-10.1	324	71	0.227	65	1	0.000015	0.000035	0.0003	0.0673	0.0020	2.2621	0.0583	0.2037	0.0030	0.669	0.0805	0.0016	1195	16	1210	38		
7691-93.1	866	306	0.365	222	4	0.000020	0.000009	0.0004	0.1091	0.0011	3.2053	0.0376	0.2478	0.0026	0.939	0.0938	0.0004	1427	13	1504	8		
7691-30.1	181	76	0.436	67	3	0.000053	0.000035	0.0009	0.1266	0.0027	5.7755	0.0932	0.3468	0.0044	0.852	0.1208	0.0010	1919	21	1968	15		
7691-76.1	256	57	0.230	94	2	0.000023	0.000022	0.0004	0.0624	0.0016	6.3355	0.0816	0.3600	0.0040	0.905	0.1276	0.0007	1982	19	2066	10		
7691-34.1	141	49	0.358	57	3	0.000055	0.000032	0.0010	0.1002	0.0029	6.7845	0.1207	0.3798	0.0053	0.854	0.1296	0.0012	2075	25	2092	16		

Uncertainties reported at 1σ (absolute) and are calculated by numerical propagation of all known sources of error; f(206)^{204} refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb-method; common Pb composition used is the surface blank; [1] 204-corrected ages; [2] 207-corrected ages (Stern 1997); * GSC grain mount IP295.

Table A5. U/Pb SHRIMP analytical data for the Calais Formation (VL-2001-12)*.

									Isotopic ratios									Ages (Ma)					
Spot name	U (ppm)	Th (ppm)	Th/U	Pb (ppm)	^{204}Pb (ppb)	^{204}Pb/^{206}Pb	± ^{204}Pb/^{206}Pb	f(206)^{204}	^{208}Pb/^{206}Pb	± ^{208}Pb/^{206}Pb	^{207}Pb/^{235}U	± ^{207}Pb/^{235}U	^{206}Pb/^{238}U	± ^{206}Pb/^{238}U	Corr Coeff	^{207}Pb/^{206}Pb	± ^{207}Pb/^{206}Pb	^{206}Pb^{1}/^{238}U	± ^{206}Pb/^{238}U	^{207}Pb/^{206}Pb	± ^{207}Pb/^{206}Pb	^{206}Pb^{2}/^{238}U	± ^{206}Pb/^{238}U
7562-86.1	700	10	0.014	52	13	0.000117	0.000052	0.0020	0.0030	0.0021	0.6742	0.0205	0.0819	0.0011	0.542	0.0597	0.0015	507	6	593	57	506	7
7562-76.1	1098	12	0.012	82	3	0.000090	0.000037	0.0016	0.0013	0.0017	0.6437	0.0129	0.0823	0.0011	0.741	0.0568	0.0008	510	6	482	30	510	6
7562-30.1	151	82	0.56	13	0	0.000260	0.000481	0.0045	0.1637	0.0225	0.6243	0.0892	0.0831	0.0015	0.251	0.0545	0.0076	515	9	391	348	517	8
7562-57.1	468	546	1.207	49	1	0.000144	0.000162	0.0025	0.3633	0.0085	0.6583	0.0351	0.0850	0.0016	0.470	0.0562	0.0027	526	10	459	109	527	10
7562-64.1	443	3	0.006	34	-1	0.000060	0.000058	0.0011	0.0007	0.0022	0.6685	0.0166	0.0853	0.0011	0.633	0.0568	0.0011	528	7	485	43	528	7
7562-50.1	667	19	0.029	54	11	0.000010	0.000010	0.0002	0.0182	0.0014	0.7448	0.0449	0.0878	0.0036	0.764	0.0615	0.0024	543	21	657	86	541	21
7562-42.1	1831	16	0.009	147	12	0.000022	0.000037	0.0004	0.0040	0.0014	0.7218	0.0120	0.0882	0.0010	0.737	0.0594	0.0007	545	6	580	25	544	6
7562-45.1	156	154	1.015	16	1	0.000014	0.000175	0.0002	0.3094	0.0156	0.7268	0.0387	0.0883	0.0013	0.392	0.0597	0.0030	545	8	593	111	545	8
7562-66.1	178	87	0.508	16	3	0.000339	0.000137	0.0059	0.1421	0.0081	0.6931	0.0358	0.0890	0.0018	0.505	0.0565	0.0025	549	11	472	103	551	11
7562-75.1	948	947	1.032	101	2	0.000009	0.000010	0.0002	0.3203	0.0032	0.7281	0.0113	0.0897	0.0011	0.825	0.0589	0.0005	554	6	562	19	554	6
7562-40.1	1322	787	0.615	129	-5	0.000010	0.000010	0.0002	0.1906	0.0019	0.7196	0.0106	0.0902	0.0011	0.889	0.0579	0.0004	557	7	525	15	557	7
7562-74.1	2059	205	0.103	176	5	0.000099	0.000025	0.0017	0.0342	0.0012	0.7210	0.0106	0.0905	0.0010	0.820	0.0578	0.0005	559	6	521	19	559	6
7562-49.1	636	5	0.008	53	3	0.000307	0.000082	0.0053	-0.0054	0.0031	0.6975	0.0225	0.0913	0.0016	0.649	0.0554	0.0014	563	10	428	56	566	10
7562-41.1	517	587	1.172	58	1	0.000004	0.000031	0.0001	0.3641	0.0054	0.7506	0.0135	0.0919	0.0010	0.714	0.0592	0.0008	567	6	575	28	567	6
7562-78.1	512	60	0.121	44	10	0.000010	0.000010	0.0002	0.0401	0.0017	0.7961	0.0144	0.0926	0.0012	0.813	0.0624	0.0007	571	7	687	23	568	7
7562-46.1	128	59	0.474	12	0	0.000032	0.000362	0.0006	0.1406	0.0146	0.7719	0.0799	0.0942	0.0021	0.338	0.0594	0.0058	580	13	582	229	580	12
7562-34.1	142	43	0.309	13	4	0.000229	0.000185	0.0040	0.0940	0.0085	0.8091	0.0479	0.0957	0.0020	0.460	0.0613	0.0033	589	12	650	118	588	11
7562-63.1	409	358	0.904	46	3	0.000045	0.000049	0.0008	0.2679	0.0045	0.8205	0.0311	0.0983	0.0016	0.527	0.0605	0.0020	605	9	622	72	604	9
7562-33.1	222	178	0.83	25	3	0.000144	0.000143	0.0025	0.2516	0.0106	0.8313	0.0425	0.1002	0.0017	0.438	0.0602	0.0028	615	10	611	103	615	10
7562-72.1	194	67	0.355	20	1	0.000241	0.000087	0.0042	0.1001	0.0052	0.8373	0.0276	0.1036	0.0013	0.497	0.0586	0.0017	635	8	553	64	637	8
7562-36.1	2039	221	0.112	209	43	0.000363	0.000040	0.0063	0.0373	0.0113	0.8843	0.0231	0.1076	0.0012	0.543	0.0596	0.0013	659	7	589	49	660	7
7562-67.1	305	80	0.27	36	7	0.000034	0.000061	0.0006	0.0822	0.0041	1.0920	0.0275	0.1192	0.0018	0.701	0.0664	0.0012	726	11	820	38	724	11
7562-62.1	1058	359	0.351	136	10	0.000014	0.000038	0.0002	0.1089	0.0020	1.1684	0.0251	0.1282	0.0014	0.596	0.0661	0.0012	778	8	810	37	777	8
7562-77.1	298	25	0.088	34	80	0.000153	0.000094	0.0027	0.0354	0.0038	1.8076	0.0449	0.1343	0.0020	0.701	0.0976	0.0017	812	12	1579	34	783	11
7562-85.1	123	35	0.295	18	6	0.000190	0.000164	0.0033	0.0983	0.0094	1.4670	0.1076	0.1492	0.0065	0.688	0.0713	0.0038	896	37	967	114	894	37
7562-89.1	513	174	0.351	81	13	0.000052	0.000032	0.0009	0.1175	0.0057	1.5545	0.0267	0.1563	0.0020	0.815	0.0722	0.0007	936	11	990	21	934	11
7562-56.1	547	231	0.436	122	3	0.000035	0.000041	0.0006	0.1421	0.0033	3.2756	0.0505	0.2054	0.0026	0.881	0.1157	0.0009	1204	14	1890	13		
7562-29.1	656	391	0.615	150	6	0.000049	0.000023	0.0009	0.1671	0.0038	3.3266	0.0509	0.2076	0.0026	0.877	0.1162	0.0009	1216	14	1899	13		
7562-38.1	1768	39	0.023	360	7	0.000022	0.000019	0.0004	0.0048	0.0007	3.2030	0.0411	0.2128	0.0023	0.890	0.1092	0.0006	1244	12	1785	11		
7562-69.1	298	50	0.174	94	16	0.000202	0.000036	0.0035	0.0368	0.0027	5.4396	0.1624	0.3153	0.0060	0.727	0.1251	0.0026	1766	30	2031	37		
7562-37.1	130	67	0.528	46	0	0.000010	0.000010	0.0002	0.1692	0.0033	4.7987	0.0904	0.3241	0.0051	0.887	0.1074	0.0009	1810	25	1756	16		
7562-28.1	399	14	0.035	126	6	0.000054	0.000021	0.0009	0.0087	0.0014	5.0995	0.0728	0.3260	0.0041	0.923	0.1134	0.0006	1819	20	1855	10		
7562-35.1	589	85	0.149	198	4	0.000021	0.000010	0.0004	0.0448	0.0016	5.2549	0.0643	0.3371	0.0037	0.933	0.1131	0.0005	1873	18	1849	8		
7562-31.1	162	1	0.008	55	3	0.000068	0.000063	0.0012	0.0009	0.0024	6.1052	0.1116	0.3513	0.0047	0.807	0.1261	0.0014	1941	22	2044	19		
7562-22.1	1356	125	0.095	530	5	0.000010	0.000010	0.0002	0.0306	0.0006	7.3222	0.0859	0.3897	0.0043	0.976	0.1363	0.0004	2121	20	2180	4		
7562-27.1	203	184	0.939	116	1	0.000010	0.000010	0.0002	0.2678	0.0103	11.0628	0.1691	0.4591	0.0062	0.932	0.1748	0.0010	2435	28	2604	9		
7562-9.1	229	153	0.689	138	2	0.000020	0.000025	0.0003	0.1893	0.0021	12.9786	0.1676	0.5090	0.0058	0.926	0.1849	0.0009	2653	25	2697	8		

Uncertainties reported at 1σ (absolute) and are calculated by numerical propagation of all known sources of error; f(206)^{204} refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb-method; common Pb composition used is the surface blank; [1] 204-corrected ages; [2] 207-corrected ages (Stern 1997); * GSC grain mount IP296.

Table A6. U/Pb SHRIMP analytical data for the Baskahegan Formation (VL-2001-01)*.

									Isotopic ratios									Ages (Ma)					
Spot name	U (ppm)	Th (ppm)	$\frac{Th}{U}$	Pb (ppm)	^{204}Pb (ppb)	$\frac{^{204}Pb}{^{206}Pb}$	$\pm\frac{^{204}Pb}{^{206}Pb}$	f(206)^{204}	$\frac{^{208}Pb}{^{206}Pb}$	$\pm\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{207}Pb}{^{235}U}$	$\pm\frac{^{207}Pb}{^{235}U}$	$\frac{^{206}Pb}{^{238}U}$	$\pm\frac{^{206}Pb}{^{238}U}$	Corr Coeff	$\frac{^{207}Pb}{^{206}Pb}$	$\pm\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{206}Pb^{1}}{^{238}U}$	$\pm\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{206}Pb}$	$\pm\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{206}Pb^{2}}{^{238}U}$	$\pm\frac{^{206}Pb}{^{238}U}$
7563-76.2	93	72	0.799	8	3	0.000607	0.000371	0.0105	0.2201	0.0167	0.6351	0.0710	0.0828	0.0017	0.300	0.0556	0.0060	513	10	437	259	514	9
7563-19.1	403	198	0.507	35	7	0.000040	0.000062	0.0007	0.1587	0.0042	0.7023	0.0235	0.0839	0.0017	0.707	0.0607	0.0014	520	10	628	52	518	10
7563-76.1	144	135	0.973	14	4	0.000392	0.000204	0.0068	0.3059	0.0102	0.6768	0.0415	0.0850	0.0012	0.343	0.0578	0.0034	526	7	521	133	526	7
7563-53.1	170	122	0.744	16	-1	0.000229	0.000111	0.0040	0.2314	0.0069	0.6311	0.0250	0.0849	0.0010	0.417	0.0539	0.0020	525	6	369	84	527	6
7563-34.1	321	3	0.010	25	1	0.000049	0.000064	0.0009	0.0033	0.0025	0.6783	0.0182	0.0853	0.0011	0.578	0.0577	0.0013	528	6	516	49	528	6
7563-35.1	140	58	0.431	13	2	0.000142	0.000233	0.0025	0.1331	0.0097	0.7252	0.0497	0.0892	0.0014	0.346	0.0589	0.0038	551	8	565	148	551	8
7563-10.1	66	66	1.033	7	2	0.001152	0.000444	0.0200	0.3186	0.0202	0.5906	0.0918	0.0900	0.0016	0.239	0.0476	0.0072	555	10	79	326	562	9
7563-23.1	221	248	1.160	25	4	0.000010	0.000010	0.0002	0.3610	0.0056	0.7862	0.0197	0.0921	0.0012	0.635	0.0619	0.0012	568	7	670	42	566	7
7563-39.1	380	224	0.608	38	19	0.000705	0.000128	0.0122	0.1842	0.0081	0.7393	0.0362	0.0927	0.0025	0.649	0.0579	0.0022	571	15	525	85	572	15
7563-43.1	158	195	1.276	18	2	0.000133	0.000289	0.0023	0.3972	0.0135	0.7702	0.0623	0.0931	0.0017	0.338	0.0600	0.0046	574	10	604	175	573	9
7563-11.1	71	76	1.107	8	2	0.000252	0.000213	0.0044	0.3350	0.0125	0.7763	0.0510	0.0934	0.0019	0.421	0.0603	0.0036	575	11	615	135	575	11
7563-54.1	312	138	0.457	30	1	0.000121	0.000120	0.0021	0.1373	0.0060	0.7464	0.0292	0.0933	0.0013	0.467	0.0580	0.0020	575	8	531	78	576	8
7563-81.1	57	48	0.867	6	1	0.000010	0.000010	0.0002	0.2783	0.0095	0.8353	0.0285	0.0950	0.0018	0.648	0.0638	0.0017	585	11	735	56	582	11
7563-52.1	285	294	1.063	33	1	0.000104	0.000211	0.0018	0.3224	0.0096	0.7706	0.0467	0.0956	0.0013	0.336	0.0585	0.0034	588	7	548	131	589	7
7563-70.1	240	98	0.422	24	0	0.000164	0.000077	0.0029	0.1358	0.0046	0.7487	0.0233	0.0954	0.0014	0.570	0.0569	0.0015	588	8	488	58	589	8
7563-47.1	875	106	0.125	79	9	0.000125	0.000042	0.0022	0.0342	0.0019	0.7889	0.0141	0.0958	0.0010	0.681	0.0597	0.0008	590	6	593	29	590	6
7563-31.1	410	312	0.788	44	2	0.000010	0.000010	0.0002	0.2488	0.0095	0.8006	0.0139	0.0960	0.0012	0.798	0.0605	0.0006	591	7	621	23	591	7
7563-77.1	66	69	1.077	8	2	0.000325	0.000483	0.0056	0.3170	0.0215	0.8402	0.1129	0.0987	0.0032	0.358	0.0618	0.0078	607	19	666	297	605	18
7563-8.1	295	152	0.531	32	-2	0.000002	0.000104	0.0000	0.1708	0.0051	0.8400	0.0279	0.1021	0.0014	0.506	0.0597	0.0017	627	8	592	64	627	8
7563-59.1	135	124	0.954	16	3	0.000198	0.000169	0.0034	0.3189	0.0100	0.8725	0.0445	0.1029	0.0015	0.394	0.0615	0.0029	631	9	658	105	631	8
7563-49.1	288	182	0.651	32	2	0.000020	0.000064	0.0003	0.2025	0.0041	0.8783	0.0217	0.1034	0.0013	0.600	0.0616	0.0012	634	7	661	43	634	7
7563-80.1	377	272	0.744	44	4	0.000010	0.000010	0.0002	0.2221	0.0064	0.9131	0.0138	0.1057	0.0012	0.808	0.0626	0.0006	648	7	696	19	647	7
7563-60.1	91	63	0.721	11	1	0.000016	0.000120	0.0003	0.2382	0.0079	0.9331	0.0402	0.1064	0.0021	0.554	0.0636	0.0023	652	12	728	79	650	12
7563-33.1	250	52	0.217	26	5	0.000168	0.000092	0.0029	0.0668	0.0041	0.9325	0.0326	0.1087	0.0017	0.555	0.0622	0.0018	665	10	682	64	665	10
7563-44.1	41	34	0.867	5	1	0.000010	0.000010	0.0002	0.2731	0.0130	1.0206	0.0529	0.1146	0.0033	0.647	0.0646	0.0026	699	19	762	86	698	19
7563-61.1	220	120	0.565	27	3	0.000030	0.000160	0.0005	0.1822	0.0079	1.0273	0.0493	0.1159	0.0023	0.522	0.0643	0.0027	707	13	750	90	706	13
7563-90.1	161	62	0.399	20	2	0.000102	0.000148	0.0018	0.1149	0.0080	1.0886	0.0459	0.1223	0.0016	0.419	0.0646	0.0025	744	9	760	84	743	9
7563-34.2	77	30	0.405	10	10	0.000415	0.000191	0.0072	0.1528	0.0105	1.3260	0.0734	0.1272	0.0031	0.550	0.0756	0.0035	772	18	1084	96	763	18
7563-13.1	441	299	0.700	61	7	0.000018	0.000023	0.0003	0.2052	0.0042	1.1812	0.0190	0.1281	0.0015	0.817	0.0669	0.0006	777	9	834	20	775	9
7563-12.1	245	239	1.007	37	-1	0.000083	0.000046	0.0015	0.3041	0.0076	1.1209	0.0228	0.1282	0.0016	0.686	0.0634	0.0010	778	9	722	32	779	9
7563-74.1	270	113	0.431	37	1	0.000096	0.000071	0.0017	0.1300	0.0103	1.1771	0.0343	0.1314	0.0019	0.600	0.0650	0.0015	796	11	773	50	796	11
7563-32.1	210	220	1.082	39	3	0.000040	0.000054	0.0007	0.3288	0.0046	1.5221	0.0605	0.1553	0.0024	0.496	0.0711	0.0025	930	13	960	73	929	14
7563-9.1	118	50	0.438	19	6	0.000304	0.000106	0.0053	0.1268	0.0055	1.5233	0.0564	0.1559	0.0033	0.665	0.0709	0.0020	934	18	954	58	933	18
7563-15.1	373	72	0.198	59	5	0.000051	0.000029	0.0009	0.0588	0.0022	1.6195	0.0313	0.1629	0.0022	0.773	0.0721	0.0009	973	12	989	25	972	12
7563-84.1	103	45	0.446	20	8	0.000493	0.000160	0.0085	0.1192	0.0264	1.9361	0.0788	0.1912	0.0026	0.441	0.0734	0.0027	1128	14	1026	76		
7563-40.1	84	65	0.800	19	1	0.000079	0.000101	0.0014	0.2436	0.0065	2.0982	0.0608	0.1949	0.0026	0.559	0.0781	0.0019	1148	14	1149	49		
7563-46.1	330	81	0.255	65	4	0.000079	0.000077	0.0014	0.0733	0.0033	2.1727	0.0473	0.1975	0.0025	0.677	0.0798	0.0013	1162	14	1192	32		
7563-22.1	54	74	1.404	14	2	0.000181	0.000153	0.0031	0.4239	0.0146	2.2591	0.0901	0.1997	0.0038	0.577	0.0820	0.0027	1174	20	1246	66		
7563-57.1	74	27	0.377	15	5	0.000426	0.000254	0.0074	0.1032	0.0106	2.1453	0.1536	0.2008	0.0062	0.536	0.0775	0.0047	1180	33	1134	126		
7563-41.1	33	22	0.702	8	0	0.000010	0.000010	0.0002	0.2174	0.0111	2.4010	0.0682	0.2059	0.0038	0.732	0.0846	0.0017	1207	20	1306	38		
7563-85.1	428	19	0.046	84	0	0.000006	0.000021	0.0001	0.0142	0.0011	2.3368	0.0319	0.2076	0.0023	0.881	0.0816	0.0005	1216	12	1237	13		
7563-21.1	161	121	0.774	42	0	0.000010	0.000010	0.0002	0.2369	0.0042	2.6860	0.0604	0.2284	0.0038	0.805	0.0853	0.0012	1326	20	1322	26		
7563-51.1	51	26	0.517	14	0	0.000010	0.000010	0.0002	0.1560	0.0043	3.0121	0.0618	0.2463	0.0034	0.757	0.0887	0.0012	1420	18	1397	26		
7563-20.1	66	55	0.861	22	1	0.000031	0.000119	0.0005	0.2446	0.0097	4.3212	0.1450	0.2905	0.0042	0.532	0.1079	0.0031	1644	21	1764	53		
7563-25.1	297	176	0.612	103	0	0.000001	0.000013	0.0000	0.1760	0.0021	5.0465	0.0915	0.3126	0.0047	0.884	0.1171	0.0010	1754	23	1912	15		
7563-1.1	101	61	0.624	35	1	0.000028	0.000042	0.0005	0.1780	0.0046	5.0550	0.1008	0.3135	0.0044	0.784	0.1169	0.0015	1758	22	1910	23		
7563-72.1	354	206	0.601	124	15	0.000157	0.000029	0.0027	0.1790	0.0019	4.9518	0.0681	0.3146	0.0036	0.892	0.1142	0.0007	1763	18	1867	11		
7563-75.1	282	173	0.636	105	1	0.000018	0.000022	0.0003	0.1816	0.0050	5.2827	0.0749	0.3349	0.0041	0.907	0.1144	0.0007	1862	20	1871	11		
7563-88.1	366	232	0.656	141	3	0.000025	0.000028	0.0004	0.1974	0.0019	5.4545	0.0955	0.3409	0.0041	0.760	0.1161	0.0013	1891	19	1896	21		
7563-55.1	73	31	0.435	27	4	0.000199	0.000136	0.0034	0.1262	0.0067	6.0838	0.1535	0.3481	0.0049	0.652	0.1268	0.0024	1925	23	2054	34		
7563-14.1	173	101	0.603	69	2	0.000044	0.000049	0.0008	0.1779	0.0028	6.1280	0.1107	0.3592	0.0040	0.705	0.1237	0.0016	1978	19	2011	23		
7563-18.1	221	169	0.790	94	1	0.000010	0.000010	0.0002	0.2178	0.0050	6.5513	0.1228	0.3666	0.0064	0.965	0.1296	0.0007	2013	30	2093	9		
7563-30.1	210	139	0.683	88	4	0.000058	0.000025	0.0010	0.1912	0.0022	6.5821	0.0860	0.3703	0.0041	0.900	0.1289	0.0007	2031	19	2083	10		
7563-50.1	117	175	1.546	59	2	0.000066	0.000044	0.0011	0.4367	0.0096	6.8284	0.1716	0.3760	0.0067	0.790	0.1317	0.0020	2058	32	2121	27		
7563-38.1	597	153	0.264	234	5	0.000027	0.000012	0.0005	0.0743	0.0014	6.7261	0.0876	0.3791	0.0047	0.971	0.1287	0.0004	2072	22	2080	6		
7563-3.1	170	97	0.590	74	3	0.000061	0.000050	0.0011	0.1666	0.0027	7.3936	0.1066	0.3886	0.0043	0.841	0.1380	0.0011	2116	20	2202	14		
7563-86.1	151	84	0.571	66	3	0.000057	0.000037	0.0010	0.1611	0.0030	7.4211	0.1177	0.3909	0.0051	0.883	0.1377	0.0010	2127	24	2198	13		
7563-78.1	477	240	0.519	267	2	0.000010	0.000010	0.0002	0.1324	0.0015	14.8766	0.3290	0.4800	0.0098	0.955	0.2248	0.0015	2527	43	3015	11		

Uncertainties reported at 1σ (absolute) and are calculated by numerical propagation of all known sources of error; f(206) ^{204} refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb-method; common Pb composition used is the surface blank; ^{1} 204-corrected ages; ^{2} 207-corrected ages (Stern 1997); * GSC grain mount IP295.

Table A7. U/Pb SHRIMP analytical data for the Oak Bay Formation (21G/3g -1)*.

									Isotopic ratios									Ages (Ma)					
Spot name	U (ppm)	Th (ppm)	Th/U	Pb (ppm)	^{204}Pb (ppb)	^{204}Pb/^{206}Pb	± ^{204}Pb/^{206}Pb	f(206)^{204}	^{208}Pb/^{206}Pb	± ^{208}Pb/^{206}Pb	^{207}Pb/^{235}U	± ^{207}Pb/^{235}U	^{206}Pb/^{238}U	± ^{206}Pb/^{238}U	Corr Coeff	^{207}Pb/^{206}Pb	± ^{207}Pb/^{206}Pb	^{206}Pb^{1}/^{238}U	± ^{206}Pb/^{238}U	^{207}Pb/^{206}Pb	± ^{207}Pb/^{206}Pb	^{206}Pb^{2}/^{238}U	± ^{206}Pb/^{238}U
Conglomerate (clasts and matrix)																							
3G1-32.1	58	49	0.877	5	16	0.003802	0.000380	0.0684	0.2713	0.0525	0.5671	0.0786	0.0785	0.0032	0.405	0.0524	0.0067	487	19	302	301	490	19
3G1-45.1	87	74	0.878	8	4	0.000716	0.001742	0.0129	0.2778	0.0688	0.7477	0.3166	0.0799	0.0055	0.282	0.0678	0.0278	496	33	864	864	489	29
3G1-49.1	134	155	1.200	13	25	0.002584	0.001058	0.0464	0.3715	0.0447	0.7015	0.2346	0.0816	0.0090	0.442	0.0623	0.0188	506	54	685	685	503	53
3G1-43.1	73	59	0.839	7	5	0.000970	0.000229	0.0174	0.2687	0.0111	0.7556	0.1322	0.0829	0.0104	0.791	0.0661	0.0071	514	62	809	244	508	61
3G1-52.1	95	82	0.893	9	4	0.000587	0.000408	0.0105	0.2930	0.0188	0.8294	0.0848	0.0843	0.0024	0.389	0.0714	0.0068	522	14	968	207	513	13
3G1-7.1	65	55	0.877	6	5	0.001126	0.000342	0.0202	0.2588	0.0145	0.7051	0.0668	0.0850	0.0015	0.302	0.0602	0.0055	526	9	609	210	524	8
3G1-20.1	388	239	0.636	36	4	0.000154	0.000040	0.0028	0.2004	0.0037	0.6961	0.0294	0.0852	0.0032	0.929	0.0592	0.0009	527	19	576	35	526	19
3G1-3.1	58	55	0.975	6	4	0.000851	0.000572	0.0153	0.2931	0.0233	0.6907	0.1141	0.0859	0.0035	0.362	0.0583	0.0091	531	21	541	381	531	20
3G1-23.1	68	62	0.952	7	8	0.001486	0.000336	0.0266	0.2459	0.0208	0.7062	0.0821	0.0865	0.0042	0.526	0.0593	0.0059	535	25	576	233	534	25
3G1-15.1	71	76	1.102	7	7	0.001349	0.000123	0.0242	0.3260	0.0169	0.6730	0.0453	0.0866	0.0014	0.364	0.0564	0.0036	535	9	467	147	536	9
3G1-58.1	139	164	1.220	15	5	0.000454	0.000122	0.0081	0.3671	0.0254	0.7442	0.0361	0.0879	0.0019	0.560	0.0614	0.0025	543	12	654	89	541	11
3G1-100.1	70	48	0.714	7	9	0.001710	0.000592	0.0306	0.2349	0.0255	0.6557	0.1219	0.0883	0.0037	0.340	0.0539	0.0095	545	22	366	366	548	21
3G1-76.1	149	137	0.952	16	3	0.000307	0.000149	0.0055	0.3147	0.0138	0.7726	0.0548	0.0887	0.0045	0.790	0.0632	0.0028	548	27	715	96	545	26
3G1-5.1	65	48	0.773	6	3	0.000660	0.000271	0.0118	0.2387	0.0182	0.6746	0.0654	0.0888	0.0028	0.434	0.0551	0.0049	548	16	417	210	550	16
3G1-6.1	125	139	1.155	14	1	0.000108	0.000170	0.0019	0.3654	0.0110	0.7880	0.0500	0.0892	0.0029	0.609	0.0641	0.0033	551	17	744	111	547	17
3G1-18.1	51	47	0.934	5	6	0.001511	0.000582	0.0270	0.3134	0.0306	0.6403	0.1345	0.0896	0.0062	0.441	0.0518	0.0098	553	37	277	385	558	37
3G1-11.1	67	73	1.125	7	5	0.000881	0.000266	0.0158	0.2986	0.0229	0.6431	0.0609	0.0899	0.0036	0.524	0.0519	0.0042	555	21	280	198	559	21
3G1-66.1	91	86	0.980	9	10	0.001394	0.000201	0.0249	0.2767	0.0115	0.6144	0.0932	0.0900	0.0060	0.547	0.0495	0.0063	555	36	173	274	561	36
3G1-60.1	65	56	0.893	7	7	0.001406	0.000034	0.0251	0.2934	0.0156	0.7453	0.0763	0.0901	0.0089	0.987	0.0600	0.0010	556	53	604	36	555	53
3G1-57.1	51	43	0.867	5	4	0.000987	0.000227	0.0176	0.2865	0.0141	0.7504	0.0798	0.0905	0.0025	0.379	0.0601	0.0060	558	15	608	230	558	15
3G1-70.1	97	108	1.152	11	6	0.000733	0.001048	0.0131	0.3753	0.0405	0.7738	0.2129	0.0906	0.0033	0.254	0.0620	0.0166	559	19	673	673	557	17
3G1-33.1	71	60	0.871	7	5	0.000974	0.000347	0.0174	0.2518	0.0141	0.7883	0.0830	0.0906	0.0031	0.438	0.0631	0.0060	559	18	712	217	556	18
3G1-24.1	69	58	0.869	7	2	0.000363	0.000219	0.0065	0.2895	0.0147	0.7705	0.0670	0.0913	0.0029	0.476	0.0612	0.0047	563	17	646	175	562	17
3G1-34.1	123	148	1.240	14	5	0.000480	0.000077	0.0086	0.3843	0.0107	0.7745	0.0651	0.0916	0.0072	0.964	0.0613	0.0014	565	42	650	49	563	42
3G1-29.1	75	63	0.874	8	3	0.000496	0.000435	0.0089	0.3089	0.0184	0.7754	0.0988	0.0917	0.0039	0.447	0.0614	0.0071	565	23	652	268	564	23
3G1-28.1	83	72	0.893	9	4	0.000565	0.000216	0.0101	0.2931	0.0146	0.7695	0.0545	0.0923	0.0024	0.478	0.0605	0.0038	569	14	620	141	568	14
3G1-1.1	58	47	0.841	6	0	0.000010	0.000291	0.0002	0.2725	0.0198	0.8429	0.0730	0.0925	0.0037	0.561	0.0661	0.0048	570	22	809	159	566	21
3G1-96.1	78	89	1.186	9	0	0.000039	0.000316	0.0007	0.4052	0.0148	0.8390	0.0888	0.0925	0.0044	0.553	0.0658	0.0059	571	26	799	198	566	26
3G1-8.1	50	45	0.926	5	4	0.001052	0.000136	0.0188	0.2765	0.0103	0.7439	0.0735	0.0928	0.0040	0.542	0.0582	0.0049	572	24	536	194	572	24
3G1-73.1	86	61	0.737	9	6	0.000867	0.000075	0.0155	0.2113	0.0124	0.7272	0.0481	0.0934	0.0055	0.931	0.0565	0.0014	576	32	471	55	578	32
3G1-37.1	163	104	0.658	17	5	0.000400	0.000221	0.0071	0.1993	0.0095	0.7496	0.0614	0.0935	0.0025	0.442	0.0581	0.0043	576	15	535	171	577	15
3G1-2.1	65	54	0.855	7	3	0.000595	0.000841	0.0106	0.2630	0.0323	0.7416	0.1833	0.0936	0.0043	0.304	0.0575	0.0136	577	25	510	510	578	24
3G1-39.1	95	119	1.292	11	8	0.000993	0.000469	0.0177	0.4098	0.0251	0.8018	0.1131	0.0939	0.0033	0.365	0.0619	0.0082	579	19	672	312	577	19
3G1-36.1	70	74	1.089	8	7	0.001148	0.000093	0.0205	0.3313	0.0120	0.6931	0.0454	0.0941	0.0048	0.845	0.0534	0.0019	580	28	346	82	584	29
3G1-4.1	222	137	0.636	23	2	0.000127	0.000093	0.0023	0.2061	0.0097	0.8060	0.0379	0.0949	0.0027	0.697	0.0616	0.0021	584	16	661	74	583	16
3G1-55.1	66	57	0.884	7	3	0.000613	0.000046	0.0109	0.2920	0.0062	0.8224	0.0398	0.0957	0.0035	0.820	0.0623	0.0017	589	20	685	61	587	20
3G1-92.1	89	97	1.123	10	7	0.000960	0.000174	0.0171	0.3422	0.0161	0.7769	0.0511	0.0977	0.0037	0.674	0.0577	0.0028	601	22	517	111	603	22
3G1-65.1	81	70	0.893	10	4	0.000557	0.000273	0.0099	0.3021	0.0339	1.0704	0.1722	0.1004	0.0046	0.399	0.0773	0.0115	617	27	1129	329	605	27
3G1-51.1	208	172	0.857	24	3	0.000139	0.000054	0.0025	0.2751	0.0026	0.8223	0.0251	0.1010	0.0016	0.610	0.0591	0.0014	620	9	570	54	621	9
3G1-27.1	214	157	0.757	25	5	0.000287	0.000476	0.0051	0.2350	0.0186	0.8740	0.1230	0.1027	0.0037	0.373	0.0617	0.0081	630	22	664	310	630	21
3G1-81.1	644	665	1.067	86	6	0.000095	0.000009	0.0017	0.3433	0.0094	0.9273	0.0482	0.1098	0.0056	0.992	0.0612	0.0004	672	32	648	14	672	33
3G1-14.1	264	180	0.704	33	3	0.000101	0.000168	0.0018	0.2229	0.0075	0.9953	0.0517	0.1115	0.0027	0.563	0.0648	0.0028	681	15	767	94	679	15
3G1-90.1	585	171	0.303	67	13	0.000232	0.000065	0.0041	0.0926	0.0079	0.9867	0.0703	0.1154	0.0075	0.955	0.0620	0.0013	704	44	675	46	705	44
3G1-12.1	956	298	0.322	179	4	0.000028	0.000008	0.0005	0.0999	0.0014	1.9475	0.0261	0.1855	0.0023	0.947	0.0762	0.0003	1097	12	1099	9		
3G1-59.1	192	61	0.326	39	6	0.000184	0.000030	0.0031	0.1020	0.0020	2.2195	0.0664	0.2005	0.0055	0.953	0.0803	0.0007	1178	30	1204	18		
3G1-19.1	257	84	0.335	73	4	0.000064	0.000021	0.0010	0.0994	0.0031	3.6836	0.1044	0.2755	0.0073	0.965	0.0970	0.0007	1568	37	1567	14		
Granitoid cobble																							
3GB2-17.1	309	306	1.023	34	6	0.000245	0.000045	0.0044	0.3157	0.0033	0.7267	0.0229	0.0922	0.0021	0.795	0.0572	0.0011	569	12	497	43	570	12
3GB2-13.1	129	92	0.736	13	9	0.000847	0.000799	0.0151	0.2291	0.0319	0.7535	0.1671	0.0909	0.0039	0.314	0.0601	0.0128	561	23	608	540	560	22
3GB2-23.1	284	283	1.029	31	6	0.000279	0.000063	0.0050	0.3243	0.0054	0.7429	0.0257	0.0918	0.0018	0.662	0.0587	0.0015	566	11	556	58	566	11
3GB2-24.1	193	135	0.722	18	10	0.000659	0.000086	0.0118	0.2255	0.0068	0.6965	0.0360	0.0866	0.0019	0.532	0.0583	0.0026	535	11	542	100	535	11
3GB2-28.1	294	226	0.795	28	7	0.000325	0.000108	0.0058	0.2508	0.0052	0.6873	0.0275	0.0857	0.0015	0.554	0.0582	0.0020	530	9	537	75	530	9
3GB2-39.1	179	133	0.767	16	5	0.000432	0.000143	0.0078	0.2445	0.0101	0.6717	0.0500	0.0816	0.0048	0.851	0.0597	0.0024	506	28	592	88	504	28
3GB2-35.1	369	310	0.870	34	7	0.000273	0.000031	0.0049	0.2817	0.0033	0.6605	0.0237	0.0809	0.0027	0.956	0.0592	0.0006	501	16	575	23	500	16
3GB2-45.1	428	353	0.852	42	14	0.000430	0.000061	0.0077	0.2759	0.0221	0.7099	0.0439	0.0854	0.0045	0.899	0.0603	0.0017	528	27	615	60	527	26

Uncertainties reported at 1 σ (absolute) and are calculated by numerical propagation of all known sources of error; f(206) ^{204} refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb-method; common Pb composition used is the surface blank; [1] 204-corrected ages; [2] 207-corrected ages (Stern 1997); * Zircon standard used on grain mount is SL13 (Age = 563 Ma). The external uncertainties associated with the calibration of the mount is 1.10%.