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# SYNACCRETIONARY SEDIMENTARY AND VOLCANIC ROCKS IN THE ORDOVICIAN TETAGOUCHE BACKARC BASIN, NEW BRUNSWICK, CANADA: EVIDENCE FOR A TRANSITION FROM FOREDEEP TO FOREARC BASIN SEDIMENTATION

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**ABSTRACT. Development of an Upper Ordovician to lower Silurian (Llandovery) accretionary wedge (Brunswick subduction complex) along the composite Laurentian margin accompanied subduction of the Tetagouche backarc basin and coincided with synaccretionary sedimentation in the Bathurst and Fournier supergroups in northern New Brunswick. These dominantly turbiditic synaccretionary units conformably to unconformably overlie Upper Ordovician pelagic shale and chert in the upper stratigraphic levels of several of the nappes that compose the imbricate thrust stack of the subduction complex. Local occurrences of tectonic mélange at the contacts between the turbidites and their pelagic substrate are consistent with deposition of at least some of the former during thrust-related deformation in the accretionary wedge. Detrital zircon data indicate maximum depositional ages ranging from 454 ± 3 to 459 ± 8 Ma, coeval with initiation of subduction of the Tetagouche backarc basin. In the Elmtree inlier, arc tholeiitic basalt disconformably or unconformably overlies Darriwilian MORB-type pillowed flows that constitute backarc oceanic crust of the Tetagouche basin. Sedimentary rocks immediately below and intercalated with the arc tholeiites contain detrital zircons ranging from 444 ± 6 Ma to 455 ± 10 Ma, suggesting that the tholeiites are related to backarc subduction.**

**Detrital zircon age spectra from all sampled units exhibit a distinct Laurentian signature, indicating an abrupt change in provenance coeval with closure of the backarc basin and Ganderia – Laurentia collision. The lithology and implied ages of the Bathurst and Fournier synaccretionary sedimentary rocks support a correlation with siliciclastic and carbonate-rich turbidites of the Matapedia cover sequence, which were deposited farther west in a forearc setting (Matapedia forearc) with respect to subduction of Tetagouche backarc oceanic lithosphere. The implication of Late Ordovician influx onto the accretionary wedge and foredeep of sediments having a Laurentian affiliation (like those in the Matapedia forearc), demonstrates trenchward migration of forearc sedimentation between *ca.* 450 and 430 Ma. This southeastward (present coordinates) expansion occurred in concert with episodic accretion of buoyant crustal blocks that populated the Tetagouche – Exploits basin, and concomitant southeastward step-back of the subduction zone.**

Key words: synaccretionary, detrital zircon, Popelogan arc, Tetagouche backarc, Matapedia forearc, Brunswick subduction complex, Bathurst Supergroup, Fournier Supergroup, Ganderia, Salinic orogeny, turbidites

## INTRODUCTION

The Early Paleozoic evolution of the northern Appalachians records the opening and closing of the Iapetus ocean between the opposing Laurentian and Gondwanan margins (van Staal and others, 1998, 2009). Coincident with closure, a series of oceanic and continental arcs, back-arcs and microcontinents successively collided with Laurentia

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and resulted in episodic, Early Ordovician to Early Devonian orogenesis, the locus of which shifted progressively southeastward (present coordinates) over time. One of the accreted continental blocks was Ganderia, which rifted from the Amazonian margin of Gondwana at *ca.* 505 Ma (van Staal and others, 1996, 2009, 2012). Southeast-directed subduction of Iapetan oceanic crust along Ganderia's leading edge led to successive construction of the Penobscot (*ca.* 515–480 Ma) and Popelogan (*ca.* 478–453 Ma) arcs and formation of backarc basins (van Staal and others, 2009; Zagorevski and others, 2010; Fyffe and others, 2011). The Tetagouche backarc basin developed in the Middle to Late Ordovician by extension of Ganderian continental crust and rifting of the Popelogan arc. Volcanic and sedimentary rocks associated with extension and rifting of the Popelogan arc, and spreading in the Tetagouche backarc basin, are assigned, respectively, to the Bathurst and Fournier supergroups in the Miramichi and Elmtree inliers of northern New Brunswick (fig. 1). In New Brunswick, pre-backarc rifting volcanic rocks of the Popelogan arc (Meductic Group) are preserved in the Woodstock area, whereas post-rifting arc volcanism is represented by the Balmoral Group, mainly in the Popelogan inlier (fig. 1).

The evolution of the Popelogan arc, from its Early Ordovician origins to its collision with composite Laurentia (that is, the Notre Dame belt; fig. 1) in the Late Ordovician (*ca.* 450–455 Ma) has been described by van Staal and others (1998, 2003, 2009, 2016). The collision of the composite Laurentian margin and the leading peri-Gondwanan element (the Ganderian Popelogan arc) marks the end of the Taconic orogenic cycle. Continued convergence of Ganderia was accommodated by a subduction polarity reversal and northwest-directed subduction of Tetagouche backarc lithosphere beneath composite Laurentia between the Late Ordovician and middle Silurian (*ca.* 450–430 Ma; van Staal, 1987, 1994). (Note that, in this paper, 'early' and 'lower' Silurian refer to the Llandoverian epoch/series, and 'middle' Silurian to the Wenlockian epoch/series). Subduction of Tetagouche backarc crust was accompanied by development of an accretionary wedge (Brunswick subduction complex) comprising a series of stacked thrust nappes that encompass all rocks of the Fournier and Bathurst supergroups. Deformation of the accretionary wedge marks the beginning of the Salinic orogenic cycle, which culminated in Ganderia − Laurentia collision at *ca.* 430 Ma with entry of the buoyant Gander margin into the subduction zone. Evolution of the Brunswick subduction complex, including temperature-pressure pathways, formation of a distinctive belt of blueschist, timing of nappe emplacement, and evidence for its structural exhumation and erosion, has been described by van Staal and others (1990, 2001, 2003, 2008, 2009).

Middle Ordovician volcanic units of the Fournier and Bathurst supergroups are overlain by Upper Ordovician deep marine sedimentary rocks, consisting mainly of varicolored chert and overlying dark gray to black shale. This pelagic – hemipelagic blanket is regionally widespread within Ganderia and can be traced from Newfoundland into New England (fig. 1); it records true oceanic conditions, distinguished by a lack of clastic input, in the Tetagouche backarc basin immediately prior to and following initiation of northwest-directed subduction at *ca.* 450 Ma. In spite of the submarine conditions that must have continued to prevail as the subduction complex evolved between the Late Ordovician (*ca.* late Katian) and early Wenlockian, sedimentary rocks overlying early to mid Katian shale and chert have been very poorly documented or simply unrecognized as distinct units, with the exception of the Tomogonops Formation (Langton, 1993).

This paper describes three newly-recognized belts of clastic, dominantly turbiditic sedimentary rocks in the Bathurst and Fournier supergroups; these units, along with the Tomogonops Formation, each constitute the youngest rocks in the local stratigraphic succession in which they occur. All four units conformably to unconformably

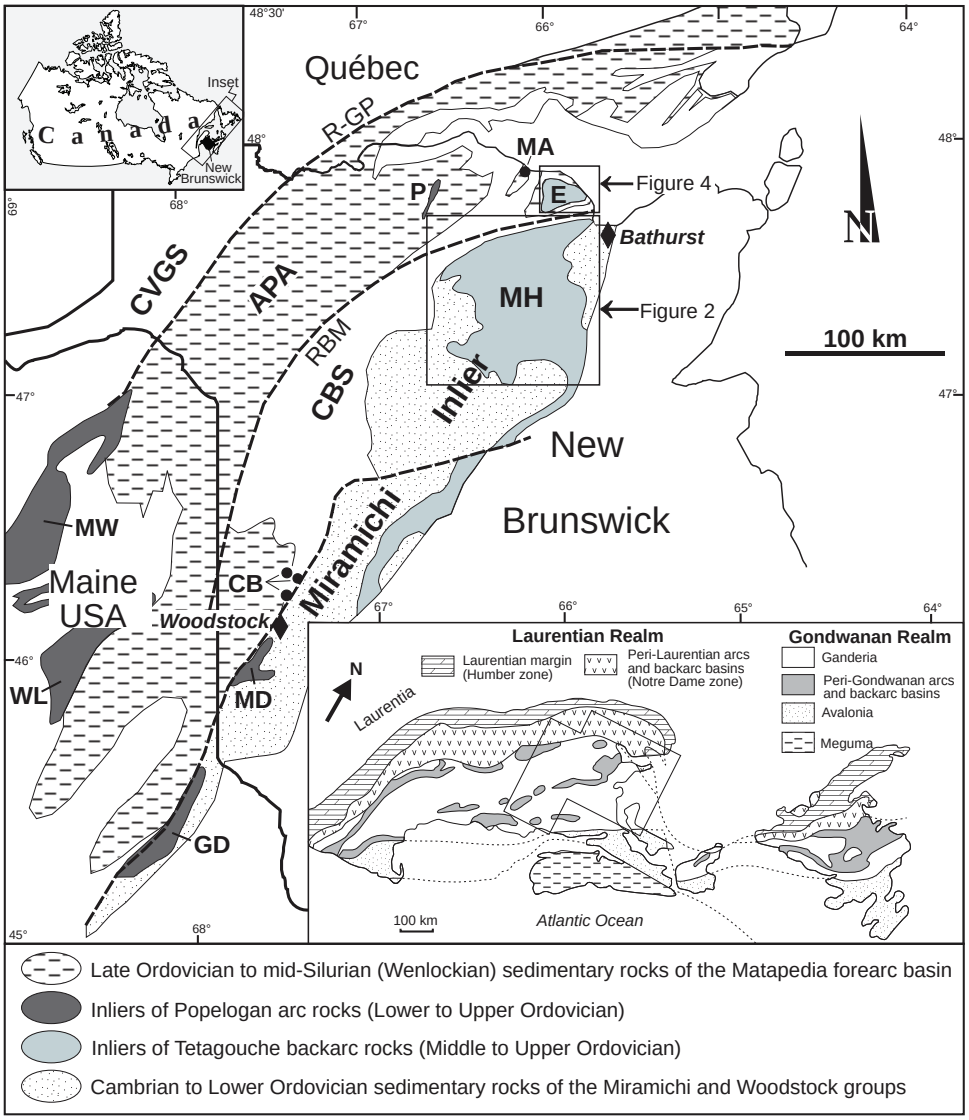


Fig. 1. Location map showing the major geological elements of northwestern New Brunswick. The Matapedia cover sequence comprises three zones (after Rodgers, 1970): CVGS: Connecticut Valley – Gaspé Synclinorium; APA: Aroostook – Percé Anticlinorium; and CBS: Chaleur Bay Synclinorium. Sedimentary rocks of the Matapedia forearc basin (dashed pattern) are restricted to the Aroostook – Percé zone. Volcanic and sedimentary rocks of the Tetagouche backarc basin are exposed in the Miramichi Highlands (MH) and Elmtree inlier (E), whereas dominantly volcanic rocks of the Popelogan arc are exposed in the Popelogan (P), Meductic (MD), Weeksboro – Lunksoos (WL) and Munsungan – Winterville (MW) inliers, below the Matapedia cover rocks. CB: small inliers of the Middle Ordovician Craig Brook Formation; MA: small inlier of Matapedia forearc rocks; RBM: Rocky Brook – Millstream Fault; R-GP: Restigouche – Grand Pabos Fault. Inset: Lithotectonic divisions of the northern Appalachians, after Hibbard and others (2006).

overlie and are locally in tectonic contact with older rocks of the Bathurst and Fournier supergroups, although all have also been incorporated, to some extent, in the Brunswick subduction complex because they are at least locally deformed by $D_1$ (van Staal and others, 2001). We report detrital zircon data that support syntectonic

deposition of these rocks during progressive deformation in the Brunswick subduction complex, and a linkage with coeval, Laurentia-derived sedimentary rocks of the Matapedia basin, situated farther west (fig. 1) in the forearc region with respect to subduction of Tetagouche backarc crust. We show that these lithological and detrital zircon data signal an abrupt Late Ordovician influx of siliciclastic sediment onto the accretionary wedge and adjacent foredeep; these siliciclastic sedimentary rocks display a Laurentian provenance, demonstrating trenchward migration of forearc sedimentation. In addition, detrital zircon data from sedimentary rocks that underlie and intercalate with arc-related tholeiitic basalt in the Elmtree inlier (fig. 1) are presented in support of an unconformable relationship with underlying, Middle Ordovician ophiolitic rocks of the Devereaux Complex, supporting a genetic link with subduction of Tetagouche backarc oceanic lithosphere.

## REGIONAL SETTING

### *Backarc Extension and Spreading: Bathurst and Fournier Supergroups*

Tetagouche backarc crust comprises two distinct domains associated with progressive crustal extension and arc rifting: the Bathurst Supergroup represents the products of crustal extension and rifting of the Popelogan arc (continental domain), whereas the Fournier Supergroup represents the phase of oceanic lithosphere formation (oceanic domain). Each comprises three major thrust nappes that contain coeval, north-younging successions of volcanic and sedimentary rock. The Bathurst Supergroup consists of Floian to Katian volcanic and sedimentary rocks deposited during rifting and dismemberment of Ganderian continental crust, contemporaneous with Popelogan arc volcanism. The three major tectonostratigraphic subdivisions of the Bathurst Supergroup are, from structural top to bottom, the California Lake, Tetagouche and Sheephouse Brook groups (figs. 2 and 3). Each of these tectonostratigraphic units comprises late Floian – Darriwilian, dominantly felsic volcanic rocks, overlain by late Darriwilian – *ca.* mid Katian alkalic and mid-ocean ridge (MORB)-like basalt and deep marine sedimentary rocks (chert and shale) that are assigned to the Boucher Brook Formation (California Lake Group), Little River Formation (Tetagouche Group) and Slacks Lake Formation (Sheephouse Brook Group). The Boucher Brook Formation (California Lake Group) is locally overlain by siliciclastic turbidites of the Middle River Formation (new name), whereas the Little River Formation is overlain in the southeastern part of the Tetagouche Group by siliciclastic turbidites of the Tomogonops Formation and in the northern part by mixed calcareous and siliciclastic turbidites of the Melanson Brook Formation (new name) (figs. 2 and 3).

The newly erected, Darriwilian – Katian Fournier Supergroup (van Staal and Wilson, 2014) consists, from structurally highest to lowest, of the Devereaux (ophiolitic) Complex, the Pointe Verte Group, and Sormany Group (figs. 3 and 4). The tectonic contact between the Devereaux Complex and Pointe Verte Group is marked by a thin zone of mélange (fig. 5) that is locally structurally truncated, whereas the Pointe Verte and Sormany groups are juxtaposed along a thick and extensive belt of mélange (Belledune River Mélange; figs. 3 and 4). The Devereaux Complex comprises, in ascending order, the Black Point Gabbro (including minor pyroxenite and trondhjemite), the Belledune Point sheeted dikes, and pillow basalt of the Turgeon Road Formation. The Pointe Verte Group consists of the Prairie Brook Formation (a generally fining-upward succession of sedimentary rocks) and overlying Madran Formation (high-Cr alkalic pillow basalt). The Sormany Group is composed of the Armstrong Brook Formation (pillow basalt) and Millstream Formation (turbiditic wacke, fine-grained sedimentary rocks and limestone) in the northern part of the Miramichi inlier (figs. 2 and 3), and the Elmtree Formation (fine-grained sedimentary rocks) in the Elmtree inlier (figs. 3 and 4). Along the northern margin of the

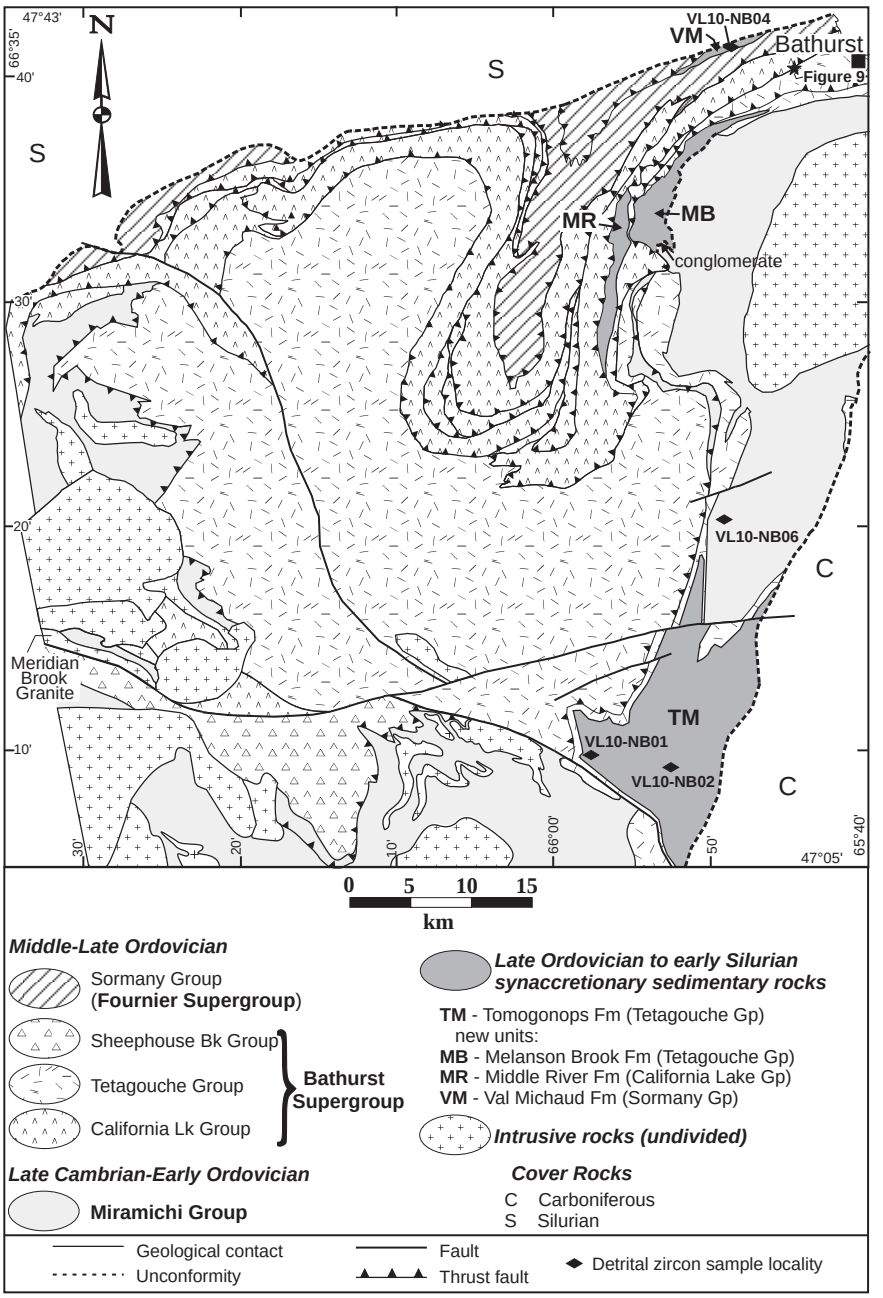


Fig. 2. Geological map of the Miramichi Highlands showing the distribution of major tectonostratigraphic elements (groups), the synaccretionary units discussed in this paper, and the location of samples collected for detrital zircon analysis. See figure 1 for location.

Miramichi inlier, the Millstream Formation is locally overlain by quartzofeldspathic sedimentary rocks of the Val Michaud Formation (new name; figs. 2 and 3). The Elmtree Formation, although consisting mainly of dark gray to black shale and

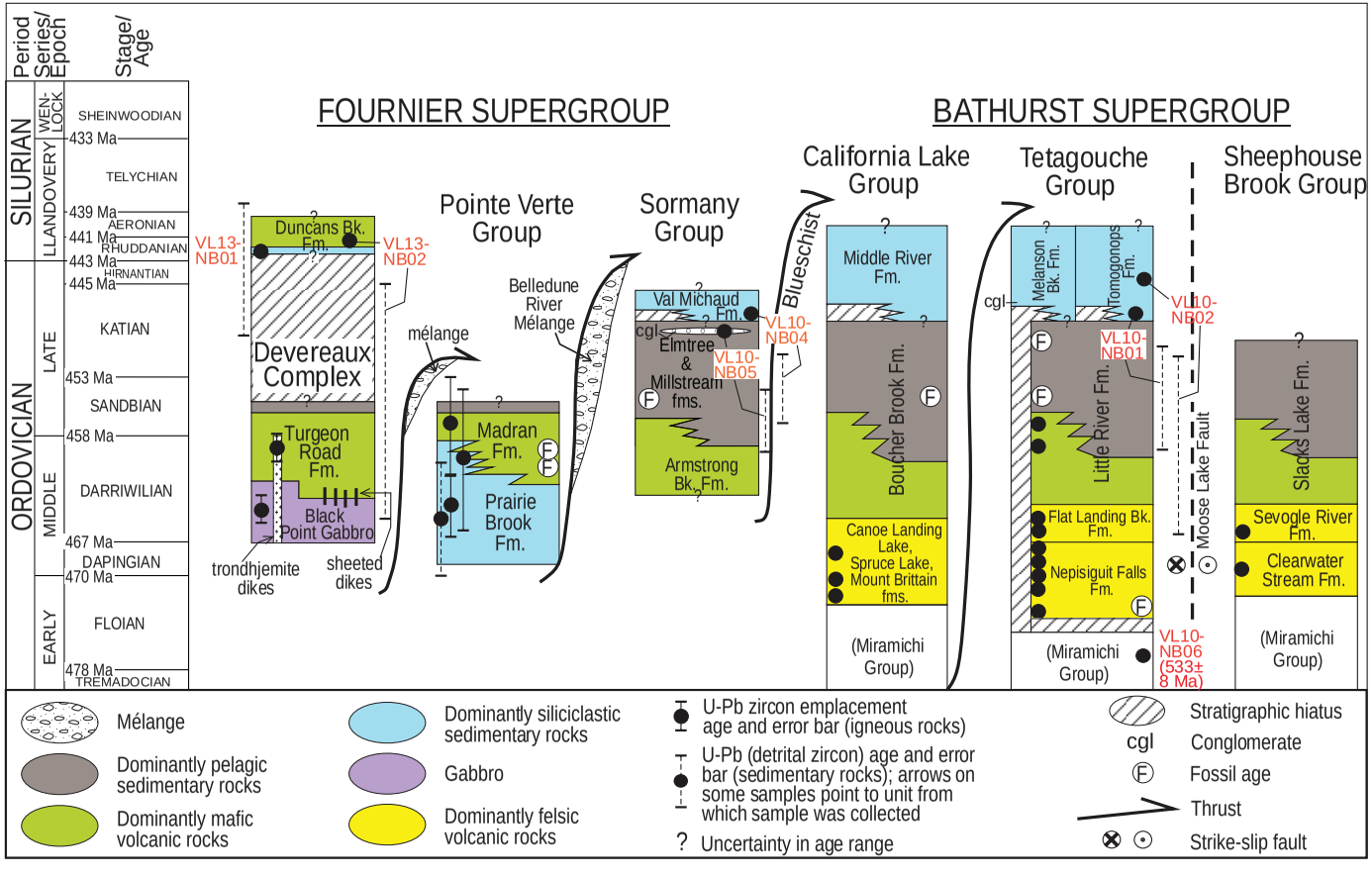


Fig. 3. Stratigraphic columns showing the tectonostratigraphic relationships between the various groups/nappes composing the Bathurst and Fournier supergroups. Detrital zircon sample numbers are shown in red font, and the age range of interpreted youngest populations are plotted as dashed lines beside the columns (see also figs. 13 and 14).

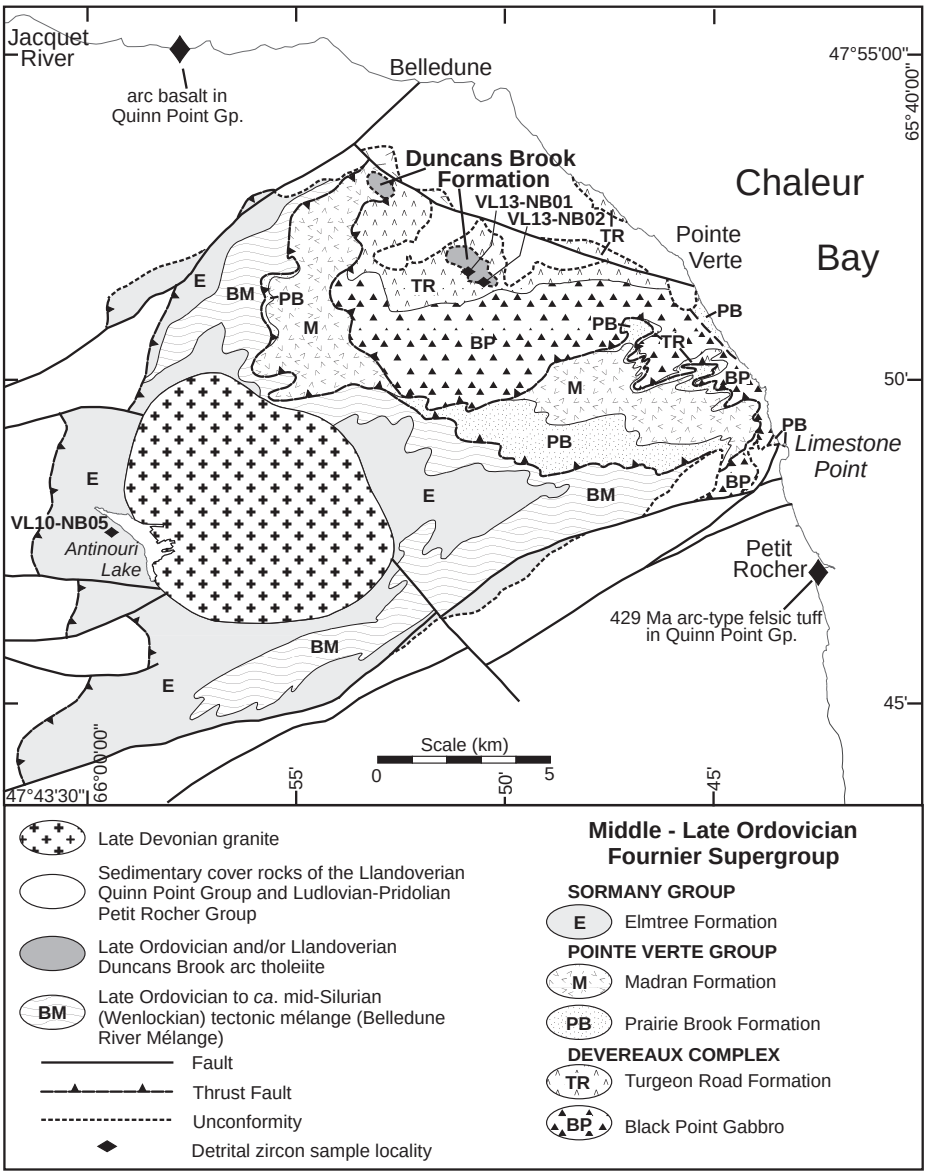


Fig. 4. Geological map of the Fournier Supergroup in the Elmtree inlier, showing location of samples collected for detrital zircon analysis, and subduction-related, Llandoverian – Wenlockian volcanic rocks of the Quinn Point Group (Wilson and others, 2008). See figure 1 for location.

siltstone, is locally (west of Antinouri Lake; fig. 4) dominated by quartzose wacke containing minor pebbly conglomerate. Poor exposure prevents an understanding of the field relationship of these rocks to the dominant pelagic shale, hence a sample was collected for detrital zircon analysis to confirm a suspected younger age (see below).

Also in the Elmtree inlier, an areally restricted unit recognized by Winchester and others (1992) and referred to by them as the Duncans Brook arc tholeiite (figs. 3 and 4), is herein assigned formation status. The Duncans Brook Formation is spatially

Fig. 5. Tectonic mélange at the contact between the Devereaux Complex and Pointe Verte Group, Fournier Supergroup. The length of the hammer here and in subsequent photos is 40 cm.

associated with MORB-like basalt of the underlying Turgeon Road Formation, but its relationship with the Turgeon Road remained enigmatic until the recent discovery of a thin unit of quartz-rich sandstone and minor conglomerate between the two units, implying an unconformable relationship.

*Forearc Sedimentation: The Matapedia Cover Sequence*

The stratigraphic framework and evolution of the Matapedia cover sequence (MCS) in northern New Brunswick has been described by Wilson and others (2004). The MCS developed following the late Taconic collision of the Popelogan arc with Laurentia, and locally oversteps deformed Cambrian to Middle Ordovician rocks of the Humber and Notre Dame zones to the west, and Ganderia to the east (Malo and Bourque, 1993; van Staal and de Roo, 1995; fig. 1). Popelogan arc − Laurentia collision is recorded in western New Brunswick by an unconformity between the Middle Ordovician Craig Brook Formation (fig. 1) and Upper Ordovician rocks of the MCS (St. Peter, 1982; Fyffe and others, 2011), and in northern New Brunswick by a Late Ordovician disconformity between the MCS and underlying Darriwilian arc basalt and Sandbian chert of the Balmoral Group (Wilson, 2003; Wilson and others, 2004; fig. 1). Evidence that the Popelogan arc constitutes the substrate to the MCS consists of several major inliers of pre-Late Ordovician volcanic and sedimentary rocks in Maine, New Brunswick and the Gaspé Peninsula (van Staal and others, 2016) (fig. 1). In New Brunswick, the Notre Dame – Ganderia zone contact, corresponding to the Laurentia – Ganderia suture (Red Indian Line) is believed to occur at or near the trace of the Restigouche – Grand Pabos Fault (fig. 1), although the actual boundary is obscured by the cover rocks (Dupuis and others, 2009).

Post-Taconic closure of the Tetagouche backarc basin was achieved by northwest-directed subduction beneath the composite Laurentian margin, beginning *ca.* late Katian and terminating by early to middle Wenlockian (van Staal, 1994; van Staal and others, 2001, 2003, 2009). Arc magmatic activity related to Tetagouche backarc subduction is poorly represented in the northern Appalachians but includes Upper Ordovician to Llandoverian volcanic rocks of the Quimby Formation in the Bronson Hill anticlinorium of New England (Tucker and Robinson, 1990; Moench and Aleinikoff, 2002), Llandoverian intrusive and volcanic rocks in western Newfoundland (Whalen, 1989; Whalen and others, 2006), Llandoverian volcanic and volcaniclastic

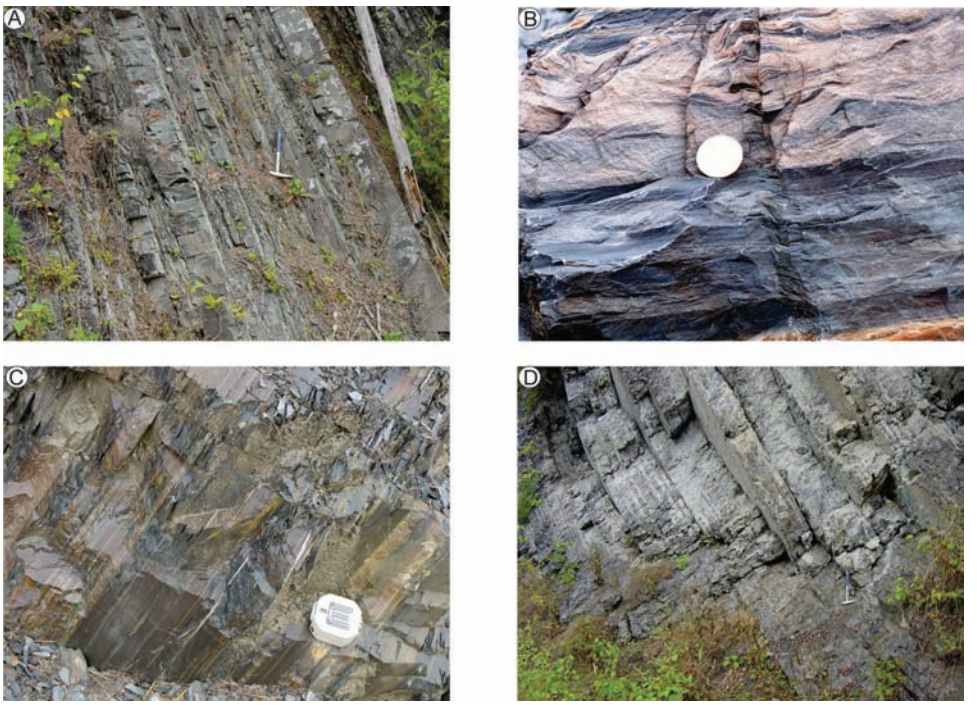


Fig. 6. (A) Interbedded fine-grained sandstone turbidites and mudstone hemipelagic deposits from the Boland Brook Formation (Grog Brook Group). (B) Parallel- and cross-laminated sandstone turbidite from the Whites Brook Formation (Grog Brook Group). Coin is 2.5 cm in diameter. (C) Thinly interbedded calcareous siltstone and calcilutite from the Pabos Formation (Matapedia Group). Compass is roughly 7 × 7 cm. (D) Thin-bedded calcilutite from the White Head Formation (Matapedia Group).

rocks of the Pointe aux Trembles and Lac Raymond formations in the western Gaspé Peninsula (David and Gariépy, 1990), and minor Llandoverian to Wenlockian volcanic rocks of the Quinn Point Group in northeastern New Brunswick (Wilson and others, 2008; fig. 4). Because these magmatic rocks were dominantly emplaced in the orogenic hinterland farther west, Late Ordovician to Wenlockian sedimentary rocks of the MCS were deposited in the arc-trench gap (that is, a forearc setting) with respect to Tetagouche backarc subduction (van Staal and de Roo, 1995; Wilson and others, 2008).

Sedimentary rocks of the Matapedia forearc are preserved in the central belt of the MCS, namely the Aroostook – Percé Anticlinorium (fig. 1). The forearc succession comprises Upper Ordovician to Llandoverian − Wenlockian turbidites, including (from base to top) a mid-late Katian siliciclastic assemblage (Grog Brook Group; figs. 6A and 6B), a Hirnantian to *ca.* late Aeronian deep-water carbonate mudstone assemblage (Matapedia Group; figs. 6C and 6D), and Aeronian to Telychian thin-bedded turbidites of the Quinn Point Group; together, these units represent a shallowing-upward, basin-fill succession that culminated with deposition of Telychian – Sheinwoodian shallow marine carbonates (Wilson and others, 2004). The latter are followed by a mid-Silurian hiatus (Salinic unconformity) recording uplift associated with the collision of the Popelogan arc (and its Ganderian substrate) with Laurentia (Wilson and Kamo, 2012; van Staal and others, 2016). Rocks of the MCS are correlated with Upper Ordovician to Silurian turbidites (graywacke, sandstone, shale and conglomerate) of the Badger Group in Newfoundland, which conformably overlie Katian black

shale of the Lawrence Harbour Formation (Williams and others, 1995; O'Brien, 2003; Waldron and others, 2012).

### SYNACCRETIONARY SEDIMENTARY ROCKS OF THE BRUNSWICK SUBDUCTION COMPLEX

In the eastern and northern parts of the Miramichi Highlands (figs. 1 and 2), rocks that are lithologically similar to some of those that make up the forearc succession (Grog Brook and Matapedia groups) in the MCS are assigned to four formations, including three that are newly introduced herein. In the southeastern and northeastern parts of the Tetagouche Group, respectively, the Tomogonops Formation conformably to unconformably overlies and is locally in tectonic contact with the Little River Formation, and the Melanson Brook Formation conformably(?) to unconformably overlies the Little River Formation and unconformably overlies the Cambrian to Early Ordovician Miramichi Group (fig. 2). In the California Lake Group, the Middle River Formation overlies and is locally tectonically juxtaposed against the Boucher Brook Formation. In the Sormany Group, the Val Michaud Formation is locally in tectonic contact with the Millstream Formation, but elsewhere the nature of the contact is unclear. All these units are unfossiliferous (processing of numerous rock samples shows that microfossils are also absent), which may explain why lithological differences between them and underlying Sandbian – Katian pelagic shale were largely unappreciated in the past. However, several other criteria serve to distinguish these unfossiliferous rocks from the pelagic shale, including: 1) their dominantly quartzose or quartzofeldspathic composition; 2) their lighter color and coarser grain size; 3) their well-developed sedimentary structures and bedforms compared to the underlying rocks, in which such features are rare to absent; and 4) the calcareous nature of some units, especially the Melanson Brook Formation and parts of the Tomogonops Formation.

#### *Tomogonops Formation (Tetagouche Group)*

The name 'Tomogonops Formation' (fig. 2) was introduced by Langton (1993), although Dawson (1961) first recognized these rocks as a distinct mappable unit and placed them at the top of his Tetagouche Group. Similarly, Irrinki (1971) mapped "feldspathic and lithic graywackes, and locally calcareous laminated slate and phyllite" that he regarded as the upper part of the Tetagouche Group in this area. The Tomogonops Formation is lithologically diverse, but mainly consists of light to medium gray or greenish gray, fine- to medium-grained, thin- to medium-bedded, massive to laminated, locally calcareous quartz wacke, sandstone, slaty siltstone, and minor thicker-bedded (up to 1 m) feldspathic and lithic wacke and conglomerate. Sandstone locally displays sedimentary structures typical of deposition as turbidites, such as graded bedding, and parallel-, cross-, and convolute lamination (figs. 7A and 7B). In places, the unit is dominated by medium- to thick-bedded, feldspathic to arkosic wacke intercalated with dark gray, parallel-laminated mudstone.

Langton (1995) recognized a conformable contact between the Little River Formation and overlying Tomogonops Formation near sample location VL10-NB01 (fig. 2); similarly, near the northern limit of Tomogonops exposure, Walker (2005) concluded that the contact is gradational, placing the lower contact of the Tomogonops Formation at the base of the first calcareous bed. In contrast, recent examination by the principal author of core recovered during exploration drilling about 10 km northeast of VL10-NB01 revealed that the two units are tectonically juxtaposed at that location, supporting Langton's (1996) observation that the regional distribution of the Tomogonops Formation implies that locally the contact must be unconformable or tectonic.

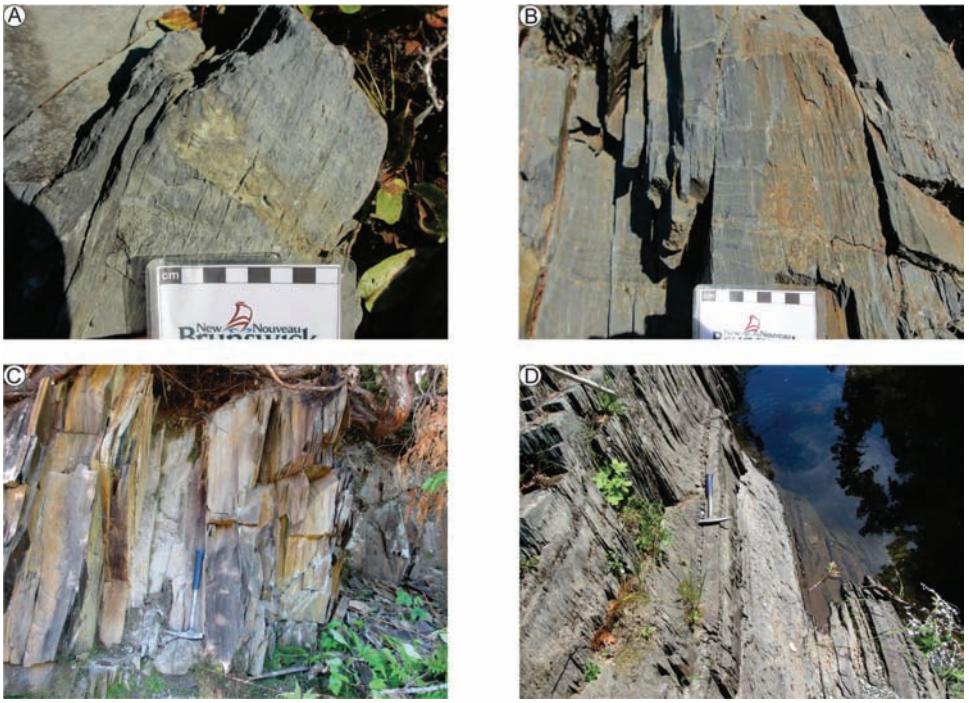


Fig. 7. (A) Parallel- and cross-laminated turbidites from the Tomogonops Formation. (B) Thin-bedded sandstone turbidites of the Tomogonops Formation. (C) Thin-bedded calcilutite from the Melanson Brook Formation: compare with figure 6C from the Matapedia Group. (D) Thin-bedded to laminated, strongly calcareous slaty siltstone (calcisiltite) of the Melanson Brook Formation.

*Melanson Brook Formation (Tetagouche Group)*

The Melanson Brook Formation (fig. 2) consists mainly of dark gray or greenish gray, massive to prominently laminated, moderately to strongly calcareous, but locally non-calcareous slaty siltstone that grades to calcisiltite or calcilutite (carbonate mudstone; fig. 7C). Thin-bedded to laminated calcareous siltstone having a prominent $S_{1-2}$ slaty cleavage is the dominant lithotype (fig. 7D), although local sandstone beds display graded bedding, cross-laminations and load casts demonstrating that at least part of the Melanson Brook consists of turbidites deposited in a relatively deep marine, slope environment. On its eastern margin, the Melanson Brook Formation unconformably overlies Lower Ordovician sedimentary rocks of the Patrick Brook Formation (Miramichi Group), and rounded pebbles and cobbles sourced from that unit locally form conglomerate beds at the base of the Melanson Brook (fig. 2). On the west, the contact with the California Lake Group is interpreted as tectonic, but the contact with underlying rocks of the Little River Formation (Tetagouche Group) may be in part tectonic and in part disconformable.

Designation of the Melanson Brook Formation as a distinct unit is made with caution, as these rocks occur in the same general area as calcareous mudstone and sandstone that lie at the base of the Tetagouche Group and disconformably overlie the Miramichi Group, namely the Vallée Lourdes Member of the Nepisiguit Falls Formation (Fyffe and others, 1997; van Staal and others, 2003). The thin Vallée Lourdes Member contains brachiopods (Fyffe, 1976) and conodonts (Nowlan, 1981) of Floian to Dapingian age; cross-bedding in calcarenitic sandstone and the local presence of

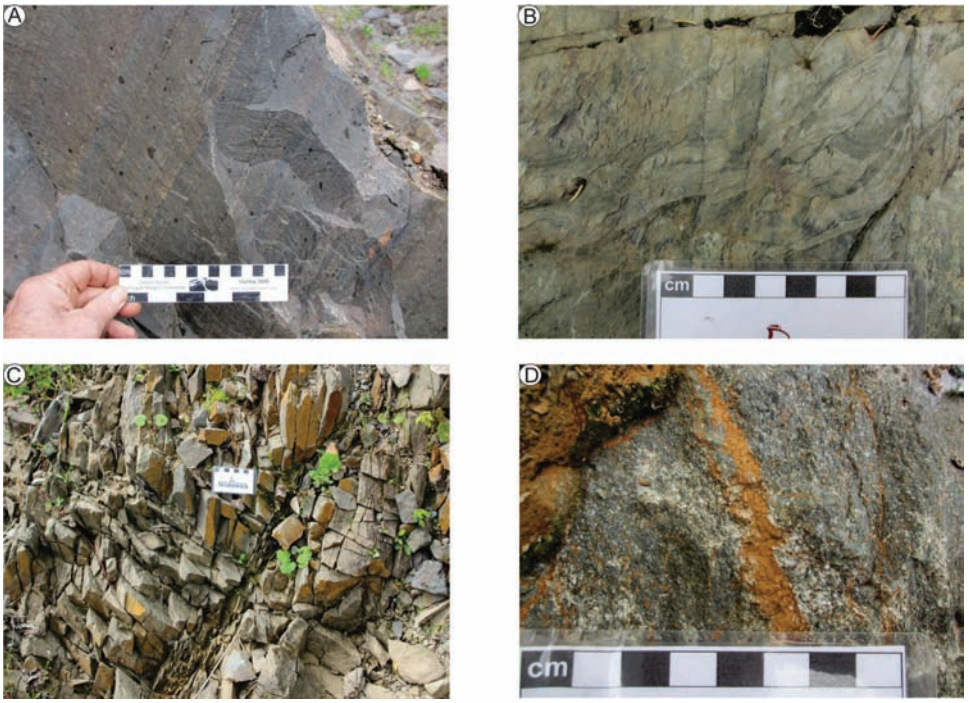


Fig. 8. (A) Thin-bedded turbidites exhibiting graded bedding and parallel lamination in the Middle River Formation. (B) Cross-laminated and convolute-laminated turbidite from the Middle River Formation. Compare these photos with figures 7A and 7B from the Tomogonops Formation. (C) Brown-weathered feldspathic sandstone from the Val Michaud Formation. (D) Coarse-grained, locally pebbly, quartzofeldspathic sandstone from the Val Michaud Formation.

cobble-boulder conglomerate suggests deposition in shallower water compared to the Melanson Brook Formation. In contrast, the latter occurs as a thick succession of unfossiliferous, typically thin-bedded to laminated calcareous mudstone and fine-grained sandstone (fig. 7D) hosting local sandy turbidite beds. Furthermore, the Melanson Brook belt truncates older rocks of the Tetagouche Group southwest of Bathurst (fig. 2); at its northern extremity, it pinches out within the Little River Formation, which it therefore appears to overlie disconformably. The abundance of dark gray calcilutite in the Melanson Brook invites comparison with poorly fossiliferous (in New Brunswick) carbonate mudstone turbidites of the White Head Formation in the Matapedia forearc basin (Ayrton and others, 1969; St. Peter, 1978; Malo, 1988).

### *Middle River Formation (California Lake Group)*

The Middle River Formation (fig. 2) dominantly consists of medium to dark gray or greenish gray, typically prominently laminated but locally massive or cryptically laminated, non-calcareous slaty siltstone, along with varying proportions of light to medium gray, fine- to medium-grained, thin- to medium-bedded, non-calcareous, quartzose sandstone. Sedimentary structures such as graded beds, cross-bedding, load casts, and subtle to prominent bedding laminations are commonly developed in sandstone beds and indicate deposition as turbidites (figs. 8A and 8B). These features are much more common than in the Melanson Brook Formation, but the major distinction between the two units is the dominantly calcareous nature of the latter, versus the dominantly non-calcareous character of the Middle River Formation. The

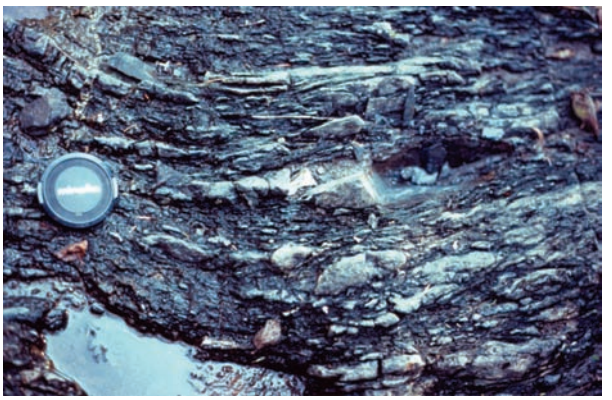

Fig. 9. Mélange containing Middle River-like sandstone clasts along the complex tectonic contact between the California Lake Group (Boucher Brook Formation) and the Tetagouche Group (Little River Formation). Lens cap is 5.5 cm in diameter. Location is along-strike from the main body of Middle River Formation (see fig. 2).

eastern contact of the Middle River Formation with the underlying Boucher Brook Formation has not been observed, but on the west, the Middle River is interpreted to be overthrust (west-to-east) by the Boucher Brook, based on several examples of tectonic mélange in the Boucher Brook Formation adjacent to the contact, including an isolated occurrence of mélange along strike to the northeast from the main body of Middle River Formation (fig. 9; location shown in fig. 2). The inferred easterly transport direction on this thrust is consistent with the interpreted vergence of thrust nappes and panels elsewhere in the Bathurst Supergroup (van Staal and de Roo, 1995; van Staal and others, 1988, 2001, 2003).

The lithotypes and sedimentary structures present in the Middle River Formation are very similar to those observed in the Tomogonops Formation (compare figs. 8A and 8B with figs. 7A and 7B), and to a lesser extent in the Melanson Brook Formation, although the abundant, medium to thick beds of feldspathic and lithic wacke seen in the Tomogonops are absent in both the Melanson Brook and Middle River formations. Turbidites that make up a large proportion of the Tomogonops and Middle River formations resemble lithofacies seen in the Grog Brook Group and suggest a linkage with the Matapedia forearc belt to the west (fig. 1).

### *Val Michaud Formation (Sormany Group)*

The Val Michaud Formation is exposed in a small area in the extreme northern part of the Miramichi Highlands (fig. 2). The Val Michaud comprises light to medium gray or light grayish green, brown to pinkish-brown weathered, fine- to medium-grained quartzofeldspathic sandstone (fig. 8C), and subsidiary light gray or light green quartzose sandstone. Minor coarse- to very coarse-grained quartzofeldspathic sandstone (fig. 8D) and rare pebble conglomerate are also present. Outcrops are generally massive; bedding and sedimentary structures are rarely observed, suggesting that most beds are thick. The dominantly arenitic nature of the sedimentary rocks, presence of relatively clean quartz sandstone, and apparent roundness of at least the coarser grains, suggest reworking in a high-energy, proximal or relatively shallow marine environment, in contrast to the other synaccretionary units described above. On the northwestern boundary of the Val Michaud Formation, shearing in mudstone of the underlying Millstream Formation (fig. 3) implies that this contact is tectonic. Deformation in the Val Michaud Formation is weak and grade of metamorphism is low

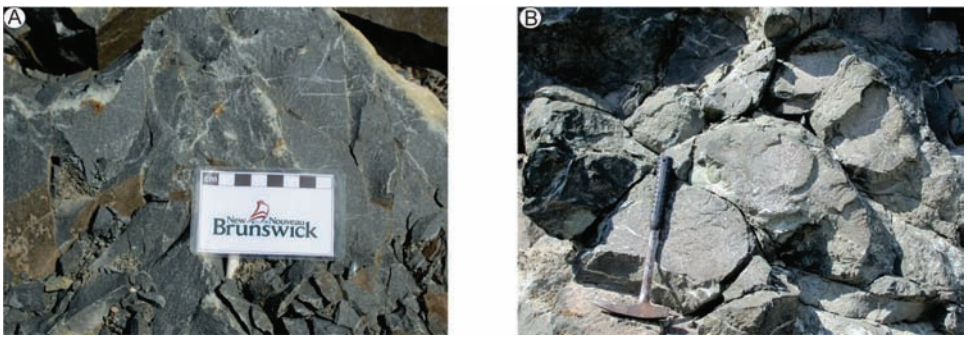


Fig. 10. (A) Quartzose sandstone from the base of the Duncans Brook Formation. (B) Pillow basalt from the Duncans Brook Formation.

(associated rocks are locally prehnite-bearing) compared to that seen in the other synaccretionary units, suggesting that these rocks remained at a relatively high structural level during deformation.

### DUNCANS BROOK FORMATION: ARC VOLCANISM ASSOCIATED WITH TETAGOUCHE BACKARC SUBDUCTION

In the Elmtree inlier, Winchester and others (1992) recognized a distinctive suite of arc tholeiitic basalt they referred to as the Duncans Brook tholeiite (figs. 3 and 4). In view of the detrital zircon age of associated sedimentary rocks and the distinctive chemistry (see below) of the basalt, this unit is herein elevated to formation status and included in the Llandoverian – Wenlockian Quinn Point Group. The type section of the Duncans Brook Formation is an aggregate quarry located south of Belledune and west of Pointe Verte (fig. 4); recent mapping and sampling have outlined the distribution of these rocks in more detail, including their occurrence in a second quarry farther to the northwest (fig. 4). The Duncans Brook Formation consists of a thin, discontinuous, basal unit of light gray, fine- to coarse-grained quartzose sandstone (fig. 10A) and conglomerate, and overlying light to medium green, massive to pillowed, Cr-rich, tholeiitic basalt (fig. 10B), minor associated hyaloclastite, and local interbedded red mudstone. The basal sandstone is very massive and rarely displays sedimentary structures or bedforms. In the south wall of the type-section quarry, basalt is juxtaposed against the sandstone along an apparent minor thrust, suggesting that the basalt is older. However, the distribution of sedimentary rocks to the south of the quarry, younging evidence from pillows, and sparse bedding attitudes, together imply that the sedimentary rocks underlie the Duncans Brook basalt and disconformably or unconformably overlie MORB-like pillowed flows (Winchester and others, 1992) of the late Darriwilian Turgeon Road Formation (Devereaux Complex). No upper contact is exposed.

Several samples of the Duncans Brook basalt were submitted for whole-rock geochemical analysis (table 1), to supplement the previously published data of Winchester and others (1992), and to compare with subduction-related basalt from the Llandoverian Weir Formation (Wilson and others, 2008; fig. 4). The analytical facility, methods and procedures are the same as reported by Wilson and others (2008). The geochemistry of the Duncans Brook basalt (fig. 11; see also Winchester and others, 1992) points to possible affiliation with volcanic rocks of the Weir Formation; for example, discrimination diagrams normally used to infer tectonic setting (fig. 11) show that both groups display chemical signatures commonly seen in subduction-related basalt. However, the Duncans Brook basalt resembles arc tholeiitic lavas,

TABLE 1

*Lithogeochemical analyses of tholeiitic basalt from the Duncans Brook Formation. Major oxides and S are reported as percentages and trace elements as parts per million*

| Sample # | RW14-TR5 | RW14-TR9 | RW14-TR10 | RW14-TR11 | RW14-TR12 | RW14-TR23 | RW14-TR30 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 45.34 | 49.79 | 49.11 | 50.79 | 51.96 | 49.49 | 46.78 |
| $TiO_2$ | 0.58 | 0.48 | 0.43 | 0.55 | 0.54 | 0.44 | 0.45 |
| $Al_2O_3$ | 13.31 | 13.72 | 12.76 | 14.83 | 13.70 | 15.56 | 16.24 |
| $Fe_2O_3t$ | 10.64 | 7.93 | 8.90 | 9.47 | 8.13 | 8.46 | 9.00 |
| MnO | 0.11 | 0.15 | 0.15 | 0.16 | 0.17 | 0.13 | 0.16 |
| MgO | 10.44 | 9.57 | 10.98 | 10.18 | 8.07 | 6.67 | 7.84 |
| CaO | 7.28 | 7.72 | 9.17 | 5.06 | 8.22 | 8.20 | 11.44 |
| $Na_2O$ | 1.99 | 3.66 | 2.95 | 4.73 | 4.55 | 4.65 | 2.49 |
| $K_2O$ | 2.05 | 0.98 | 0.67 | 0.28 | 0.67 | 0.56 | 0.06 |
| $P_2O_5$ | 0.10 | 0.06 | 0.05 | 0.08 | 0.08 | 0.06 | 0.05 |
| LOI | 6.60 | 5.61 | 4.08 | 4.73 | 4.17 | 5.83 | 4.96 |
| TOTAL | 98.47 | 99.68 | 99.25 | 100.90 | 100.30 | 100.00 | 99.48 |
| Ba | 332 | 167 | 246 | 179 | 370 | 126 | 54 |
| Cr | 242 | 425 | 641 | 465 | 360 | 89 | 113 |
| Cs | 1.9 | 0.4 | 0.5 | 0.4 | 0.2 | 2.0 | 0.6 |
| Cu | 182 | 84 | 92 | 39 | 57 | 125 | 146 |
| Ga | 15 | 12 | 11 | 12 | 12 | 16 | 15 |
| Hf | 1.1 | 0.8 | 0.7 | 1.0 | 1.0 | 0.9 | 0.6 |
| Nb | 3.9 | 5.1 | 2.8 | 3.5 | 3.8 | 1.7 | 6.0 |
| Ni | 108 | 153 | 183 | 218 | 139 | 46 | 79 |
| Pb | 2 | 2 | 2 | 2 | 3 | 2 | 4 |
| Rb | 36 | 15 | 11 | 5 | 10 | 8 | 2 |
| S | 0.584 | 0.121 | 0.115 | 0.073 | 0.090 | 0.160 | 0.091 |
| Sc | 36.0 | 38.0 | 45.0 | 40.0 | 38.0 | 39.0 | 41.0 |
| Sr | 210 | 158 | 86 | 101 | 104 | 185 | 192 |
| Ta | 0.08 | 0.19 | 0.05 | 0.15 | 0.16 | 0.09 | 0.01 |
| Th | 1.48 | 1.10 | 0.80 | 1.09 | 1.25 | 0.90 | 0.54 |
| U | 0.64 | 0.33 | 0.27 | 0.27 | 0.26 | 0.41 | 0.16 |
| V | 352 | 269 | 259 | 251 | 299 | 310 | 283 |
| Y | 15.9 | 11.2 | 10.7 | 15.8 | 14.7 | 13.1 | 10.5 |
| Zn | 48 | 58 | 60 | 64 | 55 | 55 | 56 |
| Zr | 38 | 28 | 21 | 34 | 33 | 29 | 19 |
| La | 10.80 | 5.21 | 4.22 | 7.71 | 8.16 | 4.80 | 3.68 |
| Ce | 23.30 | 11.50 | 9.09 | 15.70 | 16.20 | 10.00 | 8.09 |
| Pr | 2.89 | 1.43 | 1.21 | 2.00 | 2.02 | 1.29 | 1.12 |
| Nd | 11.90 | 6.23 | 5.40 | 8.88 | 8.76 | 5.81 | 5.38 |
| Sm | 2.69 | 1.58 | 1.45 | 2.18 | 2.07 | 1.44 | 1.43 |
| Eu | 0.81 | 0.39 | 0.41 | 0.75 | 0.70 | 0.51 | 0.51 |
| Gd | 2.74 | 1.81 | 1.72 | 2.63 | 2.44 | 1.86 | 1.62 |
| Tb | 0.46 | 0.32 | 0.31 | 0.44 | 0.43 | 0.36 | 0.29 |
| Dy | 2.82 | 2.09 | 1.91 | 2.82 | 2.65 | 2.35 | 1.90 |
| Ho | 0.58 | 0.45 | 0.40 | 0.61 | 0.56 | 0.52 | 0.41 |
| Er | 1.78 | 1.39 | 1.18 | 1.93 | 1.61 | 1.59 | 1.19 |
| Tm | 0.26 | 0.21 | 0.18 | 0.29 | 0.23 | 0.24 | 0.18 |
| Yb | 1.66 | 1.37 | 1.19 | 1.78 | 1.52 | 1.60 | 1.17 |
| Lu | 0.24 | 0.20 | 0.19 | 0.27 | 0.22 | 0.25 | 0.18 |

whereas the Weir basalt is calc-alkaline. Similarly, the Duncans Brook basalt has nearly flat rare-earth-element (REE) profiles (fig. 12A) and extended element patterns typical of island arc tholeiites (fig. 12B; Pearce, 1983), whereas the Weir basalt has

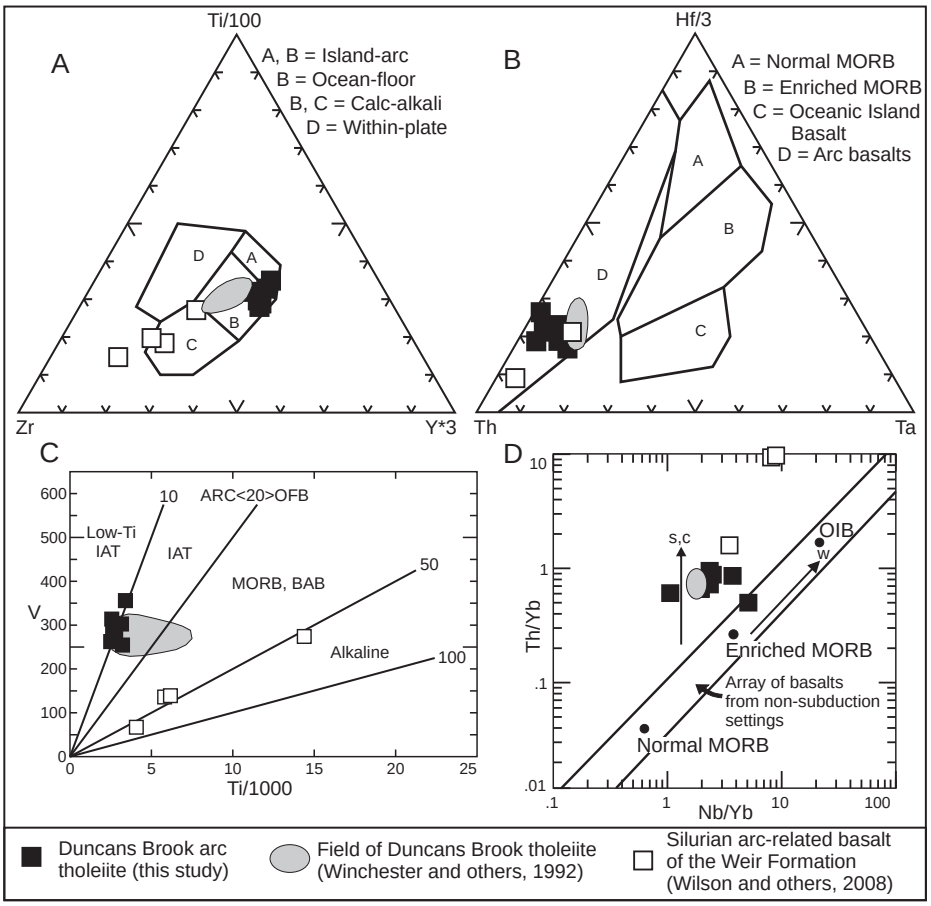


Fig. 11. Tectonic discrimination diagrams for basalt from the Duncans Brook and Weir formations. (A) Zr-Ti-Y diagram with fields defined by Pearce and Cann (1973); (B) Th-Hf-Ta diagram with fields defined by Wood and others (1979); (C) Ti vs. V diagram with fields defined by Shervais (1982); (D) Nb/Yb vs. Th/Yb diagram with fields defined by Pearce (2008). MORB – mid-ocean ridge basalt; IAT – island-arc tholeiite; OFB – ocean-floor basalt; BAB – back arc basin basalt; OIB – ocean island basalt; s, c – enrichments related to subduction and crustal contamination, respectively; w – within-plate enrichments.

sloping REE profiles and extended plots characteristic of calc-alkaline basalt erupted at active continental margins (fig. 12B).

## GEOCHRONOLOGY

The Tomogonops, Middle River, Melanson Brook, and Val Michaud formations are barren of both macro- and microfossils and contain no interbedded volcanic rocks; hence they can only be dated indirectly. The age of the Tomogonops Formation is constrained by the underlying Little River Formation, which contains graptolites assigned to the Sandbian *Diplograptus multidens* zone (Skinner, 1974; Langton, 1995). Similarly, the age of the Middle River Formation is constrained by the underlying Boucher Brook Formation, which contains conodonts assigned to the upper part of the Sandbian *Amorphognathus tvaerensis* zone (Skinner, 1974; Kennedy and others, 1979). No fossil ages are available for rocks underlying the Val Michaud or Duncans Brook formations. Detrital zircon analysis was therefore undertaken to establish

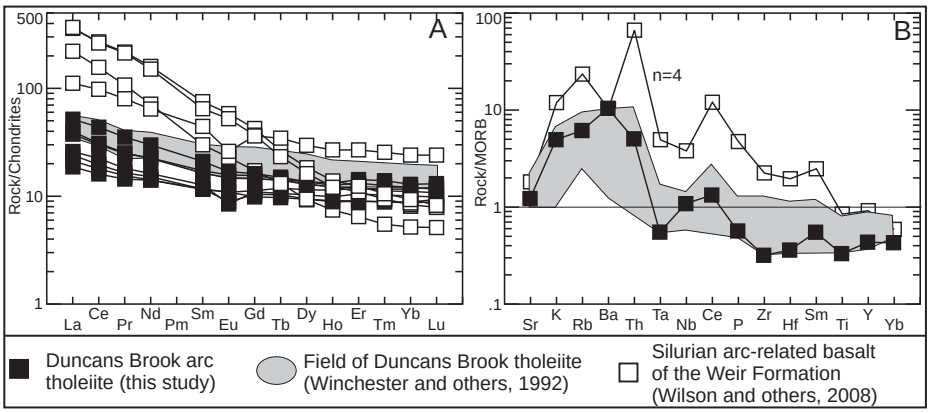


Fig. 12. (A) Chondrite-normalized rare-earth element profiles of basalt from the Duncans Brook and Weir formations. Normalizing values from Sun and McDonough (1989). (B) Mid-ocean ridge basalt-normalized extended element plot of average basalt compositions for the Duncans Brook and Weir formations. Normalizing values from Pearce (1983).

maximum depositional ages for the synaccretionary units discussed herein. Samples were collected from the Tomogonops Formation (VL10-NB01 and VL10-NB02), the Val Michaud Formation (VL10-NB04), the Elmtree Formation (VL10-NB05), and the Duncans Brook Formation (VL13-NB01 and VL13-NB02). In addition, micaceous sandstone from the Cambro-Ordovician Miramichi Group (VL10-NB06) was sampled so that the profile of detrital zircons available for recycling from older sedimentary rocks could be compared with those of the synaccretionary units. Sample descriptions and coordinates are given in table 2, and map locations are shown in figures 2 and 4. Probability density plots are illustrated in figures 13 and 14, and geochronologic data are presented in table 3. Data for samples VL10-NB01 and VL13-NB01 were reported by van Staal and others (2015); the probability density plots are included in figure 13 to allow easy comparison among all samples.

Heavy mineral separates were obtained by standard crushing, gravimetric and magnetic methods. Non-zircon components were hand-picked and removed from a representative aliquot of the heavy mineral separates. The remaining zircons were mounted in 2.54 cm epoxy rounds with natural zircon standards and polished to expose the grain interiors. Cathodoluminescence (CL) images were taken to character-

Table 2

*Summary of samples collected for detrital zircon analysis*

| Sample # | Unit | Latitude | Longitude | Description |
|---|---|---|---|---|
| VL10-NB01 | Tomogonops Fm. | 47-09-57 N | 65-57-23 W | Fine- to medium-grained sandstone |
| VL10-NB02 | Tomogonops Fm. | 47-09-38 N | 65-52-45 W | Polymictic conglomerate |
| VL10-NB04 | Val Michaud Fm. | 47-41-26 N | 65-49-24 W | Very coarse-grained quartzo-feldspathic pebbly sandstone |
| VL10-NB05 | Elmtree Fm. | 47-47-34 N | 65-59-07 W | Quartz pebble-rich quartzose wacke |
| VL13-NB01 | Duncans Brook Fm. | 47-51-41 N | 65-50-42 W | Quartzose sandstone |
| VL13-NB02 | Duncans Brook Fm. | 47-51-37 N | 65-50-23 W | Red mudstone |
| VL10-NB06 | Knights Brook Fm. | 47-20-54 N | 65-48-06 W | Fine- to medium-grained micaceous sandstone |

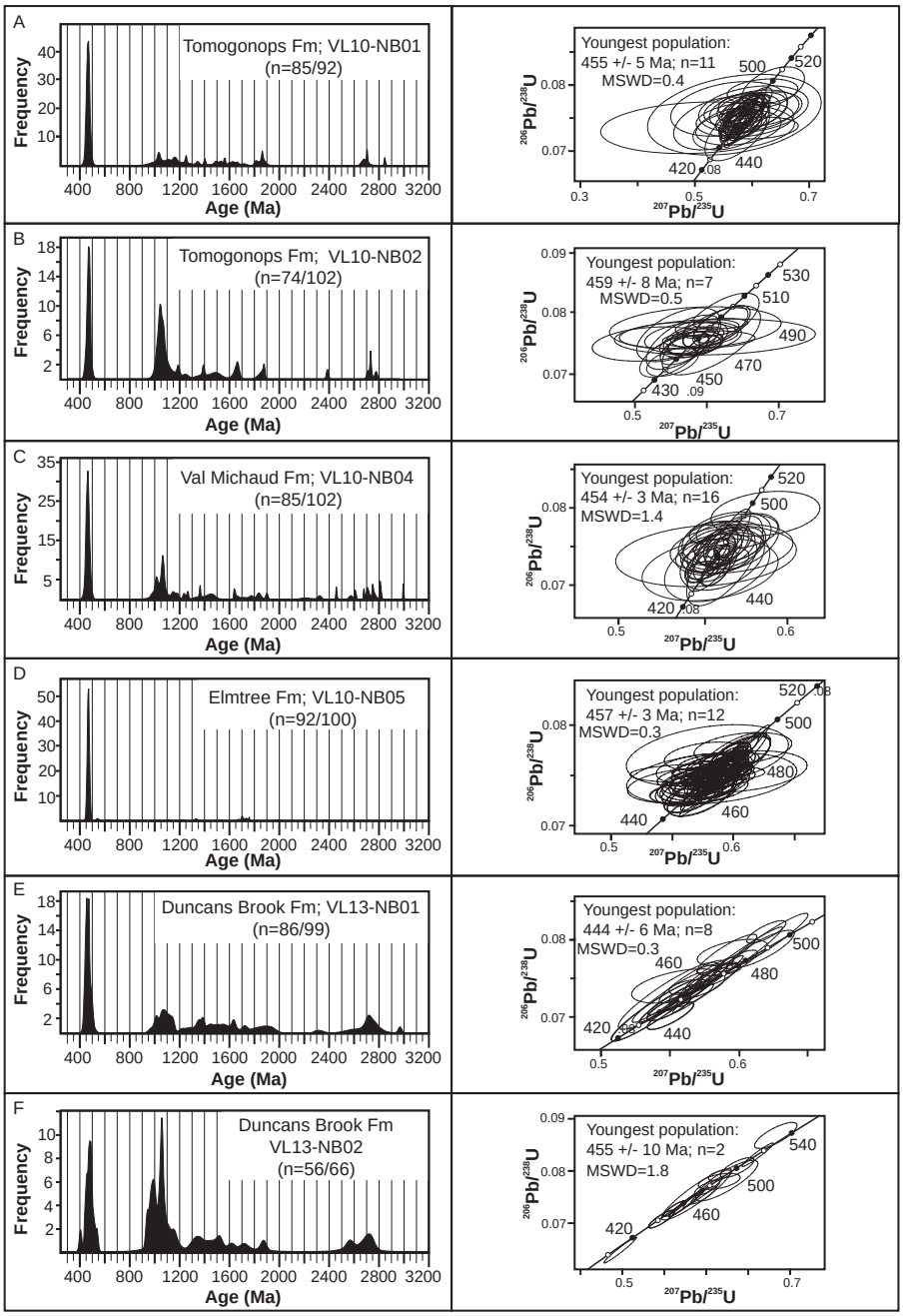


Fig. 13. Probability density plots of detrital zircon data and concordia plots of Paleozoic analyses from the (A, B) Tomogonops, (C) Val Michaud, (D) Elmtree, and (E, F) Duncans Brook formations. The youngest population ages were defined by the weighted mean of grains with $^{206}Pb/^{238}U$ ages that overlap at the 1σ level with n≥2 (Dickinson and Gehrels, 2009). Frequency noted on the vertical axis reflects histogram peak heights with 20-30 Ma bin width co-plotted with probability density plots. Plots and weighted mean ages with 2σ errors were generated by Isoplot (Ludwig, 2003).

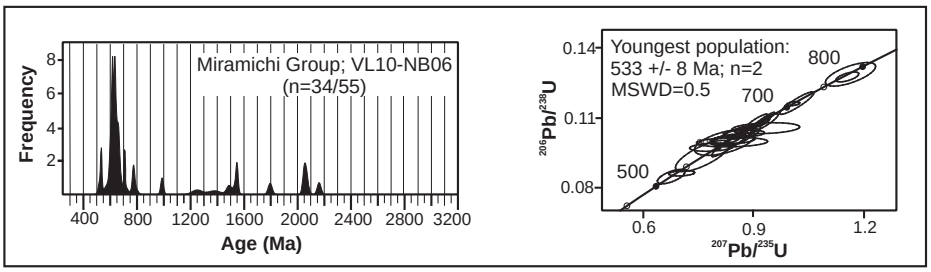


Fig. 14. Probability density plot for sample VL10-NB06 from the Miramichi Group. Frequency noted on the vertical axis reflects histogram peak heights with 25 Ma bin width co-plotted with probability density plot.

ize the internal structure and help place analytical spots in homogeneous domains within individual grains. U-Pb analysis was completed on a Nu Instruments HR ICPMS and New Wave UP193HE Excimer laser at the Arizona Laserchron Center following analytical methods of Gehrels and others (2006, 2008). U and Th concentrations and Pb/U fractionation were calibrated against the Arizona Laserchron Center Sri Lanka (SL) zircon standard (563.5 ± 3.2 Ma, 2σ; ~518 ppm U and 68 ppm Th; Gehrels and others, 2008). Fractionation corrections were monitored by analysis of secondary zircon standard R33 (420.53 ± 0.16 Ma, 2σ; Black and others, 2004; Mattinson, 2010). Common Pb corrections were made using $^{204}$Hg-corrected $^{204}$Pb measurements for each analysis and initial Pb compositions of Stacey and Kramers (1975). The $^{206}$Pb/$^{238}$U ages are used for apparent ages less than 1200 Ma whereas $^{207}$Pb/$^{206}$Pb ages are used for analyses greater than 1200 Ma. The age with lower uncertainty is used in cases where the $^{206}$Pb/$^{238}$U and $^{207}$Pb/$^{206}$Pb ages straddle 1200 Ma. Ages are excluded from discussion if (1) uncertainty of the best age is >10 percent at the 2σ level, (2) analyses >600 Ma are >10 percent discordant or >5 percent reversely discordant as determined by the difference between $^{206}$Pb/$^{238}$U and $^{207}$Pb/$^{206}$Pb ages without incorporating errors, or (3) analyses <600 Ma are discordant incorporating errors and thus avoiding exclusion due to difficulties in determination of $^{207}$Pb/$^{206}$Pb ages for Paleozoic grains.

The youngest population of zircons used to define the maximum depositional age for each sample was defined by the weighted mean of n ≥ 2 grains with $^{206}$Pb/$^{238}$U ages that overlap at the 1σ level (Dickinson and Gehrels, 2009). Analyses used for calculation of maximum depositional age are noted by an asterisk in table 3. Samples from the Tomogonops and Val Michaud formations have nearly identical Sandbian ages of 455 ± 5 Ma, 459 ± 8 Ma, and 454 ± 3 Ma, indicating that the host rocks are late Sandbian or younger and likely overlap in age with the Grog Brook Group in the Matapedia forearc basin. The maximum depositional age of the Elmtree sample (457 ± 3 Ma) is nearly identical with those of the Tomogonops and Val Michaud formations (fig. 3), confirming that it most likely post-dates the *Nemagraptus gracilis* – lower *Diplograptus multidens* age of graptolites recovered from Elmtree shale (McCutcheon and others, 1995). In the Duncans Brook Formation, the youngest populations of detrital zircons recovered from the basal quartzose sandstone (VL13-NB01) and from red mudstone intercalated with basalt (VL13-NB02) yield mean ages of 444 ± 6 Ma (~ Ordovician – Silurian boundary) and 455 ± 10 Ma, respectively, implying that the basalt is latest Ordovician or possibly early Silurian.

The probability density plots for all the above samples are remarkably similar, although sample VL10-NB05 (Elmtree Formation) contains comparatively few grains older than Early Ordovician, and sample VL13-NB02 (Duncans Brook Formation) contains a much higher proportion of late Mesoproterozoic to early Neoproterozoic

TABLE 3

*LA-ICPMS U-Pb detrital zircon geochronologic data and apparent ages. * indicates data used in calculation of maximum depositional ages*

| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | | Disc. (%) |
| VL10NB02 (n=76/102) | | | | | | | | | | | | | | | | | | | | |
| 82 | 224 | 31,624 | 0.6 | 17.9501 | 3.7 | 0.5515 | 4.3 | 0.0718 | 2.1 | 0.50 | 447 | 9 | 446 | 16 | 441 | 83 | 447 | 9 | * | |
| 41 | 144 | 22,892 | 1.1 | 18.2906 | 4.0 | 0.5477 | 5.1 | 0.0727 | 3.0 | 0.60 | 452 | 13 | 443 | 18 | 399 | 91 | 452 | 13 | * | |
| 37 | 323 | 110,396 | 0.9 | 17.9478 | 3.2 | 0.5684 | 4.0 | 0.0740 | 2.4 | 0.60 | 460 | 11 | 457 | 15 | 441 | 71 | 460 | 11 | * | |
| 67 | 198 | 34,491 | 0.6 | 17.6449 | 4.0 | 0.5825 | 4.2 | 0.0745 | 1.5 | 0.34 | 463 | 7 | 466 | 16 | 479 | 88 | 463 | 7 | * | |
| 50 | 197 | 28,396 | 0.6 | 17.8033 | 4.7 | 0.5778 | 5.1 | 0.0746 | 1.9 | 0.37 | 464 | 8 | 463 | 19 | 459 | 104 | 464 | 8 | * | |
| 42 | 92 | 17,851 | 0.6 | 19.7408 | 9.9 | 0.5218 | 10.2 | 0.0747 | 2.4 | 0.24 | 464 | 11 | 426 | 36 | 225 | 230 | 464 | 11 | * | |
| 10 | 200 | 40,051 | 0.6 | 18.2148 | 4.7 | 0.5677 | 6.0 | 0.0750 | 3.8 | 0.63 | 466 | 17 | 456 | 22 | 408 | 104 | 466 | 17 | * | |
| 22 | 145 | 18,645 | 0.9 | 17.1177 | 5.7 | 0.6064 | 7.4 | 0.0753 | 4.8 | 0.65 | 468 | 22 | 481 | 29 | 546 | 124 | 468 | 22 | * | |
| 96 | 157 | 1,631 | 0.7 | 17.2574 | 6.9 | 0.6028 | 7.0 | 0.0754 | 1.2 | 0.17 | 469 | 5 | 479 | 27 | 528 | 152 | 469 | 5 | | |
| 85 | 160 | 37,909 | 0.7 | 17.8221 | 4.5 | 0.5845 | 5.0 | 0.0756 | 2.3 | 0.45 | 470 | 10 | 467 | 19 | 457 | 100 | 470 | 10 | | |
| 47 | 129 | 37,260 | 0.6 | 17.9790 | 7.3 | 0.5810 | 7.7 | 0.0758 | 2.2 | 0.29 | 471 | 10 | 465 | 29 | 437 | 163 | 471 | 10 | | |
| 81 | 245 | 7,249 | 1.0 | 16.1421 | 17.3 | 0.6473 | 17.5 | 0.0758 | 3.0 | 0.17 | 471 | 14 | 507 | 70 | 672 | 372 | 471 | 14 | | |
| 55 | 227 | 15,234 | 0.8 | 17.5592 | 2.8 | 0.5952 | 3.2 | 0.0758 | 1.4 | 0.45 | 471 | 7 | 474 | 12 | 490 | 62 | 471 | 7 | | |
| 59 | 69 | 7,312 | 1.2 | 17.1035 | 14.9 | 0.6114 | 15.1 | 0.0758 | 2.5 | 0.17 | 471 | 11 | 484 | 58 | 547 | 326 | 471 | 11 | | |
| 31 | 233 | 24,236 | 0.6 | 17.9444 | 3.5 | 0.5828 | 3.7 | 0.0758 | 1.4 | 0.37 | 471 | 6 | 466 | 14 | 442 | 77 | 471 | 6 | | |
| 16 | 77 | 10,000 | 0.7 | 18.6986 | 9.5 | 0.5611 | 9.7 | 0.0761 | 1.8 | 0.19 | 473 | 8 | 452 | 35 | 349 | 216 | 473 | 8 | | |
| 58 | 75 | 7,027 | 0.6 | 18.7418 | 5.7 | 0.5605 | 6.8 | 0.0762 | 3.7 | 0.55 | 473 | 17 | 452 | 25 | 344 | 129 | 473 | 17 | | |
| 19 | 360 | 82,828 | 0.7 | 17.8963 | 2.5 | 0.5885 | 2.6 | 0.0764 | 0.6 | 0.25 | 475 | 3 | 470 | 10 | 447 | 56 | 475 | 3 | | |
| 33 | 223 | 32,007 | 0.5 | 17.7370 | 4.7 | 0.6006 | 4.9 | 0.0773 | 1.1 | 0.24 | 480 | 5 | 478 | 19 | 467 | 105 | 480 | 5 | | |
| 27 | 122 | 55,260 | 0.5 | 18.2433 | 13.2 | 0.5841 | 13.5 | 0.0773 | 2.9 | 0.21 | 480 | 13 | 467 | 50 | 405 | 296 | 480 | 13 | | |
| 1 | 90 | 55,815 | 0.6 | 17.2463 | 3.3 | 0.6206 | 4.2 | 0.0776 | 2.7 | 0.64 | 482 | 13 | 490 | 17 | 529 | 71 | 482 | 13 | | |
| 48 | 189 | 38,393 | 0.2 | 17.2984 | 3.2 | 0.6197 | 4.0 | 0.0777 | 2.4 | 0.61 | 483 | 11 | 490 | 16 | 523 | 70 | 483 | 11 | | |
| 5 | 176 | 19,971 | 0.8 | 17.3577 | 4.0 | 0.6192 | 4.0 | 0.0780 | 0.7 | 0.17 | 484 | 3 | 489 | 16 | 515 | 87 | 484 | 3 | | |
| 36 | 199 | 22,009 | 0.5 | 17.4442 | 4.3 | 0.6197 | 5.7 | 0.0784 | 3.7 | 0.65 | 487 | 17 | 490 | 22 | 504 | 94 | 487 | 17 | | |
| 60 | 184 | 816 | 0.4 | 13.8175 | 29.7 | 0.8627 | 29.9 | 0.0865 | 3.6 | 0.12 | 535 | 19 | 632 | 142 | 996 | 617 | 535 | 19 | | |
| 99 | 46 | 14,532 | 0.6 | 13.8171 | 5.2 | 1.6703 | 5.7 | 0.1674 | 2.4 | 0.43 | 998 | 23 | 997 | 36 | 996 | 105 | 998 | 23 | | 0 |
| 2 | 118 | 30,096 | 0.5 | 13.8840 | 2.6 | 1.6894 | 2.8 | 0.1701 | 1.2 | 0.42 | 1013 | 11 | 1005 | 18 | 987 | 52 | 1013 | 11 | | -3 |
| 34 | 77 | 27,073 | 0.2 | 13.5728 | 2.9 | 1.7360 | 3.6 | 0.1709 | 2.1 | 0.60 | 1017 | 20 | 1022 | 23 | 1033 | 58 | 1017 | 20 | | 2 |
| 62 | 98 | 60,829 | 0.1 | 13.5693 | 4.2 | 1.7489 | 4.4 | 0.1721 | 1.2 | 0.27 | 1024 | 11 | 1027 | 28 | 1033 | 85 | 1024 | 11 | | 1 |
| 57 | 83 | 30,771 | 0.4 | 13.4025 | 2.3 | 1.7813 | 3.0 | 0.1732 | 1.9 | 0.63 | 1029 | 18 | 1039 | 20 | 1058 | 47 | 1029 | 18 | | 3 |
| 100 | 110 | 70,056 | 0.4 | 13.4128 | 1.9 | 1.7856 | 2.3 | 0.1737 | 1.2 | 0.53 | 1032 | 12 | 1040 | 15 | 1057 | 39 | 1032 | 12 | | 2 |
| 15 | 174 | 91,147 | 0.1 | 13.4798 | 1.4 | 1.7789 | 2.1 | 0.1739 | 1.6 | 0.75 | 1034 | 15 | 1038 | 14 | 1047 | 28 | 1034 | 15 | | 1 |

TABLE 3
*(continued)*

| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | Disc. (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VL10NB02 (n=76/102) | | | | | | | | | | | | | | | | | | | |
| 83 | 73 | 15,637 | 0.3 | 13.7525 | 5.1 | 1.7491 | 5.1 | 0.1745 | 1.0 | 0.19 | 1037 | 9 | 1027 | 33 | 1006 | 103 | 1037 | 9 | -3 |
| 13 | 138 | 58,338 | 0.3 | 13.5867 | 2.3 | 1.7822 | 2.5 | 0.1756 | 0.8 | 0.33 | 1043 | 8 | 1039 | 16 | 1031 | 47 | 1043 | 8 | -1 |
| 93 | 67 | 30,600 | 0.7 | 13.1890 | 5.0 | 1.8379 | 5.1 | 0.1758 | 1.4 | 0.27 | 1044 | 13 | 1059 | 34 | 1090 | 99 | 1044 | 13 | 4 |
| 61 | 67 | 30,257 | 0.3 | 13.5032 | 2.9 | 1.7995 | 3.3 | 0.1762 | 1.7 | 0.50 | 1046 | 16 | 1045 | 22 | 1043 | 59 | 1046 | 16 | 0 |
| 14 | 125 | 60,700 | 0.5 | 13.4720 | 2.0 | 1.8077 | 2.4 | 0.1766 | 1.3 | 0.53 | 1049 | 12 | 1048 | 16 | 1048 | 41 | 1049 | 12 | 0 |
| 23 | 152 | 88,299 | 0.2 | 13.4656 | 1.7 | 1.8110 | 1.9 | 0.1769 | 0.9 | 0.46 | 1050 | 8 | 1049 | 12 | 1049 | 34 | 1050 | 8 | 0 |
| 21 | 56 | 13,557 | 0.5 | 13.5261 | 7.0 | 1.8104 | 7.2 | 0.1776 | 1.4 | 0.19 | 1054 | 13 | 1049 | 47 | 1040 | 142 | 1054 | 13 | -1 |
| 20 | 67 | 22,615 | 0.3 | 12.9262 | 3.0 | 1.8957 | 3.2 | 0.1777 | 1.1 | 0.34 | 1055 | 11 | 1080 | 21 | 1131 | 60 | 1055 | 11 | 7 |
| 25 | 86 | 30,418 | 0.3 | 13.0822 | 2.9 | 1.8852 | 4.6 | 0.1789 | 3.6 | 0.78 | 1061 | 35 | 1076 | 31 | 1107 | 58 | 1061 | 35 | 4 |
| 89 | 121 | 38,465 | 0.3 | 13.6565 | 1.5 | 1.8078 | 1.9 | 0.1791 | 1.2 | 0.60 | 1062 | 11 | 1048 | 13 | 1020 | 31 | 1062 | 11 | -4 |
| 40 | 83 | 31,215 | 0.8 | 13.4836 | 2.7 | 1.8446 | 3.5 | 0.1804 | 2.1 | 0.61 | 1069 | 21 | 1062 | 23 | 1046 | 55 | 1069 | 21 | -2 |
| 52 | 163 | 77,409 | 0.8 | 13.2493 | 1.8 | 1.8777 | 3.2 | 0.1804 | 2.6 | 0.82 | 1069 | 26 | 1073 | 21 | 1081 | 36 | 1069 | 26 | 1 |
| 72 | 413 | 209,827 | 0.3 | 13.2203 | 1.1 | 1.8846 | 1.3 | 0.1807 | 0.7 | 0.52 | 1071 | 6 | 1076 | 8 | 1086 | 22 | 1071 | 6 | 1 |
| 95 | 163 | 44,681 | 0.4 | 13.2371 | 1.6 | 1.8844 | 2.6 | 0.1809 | 2.1 | 0.81 | 1072 | 21 | 1076 | 17 | 1083 | 31 | 1072 | 21 | 1 |
| 6 | 174 | 37,572 | 0.4 | 13.2894 | 1.3 | 1.8815 | 2.5 | 0.1813 | 2.2 | 0.85 | 1074 | 21 | 1075 | 17 | 1075 | 27 | 1074 | 21 | 0 |
| 66 | 166 | 75,768 | 0.6 | 13.1988 | 1.4 | 1.8960 | 1.8 | 0.1815 | 1.0 | 0.59 | 1075 | 10 | 1080 | 12 | 1089 | 29 | 1075 | 10 | 1 |
| 43 | 71 | 28,903 | 0.5 | 13.3394 | 3.2 | 1.8927 | 3.5 | 0.1831 | 1.3 | 0.38 | 1084 | 13 | 1079 | 23 | 1068 | 65 | 1084 | 13 | -2 |
| 84 | 216 | 100,746 | 0.2 | 13.1217 | 0.6 | 1.9470 | 2.7 | 0.1853 | 2.6 | 0.97 | 1096 | 26 | 1097 | 18 | 1101 | 13 | 1096 | 26 | 0 |
| 80 | 188 | 68,817 | 0.3 | 12.9885 | 1.7 | 1.9943 | 2.4 | 0.1879 | 1.7 | 0.72 | 1110 | 18 | 1114 | 16 | 1121 | 33 | 1110 | 18 | 1 |
| 94 | 19 | 12,100 | 0.9 | 13.2875 | 9.9 | 1.9625 | 10.8 | 0.1891 | 4.3 | 0.40 | 1117 | 44 | 1103 | 73 | 1075 | 199 | 1117 | 44 | -4 |
| 76 | 150 | 175,606 | 0.3 | 13.0107 | 2.0 | 2.0395 | 3.0 | 0.1924 | 2.3 | 0.76 | 1135 | 24 | 1129 | 21 | 1118 | 39 | 1135 | 24 | -2 |
| 46 | 36 | 15,187 | 0.4 | 12.8780 | 5.3 | 2.1467 | 5.9 | 0.2005 | 2.6 | 0.44 | 1178 | 28 | 1164 | 41 | 1138 | 105 | 1178 | 28 | -4 |
| 18 | 341 | 180,334 | 0.7 | 12.5858 | 0.6 | 2.2214 | 1.1 | 0.2028 | 0.9 | 0.81 | 1190 | 9 | 1188 | 7 | 1184 | 12 | 1190 | 9 | -1 |
| 35 | 17 | 7,116 | 0.4 | 12.1955 | 7.6 | 2.2953 | 8.2 | 0.2030 | 3.1 | 0.37 | 1192 | 33 | 1211 | 58 | 1245 | 149 | 1192 | 33 | 4 |
| 7 | 105 | 74,871 | 0.7 | 12.1554 | 1.0 | 2.5608 | 2.9 | 0.2258 | 2.7 | 0.94 | 1312 | 33 | 1290 | 21 | 1252 | 20 | 1252 | 20 | -5 |
| 54 | 92 | 25,451 | 0.3 | 11.4982 | 2.3 | 2.9478 | 2.6 | 0.2458 | 1.1 | 0.42 | 1417 | 14 | 1394 | 19 | 1360 | 45 | 1360 | 45 | -4 |
| 24 | 55 | 28,808 | 0.2 | 11.3467 | 3.3 | 2.9313 | 4.7 | 0.2412 | 3.3 | 0.71 | 1393 | 42 | 1390 | 36 | 1385 | 64 | 1385 | 64 | -1 |
| 56 | 390 | 234,645 | 0.3 | 11.3086 | 0.4 | 2.9226 | 0.8 | 0.2397 | 0.7 | 0.86 | 1385 | 8 | 1388 | 6 | 1392 | 8 | 1392 | 8 | 0 |
| 70 | 50 | 25,398 | 0.8 | 11.1539 | 2.3 | 2.9927 | 2.8 | 0.2421 | 1.6 | 0.58 | 1398 | 20 | 1406 | 21 | 1418 | 43 | 1418 | 43 | 1 |
| 69 | 93 | 24,265 | 0.9 | 10.8080 | 1.5 | 3.2933 | 2.4 | 0.2581 | 1.9 | 0.79 | 1480 | 25 | 1479 | 19 | 1478 | 28 | 1478 | 28 | 0 |
| 30 | 110 | 59,460 | 0.4 | 10.6047 | 1.7 | 3.1279 | 6.3 | 0.2406 | 6.1 | 0.96 | 1390 | 77 | 1440 | 49 | 1514 | 32 | 1514 | 32 | 8 |
| 32 | 55 | 60,315 | 0.7 | 10.5770 | 2.8 | 3.4402 | 3.6 | 0.2639 | 2.3 | 0.63 | 1510 | 30 | 1514 | 28 | 1519 | 53 | 1519 | 53 | 1 |

TABLE 3
*(continued)*

| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | Disc. (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | | |
| VL10NB02 (n=76/102) | | | | | | | | | | | | | | | | | | | |
| 97 | 139 | 90,496 | 0.6 | 9.9463 | 1.0 | 3.9557 | 2.3 | 0.2854 | 2.1 | 0.90 | 1618 | 30 | 1625 | 19 | 1634 | 18 | 1634 | 18 | 1 |
| 74 | 111 | 158,153 | 0.7 | 9.8326 | 0.8 | 4.1684 | 2.3 | 0.2973 | 2.2 | 0.93 | 1678 | 32 | 1668 | 19 | 1655 | 15 | 1655 | 15 | -1 |
| 8 | 345 | 177,975 | 0.1 | 9.7840 | 0.6 | 3.7872 | 1.7 | 0.2687 | 1.6 | 0.94 | 1534 | 21 | 1590 | 13 | 1665 | 10 | 1665 | 10 | 8 |
| 11 | 291 | 9,007 | 1.0 | 9.7340 | 0.8 | 4.1203 | 1.5 | 0.2909 | 1.2 | 0.85 | 1646 | 18 | 1658 | 12 | 1674 | 14 | 1674 | 14 | 2 |
| 38 | 74 | 61,865 | 0.1 | 8.8975 | 1.2 | 5.1371 | 1.5 | 0.3315 | 0.9 | 0.61 | 1846 | 15 | 1842 | 13 | 1838 | 22 | 1838 | 22 | 0 |
| 12 | 192 | 14,405 | 0.3 | 8.7744 | 0.8 | 5.3331 | 2.5 | 0.3394 | 2.4 | 0.95 | 1884 | 38 | 1874 | 21 | 1864 | 14 | 1864 | 14 | -1 |
| 78 | 268 | 196,615 | 0.3 | 8.7026 | 0.4 | 5.3091 | 0.8 | 0.3351 | 0.7 | 0.87 | 1863 | 11 | 1870 | 7 | 1878 | 7 | 1878 | 7 | 1 |
| 39 | 162 | 157,585 | 1.0 | 6.5117 | 0.5 | 9.5356 | 0.9 | 0.4503 | 0.8 | 0.85 | 2397 | 15 | 2391 | 8 | 2386 | 8 | 2386 | 8 | 0 |
| 65 | 98 | 174,626 | 0.7 | 5.3643 | 0.6 | 13.3765 | 1.1 | 0.5204 | 0.9 | 0.86 | 2701 | 21 | 2707 | 10 | 2711 | 9 | 2711 | 9 | 0 |
| 17 | 289 | 138,438 | 0.6 | 5.3008 | 0.2 | 13.8438 | 1.4 | 0.5322 | 1.4 | 0.99 | 2751 | 31 | 2739 | 13 | 2730 | 4 | 2730 | 4 | -1 |
| 51 | 87 | 99,572 | 1.5 | 5.2796 | 0.4 | 13.8958 | 0.7 | 0.5321 | 0.5 | 0.78 | 2750 | 11 | 2743 | 6 | 2737 | 7 | 2737 | 7 | 0 |
| 4 | 98 | 113,678 | 0.4 | 5.1552 | 0.6 | 14.1637 | 2.9 | 0.5296 | 2.9 | 0.98 | 2740 | 64 | 2761 | 28 | 2776 | 10 | 2776 | 10 | 1 |
| *Rejected Analyses (>10% discordance, >5% reverse discordance, or >10% 2s age uncertainty)* | | | | | | | | | | | | | | | | | | | |
| 92 | 383 | 81,815 | 0.7 | 17.7099 | 1.2 | 0.5551 | 5.3 | 0.0713 | 5.2 | 0.98 | 444 | 22 | 448 | 19 | 471 | 26 | | | |
| 63 | 61 | 733 | 0.4 | 18.4179 | 11.6 | 0.5478 | 13.5 | 0.0732 | 7.0 | 0.52 | 455 | 31 | 444 | 49 | 383 | 261 | | | |
| 53 | 253 | 170 | 0.8 | 11.9155 | 18.8 | 0.8566 | 19.9 | 0.0740 | 6.3 | 0.32 | 460 | 28 | 628 | 93 | 1291 | 370 | | | |
| 64 | 162 | 34,652 | 0.4 | 9.0887 | 21.0 | 1.1339 | 27.8 | 0.0747 | 18.1 | 0.65 | 465 | 81 | 770 | 151 | 1800 | 387 | | | |
| 77 | 344 | 2,756 | 0.3 | 15.5741 | 3.8 | 0.8217 | 5.0 | 0.0928 | 3.3 | 0.65 | 572 | 18 | 609 | 23 | 749 | 81 | | | |
| 86 | 438 | 76,732 | 0.1 | 15.5906 | 2.0 | 0.8416 | 2.2 | 0.0952 | 1.0 | 0.46 | 586 | 6 | 620 | 10 | 746 | 41 | | | |
| 29 | 223 | 1,494 | 0.7 | 12.1886 | 11.5 | 1.7565 | 11.8 | 0.1553 | 2.6 | 0.22 | 930 | 23 | 1030 | 77 | 1247 | 226 | | | |
| 87 | 34 | 8,252 | 0.9 | 14.8173 | 8.1 | 1.5274 | 8.6 | 0.1641 | 2.7 | 0.32 | 980 | 25 | 941 | 53 | 853 | 169 | | | |
| 75 | 51 | 23,034 | 1.2 | 14.2240 | 4.7 | 1.6189 | 4.9 | 0.1670 | 1.4 | 0.29 | 996 | 13 | 978 | 31 | 937 | 97 | | | |
| 90 | 21 | 8,053 | 0.6 | 13.9724 | 12.3 | 1.6968 | 13.0 | 0.1720 | 4.2 | 0.32 | 1023 | 39 | 1007 | 83 | 974 | 252 | | | |
| 91 | 10 | 3,512 | 0.9 | 13.6799 | 24.1 | 1.7374 | 27.1 | 0.1724 | 12.3 | 0.46 | 1025 | 117 | 1023 | 176 | 1017 | 495 | | | |
| 49 | 73 | 33,727 | 1.2 | 13.9823 | 2.8 | 1.7002 | 3.2 | 0.1724 | 1.7 | 0.53 | 1025 | 16 | 1009 | 21 | 972 | 56 | | | |
| 9 | 68 | 43,290 | 0.2 | 14.1440 | 3.9 | 1.7102 | 4.2 | 0.1754 | 1.4 | 0.34 | 1042 | 14 | 1012 | 27 | 949 | 80 | | | |
| 44 | 28 | 21,634 | 1.3 | 13.7226 | 10.0 | 1.7814 | 10.2 | 0.1773 | 1.8 | 0.18 | 1052 | 17 | 1039 | 66 | 1010 | 204 | | | |
| 3 | 42 | 28,068 | 0.8 | 14.3517 | 6.8 | 1.7278 | 7.0 | 0.1798 | 1.5 | 0.22 | 1066 | 15 | 1019 | 45 | 919 | 140 | | | |
| 28 | 28 | 11,747 | 0.6 | 15.2319 | 11.6 | 1.6308 | 11.9 | 0.1802 | 3.0 | 0.25 | 1068 | 29 | 982 | 75 | 795 | 243 | | | |

TABLE 3
*(continued)*

| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | | Disc. (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | | | |
| VL10NB02 (n=76/102) | | | | | | | | | | | | | | | | | | | | |
| *Rejected Analyses (>10% discordance, >5% reverse discordance, or >10% 2s age uncertainty)* | | | | | | | | | | | | | | | | | | | | |
| 79 | 152 | 37,369 | 0.5 | 13.3607 | 3.0 | 1.9041 | 6.5 | 0.1845 | 5.8 | 0.89 | 1092 | 58 | 1083 | 43 | 1064 | 61 | | | | |
| 26 | 167 | 70,340 | 0.2 | 9.6207 | 3.6 | 2.6460 | 7.6 | 0.1846 | 6.8 | 0.88 | 1092 | 68 | 1314 | 56 | 1696 | 66 | | | | |
| 98 | 72 | 27,210 | 0.7 | 13.5908 | 3.2 | 1.9376 | 8.1 | 0.1910 | 7.5 | 0.92 | 1127 | 77 | 1094 | 55 | 1030 | 64 | | | | |
| 68 | 61 | 4,766 | 0.5 | 12.5408 | 5.6 | 2.1816 | 9.3 | 0.1984 | 7.5 | 0.80 | 1167 | 80 | 1175 | 65 | 1191 | 110 | | | | |
| 73 | 86 | 11,322 | 0.4 | 10.1126 | 7.4 | 3.2196 | 8.4 | 0.2361 | 3.8 | 0.46 | 1367 | 47 | 1462 | 65 | 1603 | 139 | | | | |
| 88 | 22 | 11,994 | 0.4 | 10.5316 | 29.6 | 3.5986 | 52.7 | 0.2749 | 43.6 | 0.83 | 1565 | 608 | 1549 | 445 | 1527 | 570 | | | | |
| 45 | 84 | 65,180 | 0.7 | 9.9256 | 0.9 | 4.3058 | 1.4 | 0.3100 | 1.0 | 0.72 | 1741 | 15 | 1694 | 11 | 1638 | 17 | | | | |
| 71 | 88 | 70,489 | 0.4 | 5.5294 | 0.6 | 10.8683 | 2.7 | 0.4359 | 2.6 | 0.97 | 2332 | 51 | 2512 | 25 | 2661 | 10 | | | | |
| VL10NB04 (n=85/101) | | | | | | | | | | | | | | | | | | | | |
| 36 | 165 | 28,556 | 0.8 | 17.3860 | 2.4 | 0.5698 | 3.0 | 0.0719 | 1.7 | 0.58 | 447 | 7 | 458 | 11 | 511 | 53 | 447 | 7 | * | |
| 51 | 164 | 20,276 | 0.8 | 18.1336 | 3.2 | 0.5473 | 3.3 | 0.0720 | 1.1 | 0.32 | 448 | 5 | 443 | 12 | 418 | 70 | 448 | 5 | * | |
| 15 | 59 | 14,844 | 0.9 | 17.7516 | 13.7 | 0.5595 | 14.2 | 0.0720 | 3.7 | 0.26 | 448 | 16 | 451 | 52 | 466 | 306 | 448 | 16 | * | |
| 44 | 90 | 17,816 | 0.6 | 17.4587 | 10.0 | 0.5716 | 10.8 | 0.0724 | 4.1 | 0.38 | 450 | 18 | 459 | 40 | 502 | 220 | 450 | 18 | * | |
| 35 | 167 | 16,806 | 0.9 | 18.3196 | 3.1 | 0.5462 | 3.7 | 0.0726 | 2.0 | 0.53 | 452 | 9 | 442 | 13 | 395 | 70 | 452 | 9 | * | |
| 2 | 175 | 31,240 | 0.8 | 17.6499 | 3.9 | 0.5692 | 4.4 | 0.0729 | 2.1 | 0.47 | 453 | 9 | 458 | 16 | 478 | 87 | 453 | 9 | * | |
| 33 | 173 | 28,802 | 0.6 | 17.2132 | 5.5 | 0.5864 | 7.6 | 0.0732 | 5.2 | 0.68 | 455 | 23 | 469 | 28 | 533 | 121 | 455 | 23 | * | |
| 39 | 49 | 33,219 | 0.8 | 17.3659 | 7.7 | 0.5822 | 8.5 | 0.0733 | 3.5 | 0.41 | 456 | 15 | 466 | 32 | 514 | 170 | 456 | 15 | * | |
| 57 | 153 | 17,755 | 0.9 | 17.9185 | 3.8 | 0.5649 | 5.3 | 0.0734 | 3.7 | 0.70 | 457 | 16 | 455 | 19 | 445 | 84 | 457 | 16 | * | |
| 76 | 151 | 7,698 | 0.7 | 17.7541 | 6.7 | 0.5704 | 6.9 | 0.0734 | 1.6 | 0.24 | 457 | 7 | 458 | 25 | 465 | 148 | 457 | 7 | * | |
| 21 | 244 | 59,623 | 0.7 | 17.4693 | 2.0 | 0.5797 | 2.7 | 0.0735 | 1.9 | 0.69 | 457 | 8 | 464 | 10 | 501 | 43 | 457 | 8 | * | |
| 38 | 524 | 92,985 | 0.7 | 17.4997 | 1.1 | 0.5804 | 1.8 | 0.0737 | 1.4 | 0.77 | 458 | 6 | 465 | 7 | 497 | 25 | 458 | 6 | * | |
| 93 | 58 | 30,700 | 1.4 | 18.4141 | 18.8 | 0.5534 | 19.1 | 0.0739 | 3.6 | 0.19 | 460 | 16 | 447 | 69 | 384 | 426 | 460 | 16 | * | |
| 24 | 164 | 30,414 | 0.8 | 18.1376 | 3.3 | 0.5621 | 3.8 | 0.0739 | 1.9 | 0.50 | 460 | 8 | 453 | 14 | 418 | 73 | 460 | 8 | * | |
| 30 | 126 | 27,435 | 0.9 | 17.8637 | 8.0 | 0.5717 | 8.3 | 0.0741 | 2.4 | 0.28 | 461 | 11 | 459 | 31 | 452 | 177 | 461 | 11 | * | |
| 61 | 106 | 11,191 | 0.5 | 18.1733 | 4.6 | 0.5631 | 5.1 | 0.0742 | 2.2 | 0.42 | 462 | 10 | 454 | 19 | 413 | 103 | 462 | 10 | * | |
| 69 | 341 | 56,715 | 0.8 | 17.7280 | 2.3 | 0.5788 | 3.0 | 0.0744 | 1.9 | 0.63 | 463 | 8 | 464 | 11 | 468 | 51 | 463 | 8 | | |
| 89 | 80 | 17,506 | 1.1 | 18.2678 | 5.9 | 0.5627 | 6.4 | 0.0746 | 2.4 | 0.38 | 464 | 11 | 453 | 23 | 402 | 132 | 464 | 11 | | |
| 18 | 273 | 61,168 | 0.8 | 17.9780 | 1.9 | 0.5718 | 2.4 | 0.0746 | 1.5 | 0.62 | 464 | 7 | 459 | 9 | 437 | 42 | 464 | 7 | | |

TABLE 3
*(continued)*

| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | Disc. (%) |
| VL10NB04 (n=85/101) | | | | | | | | | | | | | | | | | | | |
| 92 | 81 | 25,651 | 0.8 | 17.2299 | 11.7 | 0.5986 | 12.0 | 0.0748 | 2.8 | 0.23 | 465 | 12 | 476 | 46 | 531 | 257 | 465 | 12 | |
| 88 | 190 | 24,566 | 0.7 | 18.1390 | 4.3 | 0.5691 | 4.5 | 0.0749 | 1.0 | 0.22 | 465 | 4 | 457 | 16 | 417 | 97 | 465 | 4 | |
| 27 | 83 | 18,162 | 0.8 | 17.6256 | 5.6 | 0.5867 | 6.0 | 0.0750 | 2.2 | 0.37 | 466 | 10 | 469 | 23 | 481 | 124 | 466 | 10 | |
| 13 | 100 | 17,989 | 1.0 | 17.7380 | 4.5 | 0.5840 | 5.1 | 0.0751 | 2.3 | 0.46 | 467 | 11 | 467 | 19 | 467 | 100 | 467 | 11 | |
| 70 | 45 | 6,208 | 0.5 | 17.7105 | 7.8 | 0.5856 | 8.3 | 0.0752 | 2.7 | 0.33 | 468 | 12 | 468 | 31 | 471 | 174 | 468 | 12 | |
| 90 | 199 | 4,118 | 0.8 | 16.9934 | 4.4 | 0.6114 | 4.8 | 0.0754 | 1.9 | 0.40 | 468 | 9 | 484 | 18 | 561 | 95 | 468 | 9 | |
| 45 | 183 | 40,030 | 0.5 | 17.7009 | 3.2 | 0.5878 | 3.7 | 0.0755 | 1.8 | 0.49 | 469 | 8 | 469 | 14 | 472 | 71 | 469 | 8 | |
| 16 | 98 | 18,573 | 0.9 | 18.2943 | 7.1 | 0.5693 | 7.5 | 0.0755 | 2.5 | 0.33 | 469 | 11 | 458 | 28 | 398 | 160 | 469 | 11 | |
| 55 | 76 | 32,641 | 1.3 | 16.9494 | 6.5 | 0.6160 | 7.2 | 0.0757 | 3.1 | 0.43 | 471 | 14 | 487 | 28 | 567 | 141 | 471 | 14 | |
| 19 | 97 | 3,596 | 0.8 | 17.8009 | 8.4 | 0.5897 | 8.9 | 0.0761 | 2.9 | 0.33 | 473 | 13 | 471 | 33 | 459 | 186 | 473 | 13 | |
| 28 | 231 | 40,357 | 0.8 | 17.6043 | 2.1 | 0.6002 | 3.5 | 0.0766 | 2.8 | 0.80 | 476 | 13 | 477 | 13 | 484 | 46 | 476 | 13 | |
| 47 | 102 | 16,727 | 0.7 | 18.8299 | 4.4 | 0.5624 | 4.6 | 0.0768 | 1.2 | 0.27 | 477 | 6 | 453 | 17 | 333 | 99 | 477 | 6 | |
| 53 | 109 | 15,145 | 0.8 | 17.4450 | 7.6 | 0.6086 | 7.9 | 0.0770 | 1.9 | 0.24 | 478 | 9 | 483 | 30 | 504 | 168 | 478 | 9 | |
| 11 | 69 | 8,992 | 1.0 | 16.5955 | 9.4 | 0.6588 | 9.7 | 0.0793 | 2.4 | 0.25 | 492 | 11 | 514 | 39 | 613 | 203 | 492 | 11 | |
| 12 | 19 | 7,794 | 3.0 | 13.5939 | 11.9 | 1.6894 | 12.5 | 0.1666 | 3.7 | 0.30 | 993 | 34 | 1005 | 80 | 1029 | 242 | 993 | 34 | 4 |
| 7 | 176 | 24,912 | 1.5 | 13.3168 | 1.2 | 1.7338 | 7.2 | 0.1675 | 7.1 | 0.99 | 998 | 66 | 1021 | 47 | 1071 | 24 | 998 | 66 | 7 |
| 64 | 129 | 133,835 | 0.4 | 13.7559 | 2.4 | 1.6546 | 2.8 | 0.1651 | 1.4 | 0.49 | 985 | 12 | 991 | 18 | 1005 | 49 | 985 | 12 | 2 |
| 59 | 158 | 123,815 | 0.3 | 13.5832 | 1.5 | 1.7268 | 1.8 | 0.1701 | 1.1 | 0.60 | 1013 | 10 | 1019 | 12 | 1031 | 30 | 1013 | 10 | 2 |
| 41 | 147 | 55,949 | 0.9 | 13.4085 | 1.4 | 1.7602 | 1.9 | 0.1712 | 1.3 | 0.67 | 1019 | 12 | 1031 | 12 | 1057 | 29 | 1019 | 12 | 4 |
| 96 | 84 | 51,701 | 0.7 | 13.6331 | 2.9 | 1.7368 | 3.2 | 0.1717 | 1.4 | 0.44 | 1022 | 13 | 1022 | 20 | 1024 | 58 | 1022 | 13 | 0 |
| 77 | 103 | 69,244 | 0.6 | 13.5003 | 3.3 | 1.7368 | 3.5 | 0.1701 | 0.9 | 0.25 | 1012 | 8 | 1022 | 22 | 1043 | 67 | 1012 | 8 | 3 |
| 42 | 41 | 16,815 | 0.9 | 13.4923 | 4.9 | 1.7923 | 5.2 | 0.1754 | 1.8 | 0.34 | 1042 | 17 | 1043 | 34 | 1045 | 99 | 1042 | 17 | 0 |
| 3 | 101 | 37,137 | 1.0 | 13.4834 | 3.0 | 1.8224 | 3.4 | 0.1782 | 1.6 | 0.47 | 1057 | 16 | 1054 | 22 | 1046 | 60 | 1057 | 16 | -1 |
| 68 | 463 | 207,172 | 0.0 | 12.9940 | 0.4 | 1.8798 | 1.9 | 0.1772 | 1.9 | 0.98 | 1051 | 18 | 1074 | 13 | 1120 | 7 | 1051 | 18 | 6 |
| 54 | 168 | 51,769 | 0.4 | 13.3576 | 1.3 | 1.8420 | 2.4 | 0.1785 | 2.0 | 0.84 | 1059 | 20 | 1061 | 16 | 1065 | 27 | 1059 | 20 | 1 |
| 81 | 147 | 115,894 | 0.4 | 13.2025 | 0.9 | 1.8756 | 1.4 | 0.1796 | 1.1 | 0.77 | 1065 | 11 | 1073 | 9 | 1088 | 18 | 1065 | 11 | 2 |
| 80 | 194 | 100,512 | 1.3 | 13.3198 | 1.2 | 1.8613 | 1.4 | 0.1798 | 0.8 | 0.52 | 1066 | 7 | 1067 | 10 | 1071 | 25 | 1066 | 7 | 0 |
| 75 | 85 | 35,252 | 0.5 | 13.3182 | 2.4 | 1.8636 | 2.6 | 0.1800 | 0.8 | 0.33 | 1067 | 8 | 1068 | 17 | 1071 | 49 | 1067 | 8 | 0 |
| 62 | 389 | 168,839 | 0.1 | 12.9293 | 0.4 | 1.9235 | 1.9 | 0.1804 | 1.8 | 0.97 | 1069 | 18 | 1089 | 13 | 1130 | 9 | 1069 | 18 | 5 |
| 8 | 45 | 15,906 | 0.6 | 12.9760 | 2.5 | 1.9197 | 2.8 | 0.1807 | 1.3 | 0.47 | 1071 | 13 | 1088 | 19 | 1123 | 50 | 1071 | 13 | 5 |
| 4 | 586 | 278,585 | 0.1 | 13.3190 | 0.8 | 1.8778 | 2.1 | 0.1814 | 2.0 | 0.93 | 1075 | 20 | 1073 | 14 | 1071 | 16 | 1075 | 20 | 0 |

TABLE 3
*(continued)*

| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | Disc. (%) |
| VL10NB04 (n=85/101) | | | | | | | | | | | | | | | | | | | |
| 43 | 95 | 29,212 | 0.5 | 13.2549 | 3.5 | 1.8687 | 3.7 | 0.1796 | 1.2 | 0.32 | 1065 | 12 | 1070 | 25 | 1080 | 71 | 1065 | 12 | 1 |
| 25 | 185 | 34,089 | 0.4 | 12.7710 | 0.6 | 2.0058 | 3.5 | 0.1858 | 3.5 | 0.99 | 1098 | 35 | 1117 | 24 | 1155 | 12 | 1098 | 35 | 5 |
| 50 | 47 | 29,503 | 0.3 | 12.9149 | 2.0 | 2.1124 | 3.2 | 0.1979 | 2.5 | 0.78 | 1164 | 26 | 1153 | 22 | 1132 | 40 | 1164 | 26 | -3 |
| 56 | 41 | 17,432 | 0.8 | 12.6608 | 4.5 | 2.0346 | 5.5 | 0.1868 | 3.2 | 0.58 | 1104 | 33 | 1127 | 38 | 1172 | 90 | 1104 | 33 | 6 |
| 60 | 44 | 16,415 | 0.4 | 12.6538 | 3.5 | 2.1246 | 3.6 | 0.1950 | 1.1 | 0.30 | 1148 | 12 | 1157 | 25 | 1173 | 68 | 1148 | 12 | 2 |
| 67 | 150 | 110,758 | 0.6 | 12.4647 | 1.1 | 2.2265 | 1.6 | 0.2013 | 1.2 | 0.73 | 1182 | 13 | 1189 | 11 | 1203 | 22 | 1182 | 13 | 2 |
| 95 | 547 | 47,997 | 0.2 | 12.2536 | 0.4 | 2.2386 | 1.3 | 0.1989 | 1.2 | 0.94 | 1170 | 13 | 1193 | 9 | 1236 | 9 | 1236 | 9 | 5 |
| 99 | 376 | 141,903 | 1.1 | 12.0762 | 0.3 | 2.4208 | 1.9 | 0.2120 | 1.9 | 0.98 | 1240 | 21 | 1249 | 14 | 1265 | 7 | 1265 | 7 | 2 |
| 94 | 127 | 79,005 | 0.4 | 11.6542 | 1.5 | 2.6145 | 2.1 | 0.2210 | 1.5 | 0.70 | 1287 | 17 | 1305 | 16 | 1334 | 30 | 1334 | 30 | 4 |
| 48 | 714 | 36,656 | 0.2 | 11.4743 | 0.2 | 2.6553 | 2.2 | 0.2210 | 2.1 | 0.99 | 1287 | 25 | 1316 | 16 | 1364 | 5 | 1364 | 5 | 6 |
| 97 | 85 | 85,829 | 0.4 | 11.2981 | 1.5 | 2.9177 | 3.0 | 0.2391 | 2.6 | 0.87 | 1382 | 32 | 1387 | 22 | 1394 | 28 | 1394 | 28 | 1 |
| 83 | 70 | 57,312 | 0.8 | 10.9707 | 1.9 | 3.0301 | 2.2 | 0.2411 | 1.1 | 0.49 | 1392 | 14 | 1415 | 17 | 1450 | 37 | 1450 | 37 | 4 |
| 66 | 86 | 91,758 | 0.4 | 10.9415 | 1.4 | 3.0959 | 1.8 | 0.2457 | 1.1 | 0.61 | 1416 | 14 | 1432 | 14 | 1455 | 27 | 1455 | 27 | 3 |
| 14 | 76 | 74,092 | 0.5 | 10.9070 | 1.5 | 3.1993 | 1.9 | 0.2531 | 1.1 | 0.60 | 1454 | 15 | 1457 | 15 | 1461 | 29 | 1461 | 29 | 0 |
| 82 | 380 | 265,962 | 0.5 | 9.9039 | 0.2 | 3.9000 | 0.9 | 0.2801 | 0.9 | 0.98 | 1592 | 13 | 1614 | 8 | 1642 | 4 | 1642 | 4 | 3 |
| 84 | 92 | 56,014 | 0.9 | 9.8186 | 0.9 | 4.1522 | 1.3 | 0.2957 | 1.0 | 0.75 | 1670 | 15 | 1665 | 11 | 1658 | 16 | 1658 | 16 | -1 |
| 63 | 52 | 61,386 | 0.8 | 9.5025 | 1.6 | 4.3044 | 2.6 | 0.2967 | 2.0 | 0.79 | 1675 | 30 | 1694 | 21 | 1718 | 29 | 1718 | 29 | 3 |
| 17 | 89 | 34,758 | 0.8 | 9.2027 | 0.8 | 4.5068 | 2.8 | 0.3008 | 2.7 | 0.95 | 1695 | 40 | 1732 | 23 | 1777 | 15 | 1777 | 15 | 5 |
| 10 | 109 | 62,539 | 0.4 | 8.9157 | 0.7 | 4.9217 | 6.1 | 0.3183 | 6.1 | 0.99 | 1781 | 94 | 1806 | 52 | 1835 | 13 | 1835 | 13 | 3 |
| 6 | 51 | 37,699 | 0.3 | 8.8845 | 1.2 | 5.1265 | 1.5 | 0.3303 | 0.9 | 0.57 | 1840 | 14 | 1841 | 13 | 1841 | 23 | 1841 | 23 | 0 |
| 49 | 210 | 277,713 | 0.4 | 8.5939 | 0.5 | 5.5800 | 1.8 | 0.3478 | 1.7 | 0.96 | 1924 | 28 | 1913 | 15 | 1901 | 9 | 1901 | 9 | -1 |
| 100 | 35 | 23,862 | 1.5 | 7.1890 | 2.3 | 7.1620 | 3.3 | 0.3734 | 2.3 | 0.70 | 2045 | 40 | 2132 | 29 | 2216 | 40 | 2216 | 40 | 8 |
| 65 | 305 | 166,053 | 0.4 | 6.7524 | 0.9 | 8.7905 | 8.0 | 0.4305 | 8.0 | 0.99 | 2308 | 155 | 2317 | 73 | 2324 | 15 | 2324 | 15 | 1 |
| 9 | 130 | 100,038 | 0.3 | 6.2354 | 0.3 | 9.5351 | 2.1 | 0.4312 | 2.1 | 0.99 | 2311 | 40 | 2391 | 19 | 2460 | 4 | 2460 | 4 | 6 |
| 85 | 44 | 56,340 | 0.9 | 5.8187 | 0.9 | 11.2702 | 4.2 | 0.4756 | 4.1 | 0.98 | 2508 | 86 | 2546 | 39 | 2576 | 14 | 2576 | 14 | 3 |
| 74 | 287 | 453,546 | 0.4 | 5.6935 | 0.3 | 12.0885 | 1.3 | 0.4992 | 1.3 | 0.97 | 2610 | 28 | 2611 | 12 | 2612 | 5 | 2612 | 5 | 0 |
| 1 | 115 | 138,188 | 1.4 | 5.4564 | 0.2 | 12.6096 | 0.9 | 0.4990 | 0.9 | 0.97 | 2610 | 20 | 2651 | 9 | 2683 | 4 | 2683 | 4 | 3 |
| 31 | 169 | 810,402 | 0.6 | 5.3764 | 0.4 | 13.6833 | 1.4 | 0.5336 | 1.4 | 0.96 | 2756 | 31 | 2728 | 14 | 2707 | 7 | 2707 | 7 | -2 |
| 71 | 53 | 79,228 | 0.7 | 5.3454 | 0.6 | 13.4778 | 1.6 | 0.5225 | 1.4 | 0.91 | 2710 | 32 | 2714 | 15 | 2717 | 11 | 2717 | 11 | 0 |
| 34 | 17 | 31,434 | 0.7 | 5.2606 | 1.6 | 13.3873 | 2.2 | 0.5108 | 1.5 | 0.68 | 2660 | 33 | 2707 | 21 | 2743 | 27 | 2743 | 27 | 3 |

TABLE 3
*(continued)*

| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | | Disc. (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | | | |
| VL10NB04 (n=85/101) | | | | | | | | | | | | | | | | | | | | |
| 20 | 220 | 112,898 | 0.5 | 5.2290 | 0.2 | 12.4503 | 2.2 | 0.4722 | 2.2 | 1.00 | 2493 | 46 | 2639 | 21 | 2753 | 4 | 2753 | 4 | | 9 |
| 79 | 44 | 105,131 | 1.3 | 5.1902 | 0.7 | 13.4023 | 2.9 | 0.5045 | 2.8 | 0.97 | 2633 | 60 | 2708 | 27 | 2765 | 12 | 2765 | 12 | | 5 |
| 52 | 48 | 42,751 | 0.8 | 5.0383 | 0.5 | 14.7635 | 1.5 | 0.5395 | 1.4 | 0.95 | 2781 | 32 | 2800 | 14 | 2814 | 8 | 2814 | 8 | | 1 |
| 46 | 193 | 50,542 | 0.4 | 5.0370 | 0.2 | 13.7573 | 2.1 | 0.5026 | 2.1 | 0.99 | 2625 | 45 | 2733 | 20 | 2814 | 4 | 2814 | 4 | | 7 |
| 23 | 117 | 240,424 | 1.0 | 4.4975 | 0.2 | 17.8040 | 2.2 | 0.5807 | 2.2 | 1.00 | 2952 | 53 | 2979 | 22 | 2998 | 3 | 2998 | 3 | | 2 |
| *Rejected Analyses (>10% discordance, >5% reverse discordance, or >10% 2s age uncertainty)* | | | | | | | | | | | | | | | | | | | | |
| 73 | 247 | 6,120 | 0.7 | 15.5792 | 8.6 | 0.6261 | 13.2 | 0.0707 | 10.1 | 0.76 | 441 | 43 | 494 | 52 | 748 | 182 | | | | |
| 58 | 364 | 7,030 | 4.1 | 12.8648 | 1.2 | 1.2126 | 4.9 | 0.1131 | 4.7 | 0.97 | 691 | 31 | 806 | 27 | 1140 | 23 | | | | |
| 29 | 205 | 271,147 | 0.3 | 14.4684 | 2.3 | 1.2510 | 2.6 | 0.1313 | 1.1 | 0.42 | 795 | 8 | 824 | 14 | 902 | 48 | | | | |
| 22 | 5 | 2,707 | - | 12.4411 | 29.4 | 1.8947 | 31.1 | 0.1710 | 10.0 | 0.32 | 1017 | 94 | 1079 | 210 | 1206 | 593 | | | | |
| 5 | 15 | 9,163 | 0.6 | 12.6804 | 10.6 | 1.8834 | 12.3 | 0.1732 | 6.2 | 0.51 | 1030 | 59 | 1075 | 82 | 1169 | 210 | | | | |
| 91 | 12 | 5,295 | 1.3 | 15.0070 | 16.8 | 1.6332 | 17.4 | 0.1778 | 4.5 | 0.26 | 1055 | 44 | 983 | 110 | 826 | 352 | | | | |
| 98 | 34 | 11,512 | 0.6 | 13.5366 | 7.1 | 1.8269 | 7.4 | 0.1794 | 2.2 | 0.29 | 1063 | 21 | 1055 | 49 | 1038 | 144 | | | | |
| 37 | 25 | 14,443 | 1.1 | 13.9992 | 11.8 | 1.7672 | 12.4 | 0.1794 | 3.9 | 0.31 | 1064 | 38 | 1033 | 81 | 970 | 242 | | | | |
| 87 | 38 | 704 | 0.3 | 13.1604 | 7.7 | 1.9264 | 9.2 | 0.1839 | 5.1 | 0.55 | 1088 | 51 | 1090 | 62 | 1095 | 155 | | | | |
| 78 | 47 | 20,528 | 0.4 | 12.1887 | 4.8 | 2.0986 | 5.3 | 0.1855 | 2.1 | 0.40 | 1097 | 22 | 1148 | 36 | 1247 | 95 | | | | |
| 32 | 372 | 69,890 | 0.3 | 12.0378 | 0.8 | 2.1629 | 1.5 | 0.1888 | 1.3 | 0.87 | 1115 | 13 | 1169 | 11 | 1271 | 15 | | | | |
| 86 | 17 | 10,374 | 0.6 | 11.1213 | 4.9 | 2.6236 | 7.2 | 0.2116 | 5.3 | 0.73 | 1237 | 59 | 1307 | 53 | 1424 | 95 | | | | |
| 26 | 18 | 11,363 | 0.8 | 12.2729 | 7.0 | 2.5099 | 7.4 | 0.2234 | 2.5 | 0.33 | 1300 | 29 | 1275 | 54 | 1233 | 138 | | | | |
| 40 | 14 | 14,595 | 0.7 | 11.0941 | 10.9 | 2.8150 | 12.7 | 0.2265 | 6.5 | 0.51 | 1316 | 78 | 1360 | 96 | 1428 | 209 | | | | |
| 72 | 76 | 162,957 | 0.4 | 5.5473 | 0.4 | 10.3180 | 2.8 | 0.4151 | 2.7 | 0.99 | 2238 | 52 | 2464 | 26 | 2655 | 7 | | | | |
| VL10NB05 (n=93/100) | | | | | | | | | | | | | | | | | | | | |
| 60 | 340 | 71,649 | 0.4 | 17.7591 | 2.1 | 0.5647 | 2.5 | 0.0727 | 1.3 | 0.54 | 453 | 6 | 455 | 9 | 465 | 46 | 453 | 6 | * | |
| 57 | 666 | 136,526 | 0.5 | 17.7032 | 0.7 | 0.5678 | 1.1 | 0.0729 | 0.8 | 0.79 | 454 | 4 | 457 | 4 | 472 | 14 | 454 | 4 | * | |
| 43 | 178 | 41,423 | 0.5 | 17.5422 | 2.5 | 0.5733 | 3.1 | 0.0729 | 1.8 | 0.59 | 454 | 8 | 460 | 12 | 492 | 55 | 454 | 8 | * | |
| 75 | 183 | 34,578 | 0.4 | 17.8276 | 3.9 | 0.5665 | 4.0 | 0.0733 | 1.0 | 0.26 | 456 | 5 | 456 | 15 | 456 | 86 | 456 | 5 | * | |
| 56 | 749 | 138,368 | 0.5 | 17.6600 | 0.7 | 0.5734 | 0.9 | 0.0734 | 0.5 | 0.59 | 457 | 2 | 460 | 3 | 477 | 16 | 457 | 2 | * | |

TABLE 3
*(continued)*

| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | Disc. (%) |
| VL10NB05 (n=93/100) | | | | | | | | | | | | | | | | | | | |
| 70 | 224 | 103,655 | 0.5 | 18.0022 | 2.1 | 0.5626 | 2.5 | 0.0735 | 1.2 | 0.50 | 457 | 5 | 453 | 9 | 434 | 48 | 457 | 5 | * |
| 58 | 202 | 63,784 | 0.5 | 17.8653 | 3.4 | 0.5686 | 3.8 | 0.0737 | 1.6 | 0.42 | 458 | 7 | 457 | 14 | 451 | 76 | 458 | 7 | * |
| 63 | 121 | 28,128 | 0.5 | 17.6831 | 4.1 | 0.5750 | 4.3 | 0.0737 | 1.3 | 0.31 | 459 | 6 | 461 | 16 | 474 | 90 | 459 | 6 | * |
| 32 | 219 | 57,842 | 0.4 | 17.9053 | 3.0 | 0.5684 | 3.3 | 0.0738 | 1.4 | 0.42 | 459 | 6 | 457 | 12 | 446 | 67 | 459 | 6 | * |
| 59 | 301 | 57,226 | 0.3 | 17.6449 | 2.8 | 0.5768 | 3.0 | 0.0738 | 1.0 | 0.34 | 459 | 5 | 462 | 11 | 479 | 62 | 459 | 5 | * |
| 14 | 106 | 20,836 | 0.7 | 18.2159 | 5.3 | 0.5602 | 5.5 | 0.0740 | 1.6 | 0.28 | 460 | 7 | 452 | 20 | 408 | 118 | 460 | 7 | * |
| 8 | 306 | 61,451 | 0.6 | 17.8446 | 2.1 | 0.5721 | 2.3 | 0.0740 | 1.0 | 0.42 | 460 | 4 | 459 | 9 | 454 | 46 | 460 | 4 | * |
| 77 | 316 | 67,219 | 0.3 | 17.7070 | 1.6 | 0.5778 | 1.7 | 0.0742 | 0.6 | 0.38 | 461 | 3 | 463 | 6 | 471 | 35 | 461 | 3 | |
| 13 | 170 | 39,286 | 0.3 | 17.7339 | 3.8 | 0.5774 | 4.1 | 0.0743 | 1.6 | 0.38 | 462 | 7 | 463 | 15 | 468 | 84 | 462 | 7 | |
| 24 | 192 | 39,048 | 0.3 | 17.9455 | 3.3 | 0.5715 | 3.5 | 0.0744 | 1.2 | 0.35 | 463 | 5 | 459 | 13 | 441 | 73 | 463 | 5 | |
| 47 | 243 | 39,031 | 0.2 | 17.8910 | 2.6 | 0.5736 | 2.8 | 0.0744 | 1.1 | 0.38 | 463 | 5 | 460 | 10 | 448 | 58 | 463 | 5 | |
| 45 | 403 | 106,624 | 1.0 | 17.7059 | 0.9 | 0.5799 | 1.5 | 0.0745 | 1.2 | 0.79 | 463 | 5 | 464 | 5 | 471 | 20 | 463 | 5 | |
| 68 | 237 | 51,751 | 0.3 | 17.5305 | 1.9 | 0.5858 | 2.1 | 0.0745 | 0.9 | 0.42 | 463 | 4 | 468 | 8 | 493 | 41 | 463 | 4 | |
| 35 | 715 | 125,497 | 0.4 | 17.5847 | 1.2 | 0.5841 | 1.3 | 0.0745 | 0.5 | 0.37 | 463 | 2 | 467 | 5 | 486 | 26 | 463 | 2 | |
| 10 | 515 | 199,627 | 0.4 | 17.6415 | 1.0 | 0.5826 | 2.9 | 0.0745 | 2.7 | 0.94 | 463 | 12 | 466 | 11 | 479 | 22 | 463 | 12 | |
| 62 | 214 | 30,462 | 0.3 | 17.8271 | 3.0 | 0.5765 | 3.4 | 0.0745 | 1.5 | 0.45 | 463 | 7 | 462 | 12 | 456 | 67 | 463 | 7 | |
| 88 | 300 | 73,005 | 0.2 | 17.6317 | 2.9 | 0.5832 | 3.0 | 0.0746 | 0.7 | 0.24 | 464 | 3 | 467 | 11 | 480 | 65 | 464 | 3 | |
| 44 | 461 | 117,661 | 0.5 | 17.6966 | 0.8 | 0.5814 | 1.4 | 0.0746 | 1.1 | 0.79 | 464 | 5 | 465 | 5 | 472 | 19 | 464 | 5 | |
| 94 | 117 | 30,355 | 0.4 | 17.6911 | 7.6 | 0.5824 | 7.9 | 0.0747 | 2.3 | 0.29 | 465 | 10 | 466 | 30 | 473 | 168 | 465 | 10 | |
| 48 | 111 | 32,418 | 0.3 | 18.1962 | 3.2 | 0.5663 | 3.3 | 0.0747 | 1.0 | 0.29 | 465 | 4 | 456 | 12 | 410 | 72 | 465 | 4 | |
| 12 | 204 | 39,695 | 0.5 | 17.5396 | 2.6 | 0.5877 | 3.1 | 0.0748 | 1.8 | 0.57 | 465 | 8 | 469 | 12 | 492 | 57 | 465 | 8 | |
| 89 | 146 | 34,698 | 0.4 | 17.8322 | 2.3 | 0.5782 | 2.4 | 0.0748 | 0.8 | 0.31 | 465 | 3 | 463 | 9 | 455 | 51 | 465 | 3 | |
| 40 | 501 | 15,007 | 0.5 | 17.4793 | 1.8 | 0.5900 | 2.1 | 0.0748 | 1.1 | 0.50 | 465 | 5 | 471 | 8 | 500 | 41 | 465 | 5 | |
| 9 | 221 | 109,024 | 0.3 | 17.4879 | 3.0 | 0.5901 | 3.1 | 0.0748 | 0.9 | 0.28 | 465 | 4 | 471 | 12 | 499 | 66 | 465 | 4 | |
| 25 | 256 | 54,765 | 0.6 | 17.7317 | 1.4 | 0.5828 | 2.3 | 0.0749 | 1.8 | 0.78 | 466 | 8 | 466 | 9 | 468 | 32 | 466 | 8 | |
| 42 | 1713 | 477,936 | 0.4 | 17.6825 | 0.3 | 0.5857 | 0.8 | 0.0751 | 0.7 | 0.90 | 467 | 3 | 468 | 3 | 474 | 8 | 467 | 3 | |
| 3 | 337 | 163,888 | 0.5 | 17.7145 | 1.7 | 0.5847 | 2.2 | 0.0751 | 1.4 | 0.64 | 467 | 6 | 467 | 8 | 470 | 38 | 467 | 6 | |
| 84 | 753 | 308,073 | 0.8 | 17.7833 | 0.8 | 0.5826 | 1.1 | 0.0751 | 0.7 | 0.64 | 467 | 3 | 466 | 4 | 462 | 18 | 467 | 3 | |
| 34 | 238 | 46,836 | 0.3 | 17.7255 | 1.6 | 0.5851 | 1.8 | 0.0752 | 0.8 | 0.45 | 468 | 4 | 468 | 7 | 469 | 35 | 468 | 4 | |

TABLE 3
*(continued)*

| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | Disc. (%) |
| VL10NB05 (n=93/100) | | | | | | | | | | | | | | | | | | | |
| 50 | 357 | 112,016 | 0.3 | 17.6809 | 1.7 | 0.5866 | 2.0 | 0.0752 | 1.1 | 0.54 | 468 | 5 | 469 | 8 | 474 | 38 | 468 | 5 | |
| 66 | 125 | 26,602 | 0.4 | 18.1772 | 6.3 | 0.5707 | 6.4 | 0.0752 | 0.8 | 0.13 | 468 | 4 | 458 | 24 | 413 | 142 | 468 | 4 | |
| 52 | 250 | 49,570 | 0.2 | 17.5733 | 2.1 | 0.5909 | 2.4 | 0.0753 | 1.2 | 0.51 | 468 | 6 | 471 | 9 | 488 | 46 | 468 | 6 | |
| 4 | 117 | 15,693 | 0.5 | 17.1846 | 5.8 | 0.6051 | 6.0 | 0.0754 | 1.8 | 0.30 | 469 | 8 | 480 | 23 | 537 | 126 | 469 | 8 | |
| 20 | 617 | 132,511 | 0.6 | 17.7591 | 1.7 | 0.5861 | 1.8 | 0.0755 | 0.6 | 0.35 | 469 | 3 | 468 | 7 | 465 | 37 | 469 | 3 | |
| 36 | 202 | 66,517 | 0.5 | 17.8852 | 3.5 | 0.5820 | 3.6 | 0.0755 | 0.9 | 0.24 | 469 | 4 | 466 | 13 | 449 | 77 | 469 | 4 | |
| 33 | 833 | 212,323 | 0.4 | 17.5609 | 0.7 | 0.5928 | 4.1 | 0.0755 | 4.0 | 0.98 | 469 | 18 | 473 | 15 | 489 | 16 | 469 | 18 | |
| 31 | 236 | 55,106 | 0.3 | 17.8426 | 3.7 | 0.5835 | 3.8 | 0.0755 | 0.9 | 0.23 | 469 | 4 | 467 | 14 | 454 | 82 | 469 | 4 | |
| 74 | 884 | 211,046 | 0.5 | 17.6270 | 0.6 | 0.5907 | 1.4 | 0.0755 | 1.2 | 0.89 | 469 | 6 | 471 | 5 | 481 | 13 | 469 | 6 | |
| 82 | 339 | 118,310 | 0.2 | 17.7152 | 1.6 | 0.5880 | 1.7 | 0.0755 | 0.8 | 0.43 | 469 | 3 | 470 | 7 | 470 | 35 | 469 | 3 | |
| 39 | 424 | 83,394 | 0.4 | 17.7462 | 1.9 | 0.5871 | 2.0 | 0.0756 | 0.8 | 0.37 | 470 | 3 | 469 | 8 | 466 | 42 | 470 | 3 | |
| 37 | 250 | 58,246 | 0.7 | 17.7305 | 2.8 | 0.5879 | 3.1 | 0.0756 | 1.5 | 0.47 | 470 | 7 | 470 | 12 | 468 | 61 | 470 | 7 | |
| 49 | 241 | 74,094 | 0.6 | 17.6554 | 1.7 | 0.5906 | 2.3 | 0.0756 | 1.4 | 0.63 | 470 | 6 | 471 | 8 | 478 | 39 | 470 | 6 | |
| 7 | 840 | 213,167 | 0.5 | 17.6665 | 1.1 | 0.5906 | 1.3 | 0.0757 | 0.8 | 0.58 | 470 | 3 | 471 | 5 | 476 | 23 | 470 | 3 | |
| 69 | 152 | 81,476 | 0.4 | 18.1710 | 4.1 | 0.5743 | 4.3 | 0.0757 | 1.3 | 0.31 | 470 | 6 | 461 | 16 | 414 | 91 | 470 | 6 | |
| 86 | 403 | 94,801 | 0.4 | 17.6083 | 1.4 | 0.5927 | 2.2 | 0.0757 | 1.7 | 0.76 | 470 | 8 | 473 | 8 | 483 | 32 | 470 | 8 | |
| 67 | 977 | 200,363 | 0.6 | 17.6077 | 0.7 | 0.5927 | 1.2 | 0.0757 | 0.9 | 0.78 | 470 | 4 | 473 | 5 | 484 | 16 | 470 | 4 | |
| 93 | 378 | 129,231 | 0.5 | 17.7281 | 1.4 | 0.5894 | 1.7 | 0.0758 | 0.9 | 0.51 | 471 | 4 | 470 | 6 | 468 | 32 | 471 | 4 | |
| 80 | 1411 | 486,104 | 1.0 | 17.6139 | 0.4 | 0.5936 | 0.7 | 0.0758 | 0.5 | 0.77 | 471 | 2 | 473 | 3 | 483 | 10 | 471 | 2 | |
| 79 | 320 | 46,052 | 0.6 | 17.9014 | 2.4 | 0.5850 | 2.7 | 0.0760 | 1.1 | 0.41 | 472 | 5 | 468 | 10 | 447 | 54 | 472 | 5 | |
| 41 | 585 | 116,094 | 0.3 | 17.7057 | 1.2 | 0.5920 | 1.4 | 0.0760 | 0.6 | 0.46 | 472 | 3 | 472 | 5 | 471 | 27 | 472 | 3 | |
| 5 | 193 | 32,044 | 0.5 | 18.0341 | 2.9 | 0.5816 | 3.1 | 0.0761 | 0.9 | 0.30 | 473 | 4 | 465 | 12 | 430 | 66 | 473 | 4 | |
| 85 | 400 | 90,316 | 1.4 | 17.5291 | 1.3 | 0.5984 | 1.6 | 0.0761 | 0.9 | 0.54 | 473 | 4 | 476 | 6 | 493 | 29 | 473 | 4 | |
| 28 | 700 | 218,220 | 0.2 | 17.6189 | 0.7 | 0.5956 | 1.5 | 0.0761 | 1.3 | 0.87 | 473 | 6 | 474 | 6 | 482 | 16 | 473 | 6 | |
| 22 | 460 | 90,462 | 0.4 | 17.7376 | 1.3 | 0.5917 | 1.5 | 0.0761 | 0.7 | 0.48 | 473 | 3 | 472 | 6 | 467 | 29 | 473 | 3 | |
| 83 | 376 | 125,416 | 0.5 | 17.4875 | 1.6 | 0.6006 | 1.9 | 0.0762 | 1.1 | 0.58 | 473 | 5 | 478 | 7 | 499 | 35 | 473 | 5 | |
| 100 | 202 | 41,218 | 0.5 | 17.6082 | 2.5 | 0.5996 | 3.4 | 0.0766 | 2.4 | 0.69 | 476 | 11 | 477 | 13 | 483 | 55 | 476 | 11 | |
| 11 | 1739 | 92,999 | 0.5 | 17.6541 | 0.6 | 0.5981 | 1.4 | 0.0766 | 1.2 | 0.88 | 476 | 6 | 476 | 5 | 478 | 14 | 476 | 6 | |
| 92 | 192 | 29,586 | 0.4 | 17.7006 | 2.6 | 0.5966 | 2.7 | 0.0766 | 0.8 | 0.29 | 476 | 4 | 475 | 10 | 472 | 58 | 476 | 4 | |
| 81 | 729 | 103,355 | 0.6 | 17.6389 | 1.0 | 0.5988 | 1.5 | 0.0766 | 1.1 | 0.76 | 476 | 5 | 476 | 6 | 480 | 21 | 476 | 5 | |

TABLE 3
*(continued)*

| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | Disc. (%) |
| VL10NB05 (n=93/100) | | | | | | | | | | | | | | | | | | | |
| 87 | 381 | 60,475 | 0.4 | 17.7808 | 1.3 | 0.5945 | 2.0 | 0.0767 | 1.5 | 0.76 | 476 | 7 | 474 | 7 | 462 | 28 | 476 | 7 | |
| 51 | 481 | 201,934 | 0.6 | 17.7391 | 1.4 | 0.5962 | 2.0 | 0.0767 | 1.4 | 0.71 | 476 | 7 | 475 | 8 | 467 | 31 | 476 | 7 | |
| 91 | 165 | 34,058 | 0.5 | 18.3711 | 3.7 | 0.5776 | 3.9 | 0.0770 | 1.2 | 0.31 | 478 | 6 | 463 | 14 | 389 | 83 | 478 | 6 | |
| 95 | 274 | 39,825 | 0.2 | 17.5482 | 2.1 | 0.6052 | 2.8 | 0.0770 | 1.8 | 0.64 | 478 | 8 | 481 | 11 | 491 | 47 | 478 | 8 | |
| 21 | 1279 | 388,849 | 0.5 | 17.7269 | 0.4 | 0.5992 | 1.2 | 0.0770 | 1.1 | 0.93 | 478 | 5 | 477 | 4 | 469 | 10 | 478 | 5 | |
| 17 | 96 | 77,699 | 0.7 | 18.3523 | 7.1 | 0.5789 | 7.6 | 0.0770 | 2.6 | 0.35 | 478 | 12 | 464 | 28 | 391 | 159 | 478 | 12 | |
| 26 | 353 | 109,254 | 0.2 | 17.5176 | 2.0 | 0.6074 | 2.5 | 0.0772 | 1.5 | 0.60 | 479 | 7 | 482 | 10 | 495 | 44 | 479 | 7 | |
| 96 | 638 | 96,516 | 0.3 | 17.6560 | 1.2 | 0.6035 | 1.3 | 0.0773 | 0.6 | 0.46 | 480 | 3 | 479 | 5 | 477 | 26 | 480 | 3 | |
| 98 | 820 | 236,603 | 0.7 | 17.4680 | 0.8 | 0.6104 | 1.8 | 0.0773 | 1.6 | 0.90 | 480 | 8 | 484 | 7 | 501 | 18 | 480 | 8 | |
| 18 | 130 | 24,872 | 0.5 | 17.6302 | 4.1 | 0.6080 | 4.3 | 0.0777 | 1.4 | 0.31 | 483 | 6 | 482 | 17 | 481 | 91 | 483 | 6 | |
| 23 | 575 | 126,867 | 0.5 | 17.6116 | 0.8 | 0.6089 | 1.3 | 0.0778 | 1.0 | 0.80 | 483 | 5 | 483 | 5 | 483 | 17 | 483 | 5 | |
| 71 | 16 | 2,830 | 0.4 | 18.8640 | 36.3 | 0.6168 | 36.6 | 0.0844 | 4.3 | 0.12 | 522 | 22 | 488 | 143 | 329 | 849 | 522 | 22 | |
| 72 | 62 | 27,096 | 0.5 | 17.6445 | 10.6 | 0.6841 | 10.8 | 0.0875 | 1.9 | 0.18 | 541 | 10 | 529 | 45 | 479 | 236 | 541 | 10 | |
| 61 | 36 | 7,375 | 0.5 | 16.9372 | 10.9 | 0.7230 | 11.5 | 0.0888 | 3.5 | 0.31 | 549 | 18 | 552 | 49 | 569 | 238 | 549 | 18 | |
| 99 | 209 | 81,162 | 0.7 | 16.5843 | 1.7 | 0.8640 | 2.7 | 0.1039 | 2.1 | 0.78 | 637 | 13 | 632 | 13 | 614 | 36 | 637 | 13 | -4 |
| 64 | 73 | 37,022 | 0.4 | 12.7637 | 2.0 | 2.0445 | 2.3 | 0.1893 | 1.3 | 0.54 | 1117 | 13 | 1130 | 16 | 1156 | 39 | 1117 | 13 | 3 |
| 38 | 290 | 161,318 | 0.2 | 12.3454 | 0.6 | 2.2968 | 0.8 | 0.2056 | 0.5 | 0.61 | 1206 | 5 | 1211 | 6 | 1221 | 12 | 1221 | 12 | 1 |
| 29 | 259 | 205,198 | 0.7 | 11.6963 | 0.7 | 2.6857 | 1.0 | 0.2278 | 0.7 | 0.68 | 1323 | 8 | 1325 | 7 | 1327 | 14 | 1327 | 14 | 0 |
| 1 | 175 | 108,526 | 0.5 | 11.6219 | 0.8 | 2.6900 | 1.0 | 0.2267 | 0.6 | 0.60 | 1317 | 7 | 1326 | 7 | 1339 | 15 | 1339 | 15 | 2 |
| 65 | 99 | 64,992 | 0.7 | 10.5435 | 1.0 | 3.5424 | 1.5 | 0.2709 | 1.1 | 0.74 | 1545 | 15 | 1537 | 12 | 1525 | 19 | 1525 | 19 | -1 |
| 97 | 175 | 172,145 | 0.2 | 9.7496 | 0.6 | 4.2717 | 1.3 | 0.3021 | 1.2 | 0.90 | 1701 | 18 | 1688 | 11 | 1671 | 11 | 1671 | 11 | -2 |
| 90 | 251 | 33,127 | 0.5 | 9.6112 | 0.6 | 4.0943 | 2.3 | 0.2854 | 2.2 | 0.97 | 1619 | 32 | 1653 | 19 | 1697 | 10 | 1697 | 10 | 5 |
| 19 | 385 | 163,296 | 0.2 | 9.5839 | 0.2 | 4.2630 | 1.7 | 0.2963 | 1.7 | 0.99 | 1673 | 25 | 1686 | 14 | 1703 | 4 | 1703 | 4 | 2 |
| 27 | 248 | 154,717 | 0.5 | 9.4994 | 0.4 | 4.4853 | 1.7 | 0.3090 | 1.6 | 0.97 | 1736 | 24 | 1728 | 14 | 1719 | 8 | 1719 | 8 | -1 |
| 78 | 213 | 182,612 | 0.9 | 9.4085 | 0.3 | 4.5258 | 2.1 | 0.3088 | 2.1 | 0.99 | 1735 | 31 | 1736 | 17 | 1737 | 6 | 1737 | 6 | 0 |
| 2 | 370 | 262,089 | 0.6 | 9.3049 | 0.2 | 4.4675 | 1.1 | 0.3015 | 1.1 | 0.98 | 1699 | 16 | 1725 | 9 | 1757 | 4 | 1757 | 4 | 3 |
| 73 | 48 | 32,902 | 1.2 | 8.1909 | 1.2 | 6.0144 | 1.9 | 0.3573 | 1.5 | 0.79 | 1969 | 25 | 1978 | 16 | 1987 | 21 | 1987 | 21 | 1 |
| 54 | 101 | 107,700 | 0.7 | 6.5595 | 1.1 | 9.4889 | 1.6 | 0.4514 | 1.2 | 0.74 | 2402 | 24 | 2386 | 15 | 2374 | 18 | 2374 | 18 | -1 |
| 6 | 48 | 41,569 | 0.4 | 13.4843 | 3.3 | 1.8664 | 3.7 | 0.1825 | 1.6 | 0.43 | 1081 | 16 | 1069 | 24 | 1046 | 67 | 1046 | 67 | -3 |

TABLE 3
*(continued)*

| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | | Disc. (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Isotope ratios | | | | | | | | | | | Apparent ages (Ma) | | | | | | | |
| VL10NB05 (n=93/100) | | | | | | | | | | | | | | | | | | | | |
| *Rejected Analyses (>10% discordance, >5% reverse discordance, or >10% 2s age uncertainty)* | | | | | | | | | | | | | | | | | | | | |
| 46 | 16 | 3,463 | 0.4 | 17.7894 | 28.8 | 0.6547 | 32.3 | 0.0845 | 14.6 | 0.45 | 523 | 73 | 511.3 | 130.4 | 461 | 651 | | | | |
| 30 | 7 | 1,624 | 0.4 | 19.3481 | 114.5 | 0.6062 | 115.9 | 0.0851 | 17.8 | 0.15 | 526 | 90 | 481.2 | 476.1 | 271 | 946 | | | | |
| 76 | 6 | 2,946 | 0.8 | 2.3979 | 796.3 | 4.8960 | 796.4 | 0.0851 | 11.6 | 0.01 | 527 | 59 | 1801.6 | - | 3972 | 13 | | | | |
| 16 | 8 | 2,726 | 0.7 | -2.6962 | 1072 | -4.5153 | 1072 | 0.0883 | 14.7 | 0.01 | 545 | 77 | - | - | - | - | | | | |
| 15 | 7 | 1,288 | 0.4 | 30.6865 | 66.2 | 0.4085 | 67.4 | 0.0909 | 12.8 | 0.19 | 561 | 69 | 347.8 | 201.1 | - | 2139 | | | | |
| 53 | 32 | 29,862 | 0.7 | 13.7518 | 3.7 | 1.7948 | 4.5 | 0.1790 | 2.6 | 0.57 | 1062 | 25 | 1043.6 | 29.6 | 1006 | 76 | | | | |
| 55 | 13 | 8,058 | 0.4 | 13.9691 | 13.6 | 1.8569 | 13.8 | 0.1881 | 2.6 | 0.19 | 1111 | 26 | 1065.9 | 91.3 | 974 | 278 | | | | |
| VL13NB02 (n=56/66) | | | | | | | | | | | | | | | | | | | | |
| 48 | 903 | 14,594 | 0.4 | 17.9998 | 0.6 | 0.4975 | 2.6 | 0.0649 | 2.5 | 0.97 | 406 | 10 | 410 | 9 | 435 | 13 | 406 | 10 | | |
| 17 | 320 | 7,403 | 0.4 | 17.8624 | 1.0 | 0.5471 | 1.9 | 0.0709 | 1.6 | 0.85 | 441 | 7 | 443 | 7 | 452 | 22 | 441 | 7 | * | |
| 65 | 293 | 5,989 | 0.6 | 17.8879 | 0.6 | 0.5613 | 1.5 | 0.0728 | 1.3 | 0.90 | 453 | 6 | 452 | 5 | 449 | 14 | 453 | 6 | * | |
| 26 | 826 | 22,757 | 0.6 | 17.6679 | 0.6 | 0.5771 | 2.4 | 0.0739 | 2.3 | 0.97 | 460 | 10 | 463 | 9 | 476 | 13 | 460 | 10 | | |
| 61 | 761 | 11,412 | 1.4 | 17.4318 | 0.8 | 0.5971 | 1.7 | 0.0755 | 1.5 | 0.88 | 469 | 7 | 475 | 6 | 506 | 18 | 469 | 7 | | |
| 60 | 171 | 3,673 | 0.9 | 17.7233 | 1.9 | 0.5884 | 4.7 | 0.0756 | 4.3 | 0.92 | 470 | 19 | 470 | 18 | 469 | 41 | 470 | 19 | | |
| 34 | 332 | 7,327 | 0.8 | 17.5848 | 0.6 | 0.5967 | 2.7 | 0.0761 | 2.6 | 0.97 | 473 | 12 | 475 | 10 | 486 | 14 | 473 | 12 | | |
| 32 | 221 | 4,621 | 0.7 | 17.6419 | 1.1 | 0.6010 | 1.7 | 0.0769 | 1.2 | 0.75 | 478 | 6 | 478 | 6 | 479 | 24 | 478 | 6 | | |
| 50 | 204 | 4,206 | 2.3 | 17.4991 | 2.3 | 0.6155 | 2.7 | 0.0781 | 1.3 | 0.48 | 485 | 6 | 487 | 10 | 497 | 52 | 485 | 6 | | |
| 6 | 353 | 6,209 | 0.3 | 17.2749 | 2.1 | 0.6246 | 3.9 | 0.0783 | 3.3 | 0.84 | 486 | 15 | 493 | 15 | 525 | 47 | 486 | 15 | | |
| 55 | 186 | 4,565 | 0.5 | 17.7405 | 1.2 | 0.6163 | 1.5 | 0.0793 | 0.8 | 0.57 | 492 | 4 | 487 | 6 | 467 | 26 | 492 | 4 | | |
| 51 | 179 | 4,300 | 1.0 | 17.4820 | 1.4 | 0.6369 | 2.1 | 0.0808 | 1.6 | 0.75 | 501 | 8 | 500 | 8 | 499 | 30 | 501 | 8 | | |
| 30 | 636 | 16,629 | 0.4 | 17.3459 | 0.5 | 0.6614 | 1.9 | 0.0832 | 1.8 | 0.96 | 515 | 9 | 515 | 7 | 516 | 11 | 515 | 9 | | |
| 23 | 90 | 2,346 | 1.6 | 17.5463 | 1.5 | 0.6830 | 2.4 | 0.0869 | 1.9 | 0.77 | 537 | 10 | 529 | 10 | 491 | 34 | 537 | 10 | | |
| 53 | 75 | 3,375 | 0.4 | 14.0595 | 0.8 | 1.5351 | 1.4 | 0.1565 | 1.1 | 0.81 | 938 | 10 | 945 | 9 | 961 | 17 | 938 | 10 | | 2 |
| 58 | 157 | 6,351 | 2.2 | 13.9407 | 0.6 | 1.5715 | 1.7 | 0.1589 | 1.6 | 0.94 | 951 | 14 | 959 | 10 | 978 | 12 | 951 | 14 | | 3 |
| 7 | 39 | 2,086 | 0.7 | 13.9203 | 1.5 | 1.6129 | 2.5 | 0.1628 | 2.0 | 0.80 | 973 | 18 | 975 | 16 | 981 | 31 | 973 | 18 | | 1 |
| 66 | 144 | 5,504 | 0.6 | 13.8874 | 3.3 | 1.6370 | 5.1 | 0.1649 | 3.8 | 0.76 | 984 | 35 | 985 | 32 | 986 | 67 | 984 | 35 | | 0 |
| 27 | 54 | 2,779 | 0.3 | 13.8350 | 1.3 | 1.6567 | 2.0 | 0.1662 | 1.5 | 0.75 | 991 | 14 | 992 | 12 | 994 | 27 | 991 | 14 | | 0 |
| 59 | 140 | 6,298 | 0.7 | 13.8332 | 0.9 | 1.6666 | 2.3 | 0.1672 | 2.1 | 0.92 | 997 | 19 | 996 | 14 | 994 | 18 | 997 | 19 | | 0 |

TABLE 3
*(continued)*

| | | | | Isotope ratios | | | | | | | Apparent ages (Ma) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | Disc. (%) |
| VL13NB02 (n=56/66) | | | | | | | | | | | | | | | | | | | |
| 4 | 316 | 15,973 | 0.6 | 13.5905 | 0.6 | 1.6501 | 1.4 | 0.1627 | 1.2 | 0.89 | 971 | 11 | 990 | 9 | 1030 | 13 | 1030 | 13 | 6 |
| 2 | 96 | 4,528 | 1.1 | 13.5720 | 2.0 | 1.6885 | 2.8 | 0.1662 | 2.0 | 0.71 | 991 | 18 | 1004 | 18 | 1033 | 40 | 991 | 18 | 4 |
| 63 | 417 | 18,489 | 0.02 | 13.5556 | 1.3 | 1.6238 | 9.2 | 0.1596 | 9.1 | 0.99 | 955 | 80 | 979 | 58 | 1035 | 26 | 1035 | 26 | 8 |
| 12 | 70 | 4,025 | 0.4 | 13.5477 | 0.8 | 1.7983 | 1.9 | 0.1767 | 1.8 | 0.91 | 1049 | 17 | 1045 | 13 | 1036 | 16 | 1049 | 17 | -1 |
| 3 | 118 | 5,914 | 0.5 | 13.5475 | 0.9 | 1.7090 | 1.6 | 0.1679 | 1.3 | 0.83 | 1001 | 12 | 1012 | 10 | 1036 | 18 | 1001 | 12 | 3 |
| 54 | 285 | 13,133 | 0.4 | 13.5465 | 0.6 | 1.7975 | 2.3 | 0.1766 | 2.2 | 0.96 | 1048 | 22 | 1045 | 15 | 1037 | 12 | 1048 | 22 | -1 |
| 15 | 119 | 6,535 | 0.5 | 13.4726 | 1.0 | 1.8284 | 1.4 | 0.1787 | 1.0 | 0.72 | 1060 | 10 | 1056 | 9 | 1048 | 19 | 1060 | 10 | -1 |
| 52 | 404 | 21,361 | 0.2 | 13.3500 | 0.8 | 1.8476 | 3.0 | 0.1789 | 2.9 | 0.96 | 1061 | 28 | 1063 | 20 | 1066 | 17 | 1061 | 28 | 0 |
| 20 | 140 | 7,242 | 0.6 | 13.3248 | 1.0 | 1.9003 | 1.8 | 0.1836 | 1.5 | 0.83 | 1087 | 15 | 1081 | 12 | 1070 | 20 | 1087 | 15 | -2 |
| 35 | 133 | 6,819 | 0.8 | 13.2949 | 0.5 | 1.8501 | 1.5 | 0.1784 | 1.3 | 0.93 | 1058 | 13 | 1063 | 10 | 1074 | 11 | 1058 | 13 | 1 |
| 22 | 169 | 9,139 | 0.2 | 13.2699 | 0.7 | 1.8311 | 2.2 | 0.1762 | 2.1 | 0.95 | 1046 | 20 | 1057 | 14 | 1078 | 13 | 1046 | 20 | 3 |
| 14 | 142 | 8,616 | 0.4 | 13.2648 | 0.7 | 1.8530 | 1.1 | 0.1783 | 0.8 | 0.74 | 1058 | 8 | 1065 | 7 | 1079 | 15 | 1058 | 8 | 2 |
| 19 | 250 | 12,941 | 0.3 | 13.2465 | 0.6 | 1.8557 | 1.9 | 0.1783 | 1.8 | 0.95 | 1058 | 18 | 1065 | 13 | 1082 | 12 | 1058 | 18 | 2 |
| 16 | 610 | 31,408 | 0.3 | 13.1896 | 1.0 | 1.8569 | 2.6 | 0.1776 | 2.4 | 0.92 | 1054 | 24 | 1066 | 17 | 1090 | 20 | 1054 | 24 | 3 |
| 31 | 17 | 995 | 0.4 | 13.0583 | 2.2 | 1.9887 | 2.7 | 0.1883 | 1.5 | 0.55 | 1112 | 15 | 1112 | 18 | 1110 | 44 | 1112 | 15 | 0 |
| 9 | 100 | 5,987 | 0.7 | 12.8548 | 0.7 | 2.1077 | 2.2 | 0.1965 | 2.1 | 0.95 | 1157 | 22 | 1151 | 15 | 1142 | 13 | 1157 | 22 | -1 |
| 43 | 217 | 11,225 | 0.6 | 12.7806 | 0.6 | 2.1863 | 3.1 | 0.2027 | 3.1 | 0.98 | 1190 | 33 | 1177 | 22 | 1153 | 12 | 1190 | 33 | -3 |
| 18 | 144 | 9,885 | 0.5 | 12.7108 | 0.5 | 2.1054 | 2.2 | 0.1941 | 2.1 | 0.97 | 1143 | 22 | 1151 | 15 | 1164 | 10 | 1143 | 22 | 2 |
| 13 | 100 | 4,795 | 1.5 | 12.7105 | 3.7 | 1.9212 | 4.7 | 0.1771 | 2.9 | 0.61 | 1051 | 28 | 1088 | 31 | 1164 | 74 | 1164 | 74 | 10 |
| 28 | 297 | 22,502 | 0.3 | 11.6632 | 0.8 | 2.7270 | 3.9 | 0.2307 | 3.8 | 0.98 | 1338 | 46 | 1336 | 29 | 1332 | 15 | 1332 | 15 | 0 |
| 49 | 140 | 10,065 | 0.5 | 11.5768 | 0.6 | 2.8035 | 2.9 | 0.2354 | 2.8 | 0.98 | 1363 | 35 | 1356 | 22 | 1347 | 11 | 1347 | 11 | -1 |
| 57 | 489 | 34,613 | 0.4 | 11.1571 | 1.1 | 3.1282 | 5.8 | 0.2531 | 5.7 | 0.98 | 1455 | 75 | 1440 | 45 | 1418 | 20 | 1418 | 20 | -3 |
| 24 | 97 | 7,798 | 0.5 | 11.1389 | 0.7 | 2.7914 | 3.2 | 0.2255 | 3.1 | 0.98 | 1311 | 37 | 1353 | 24 | 1421 | 13 | 1421 | 13 | 8 |
| 5 | 512 | 45,039 | 0.3 | 10.8667 | 1.1 | 3.2971 | 4.7 | 0.2599 | 4.5 | 0.97 | 1489 | 60 | 1480 | 36 | 1468 | 21 | 1468 | 21 | -1 |
| 29 | 516 | 41,588 | 0.3 | 10.8420 | 1.0 | 3.2112 | 3.5 | 0.2525 | 3.4 | 0.96 | 1451 | 44 | 1460 | 27 | 1472 | 19 | 1472 | 19 | 1 |
| 11 | 311 | 26,442 | 1.6 | 10.1779 | 1.5 | 3.6103 | 2.3 | 0.2665 | 1.7 | 0.75 | 1523 | 23 | 1552 | 18 | 1591 | 28 | 1591 | 28 | 4 |
| 47 | 204 | 16,369 | 1.2 | 9.8540 | 0.7 | 3.9919 | 2.2 | 0.2853 | 2.0 | 0.94 | 1618 | 29 | 1633 | 18 | 1651 | 13 | 1651 | 13 | 2 |
| 64 | 409 | 28,674 | 0.5 | 9.5923 | 1.0 | 4.3841 | 2.4 | 0.3050 | 2.2 | 0.91 | 1716 | 33 | 1709 | 20 | 1701 | 18 | 1701 | 18 | -1 |
| 25 | 307 | 29,058 | 0.7 | 9.2576 | 1.0 | 4.7825 | 6.1 | 0.3211 | 6.0 | 0.99 | 1795 | 94 | 1782 | 51 | 1766 | 17 | 1766 | 17 | -2 |
| 36 | 255 | 23,198 | 0.9 | 8.8824 | 0.6 | 5.2370 | 1.5 | 0.3374 | 1.4 | 0.93 | 1874 | 22 | 1859 | 13 | 1841 | 10 | 1841 | 10 | -2 |

TABLE 3
*(continued)*

| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | | Disc. (%) |
| VL13NB02 (n=56/66) | | | | | | | | | | | | | | | | | | | | |
| 38 | 229 | 32,322 | 0.7 | 5.7600 | 6.6 | 11.6735 | 7.7 | 0.4877 | 3.8 | 0.50 | 2561 | 81 | 2579 | 72 | 2593 | 111 | 2593 | 111 | | 1 |
| 44 | 179 | 25,376 | 0.9 | 5.6394 | 0.7 | 11.9608 | 1.5 | 0.4892 | 1.3 | 0.88 | 2567 | 28 | 2601 | 14 | 2628 | 12 | 2628 | 12 | | 2 |
| 1 | 226 | 38,023 | 0.7 | 5.4730 | 0.7 | 13.0511 | 2.2 | 0.5181 | 2.1 | 0.94 | 2691 | 45 | 2683 | 21 | 2678 | 12 | 2678 | 12 | | 0 |
| 62 | 97 | 14,685 | 0.9 | 5.4461 | 0.7 | 13.0989 | 4.5 | 0.5174 | 4.5 | 0.99 | 2688 | 98 | 2687 | 43 | 2686 | 12 | 2686 | 12 | | 0 |
| 10 | 88 | 14,990 | 0.7 | 5.3311 | 0.7 | 13.6717 | 1.5 | 0.5286 | 1.3 | 0.89 | 2736 | 29 | 2727 | 14 | 2721 | 11 | 2721 | 11 | | -1 |
| 46 | 41 | 6,086 | 0.8 | 5.2832 | 0.9 | 13.6220 | 2.0 | 0.5220 | 1.8 | 0.90 | 2707 | 40 | 2724 | 19 | 2736 | 14 | 2736 | 14 | | 1 |
| *Rejected Analyses (>10% discordance, >5% reverse discordance, or >10% 1s age uncertainty)* | | | | | | | | | | | | | | | | | | | | |
| 56 | 2745 | 7 | 0.1 | 1.3162 | 129.0 | - | - | - | - | 0.91 | - | - | - | - | - | - | | | | |
| 33 | 224 | 4,092 | 0.7 | 17.6117 | 1.4 | 0.5350 | 2.4 | 0.0683 | 1.9 | 0.80 | 426 | 8 | 435 | 8 | 483 | 32 | | | | |
| 40 | 57 | 1,189 | 1.4 | 18.5846 | 1.8 | 0.5285 | 2.0 | 0.0712 | 1.0 | 0.48 | 444 | 4 | 431 | 7 | 363 | 40 | | | | |
| 42 | 575 | 34,361 | 0.5 | 12.9697 | 0.8 | 2.1370 | 4.2 | 0.2010 | 4.1 | 0.98 | 1181 | 44 | 1161 | 29 | 1124 | 17 | | | | |
| 41 | 331 | 17,703 | 0.4 | 12.5039 | 0.6 | 2.4007 | 1.3 | 0.2177 | 1.2 | 0.90 | 1270 | 14 | 1243 | 10 | 1196 | 11 | | | | |
| 8 | 569 | 20,276 | 0.4 | 11.6889 | 11.6 | 2.3401 | 11.7 | 0.1984 | 1.6 | 0.13 | 1167 | 17 | 1225 | 83 | 1328 | 225 | | | | |
| 37 | 122 | 9,860 | 0.6 | 10.9291 | 0.6 | 3.3845 | 2.6 | 0.2683 | 2.5 | 0.97 | 1532 | 34 | 1501 | 20 | 1457 | 11 | | | | |
| 45 | 320 | 23,755 | 0.3 | 10.7974 | 0.8 | 3.5093 | 3.6 | 0.2748 | 3.5 | 0.97 | 1565 | 48 | 1529 | 28 | 1480 | 16 | | | | |
| 39 | 267 | 16,385 | 0.6 | 8.7172 | 0.9 | 4.6791 | 2.3 | 0.2958 | 2.1 | 0.92 | 1671 | 31 | 1764 | 19 | 1875 | 16 | | | | |
| 21 | 129 | 14,604 | 0.3 | 6.0552 | 1.0 | 9.3378 | 3.0 | 0.4101 | 2.8 | 0.95 | 2215 | 53 | 2372 | 28 | 2509 | 16 | | | | |
| VL10NB06 (n=35/55) | | | | | | | | | | | | | | | | | | | | |
| 26 | 189 | 24,022 | 0.4 | 17.2655 | 2.8 | 0.6775 | 3.7 | 0.0848 | 2.4 | 0.65 | 525 | 12 | 525 | 15 | 527 | 61 | 525 | 12 | * | |
| 23 | 207 | 28,932 | 0.5 | 16.8441 | 3.2 | 0.7063 | 3.3 | 0.0863 | 0.9 | 0.27 | 534 | 5 | 543 | 14 | 581 | 69 | 534 | 5 | * | |
| 39 | 196 | 34,475 | 0.3 | 16.9333 | 4.3 | 0.7631 | 6.4 | 0.0937 | 4.7 | 0.74 | 578 | 26 | 576 | 28 | 569 | 93 | 578 | 26 | | |
| 29 | 190 | 47,106 | 1.5 | 17.0676 | 4.9 | 0.7878 | 5.0 | 0.0975 | 1.2 | 0.24 | 600 | 7 | 590 | 22 | 552 | 106 | 600 | 7 | | |
| 2 | 117 | 48,192 | 0.8 | 16.6748 | 5.5 | 0.8231 | 6.6 | 0.0995 | 3.7 | 0.56 | 612 | 21 | 610 | 30 | 602 | 118 | 612 | 21 | | -2 |
| 19 | 91 | 30,211 | 1.7 | 16.2935 | 7.5 | 0.8432 | 7.6 | 0.0996 | 1.3 | 0.18 | 612 | 8 | 621 | 35 | 652 | 160 | 612 | 8 | | 6 |
| 7 | 138 | 13,947 | 0.4 | 16.5768 | 3.4 | 0.8320 | 3.7 | 0.1000 | 1.3 | 0.34 | 615 | 7 | 615 | 17 | 615 | 74 | 615 | 7 | | 0 |
| 34 | 158 | 24,204 | 0.4 | 16.2881 | 1.6 | 0.8483 | 4.7 | 0.1002 | 4.4 | 0.94 | 616 | 26 | 624 | 22 | 653 | 35 | 616 | 26 | | 6 |
| 25 | 140 | 52,431 | 0.5 | 16.4228 | 4.6 | 0.8459 | 4.7 | 0.1007 | 1.2 | 0.26 | 619 | 7 | 622 | 22 | 635 | 98 | 619 | 7 | | 3 |

TABLE 3
*(continued)*

| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | Disc. (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Isotope ratios | | | | | | | | | | Apparent ages (Ma) | | | | | | | | |
| VL10NB06 (n=35/55) | | | | | | | | | | | | | | | | | | | |
| 9 | 658 | 47,678 | 1.5 | 16.3811 | 0.9 | 0.8484 | 1.2 | 0.1008 | 0.8 | 0.69 | 619 | 5 | 624 | 6 | 641 | 19 | 619 | 5 | 3 |
| 3 | 140 | 26,860 | 1.4 | 16.5740 | 3.5 | 0.8391 | 3.8 | 0.1009 | 1.5 | 0.38 | 619 | 9 | 619 | 18 | 616 | 76 | 619 | 9 | -1 |
| 49 | 229 | 36,334 | 0.1 | 16.5230 | 2.7 | 0.8619 | 3.0 | 0.1033 | 1.4 | 0.48 | 634 | 9 | 631 | 14 | 622 | 57 | 634 | 9 | -2 |
| 42 | 127 | 52,075 | 1.8 | 16.2816 | 4.1 | 0.8755 | 4.2 | 0.1034 | 1.0 | 0.23 | 634 | 6 | 639 | 20 | 654 | 89 | 634 | 6 | 3 |
| 15 | 210 | 83,028 | 0.9 | 16.4398 | 3.3 | 0.8684 | 3.6 | 0.1035 | 1.5 | 0.42 | 635 | 9 | 635 | 17 | 633 | 71 | 635 | 9 | 0 |
| 21 | 1018 | 270,328 | 0.0 | 16.3784 | 0.7 | 0.8720 | 1.1 | 0.1036 | 0.8 | 0.77 | 635 | 5 | 637 | 5 | 641 | 15 | 635 | 5 | 1 |
| 12 | 241 | 80,744 | 0.5 | 16.3607 | 2.4 | 0.8859 | 2.6 | 0.1051 | 1.1 | 0.44 | 644 | 7 | 644 | 12 | 644 | 51 | 644 | 7 | 0 |
| 45 | 291 | 97,756 | 0.5 | 16.0467 | 0.6 | 0.9291 | 1.2 | 0.1081 | 1.1 | 0.88 | 662 | 7 | 667 | 6 | 685 | 12 | 662 | 7 | 3 |
| 10 | 530 | 206,413 | 0.0 | 16.0012 | 1.2 | 0.9319 | 2.6 | 0.1081 | 2.3 | 0.89 | 662 | 15 | 669 | 13 | 691 | 26 | 662 | 15 | 4 |
| 47 | 430 | 60,267 | 0.4 | 16.1938 | 0.7 | 0.9277 | 2.3 | 0.1090 | 2.1 | 0.95 | 667 | 14 | 666 | 11 | 666 | 15 | 667 | 14 | 0 |
| 14 | 630 | 134,621 | 0.3 | 15.8689 | 1.1 | 1.0098 | 1.2 | 0.1162 | 0.5 | 0.42 | 709 | 3 | 709 | 6 | 709 | 22 | 709 | 3 | 0 |
| 37 | 1116 | 232,601 | 0.1 | 15.7503 | 1.3 | 1.0195 | 3.0 | 0.1165 | 2.7 | 0.91 | 710 | 18 | 714 | 15 | 725 | 27 | 710 | 18 | 2 |
| 4 | 362 | 101,462 | 0.5 | 15.2178 | 1.4 | 1.1573 | 1.8 | 0.1277 | 1.1 | 0.62 | 775 | 8 | 781 | 10 | 797 | 29 | 775 | 8 | 3 |
| 51 | 196 | 57,195 | 0.7 | 15.2390 | 2.9 | 1.1658 | 3.9 | 0.1288 | 2.6 | 0.67 | 781 | 19 | 785 | 21 | 794 | 60 | 781 | 19 | 2 |
| 18 | 199 | 79,753 | 0.4 | 13.9261 | 0.9 | 1.6407 | 1.4 | 0.1657 | 1.1 | 0.78 | 988 | 10 | 986 | 9 | 980 | 18 | 988 | 10 | -1 |
| 46 | 110 | 58,704 | 0.6 | 12.1678 | 1.9 | 2.4118 | 2.9 | 0.2128 | 2.2 | 0.75 | 1244 | 25 | 1246 | 21 | 1250 | 38 | 1250 | 38 | 0 |
| 22 | 116 | 42,532 | 0.5 | 11.3744 | 2.4 | 2.7698 | 9.2 | 0.2285 | 8.9 | 0.97 | 1327 | 106 | 1347 | 69 | 1381 | 46 | 1381 | 46 | 4 |
| 8 | 145 | 66,089 | 0.3 | 10.7405 | 1.0 | 3.1625 | 1.7 | 0.2464 | 1.4 | 0.81 | 1420 | 18 | 1448 | 13 | 1490 | 19 | 1490 | 19 | 5 |
| 13 | 157 | 217,565 | 0.3 | 10.4601 | 0.8 | 3.5604 | 1.3 | 0.2701 | 1.1 | 0.80 | 1541 | 14 | 1541 | 10 | 1540 | 15 | 1540 | 15 | 0 |
| 5 | 404 | 144,888 | 0.5 | 10.4116 | 0.4 | 3.6171 | 1.3 | 0.2731 | 1.2 | 0.95 | 1557 | 17 | 1553 | 10 | 1549 | 8 | 1549 | 8 | -1 |
| 27 | 140 | 83,025 | 0.6 | 9.1080 | 0.8 | 4.8107 | 1.7 | 0.3178 | 1.4 | 0.87 | 1779 | 22 | 1787 | 14 | 1796 | 15 | 1796 | 15 | 1 |
| 40 | 173 | 108,769 | 0.8 | 7.9036 | 0.6 | 6.5167 | 2.2 | 0.3735 | 2.1 | 0.96 | 2046 | 37 | 2048 | 20 | 2050 | 11 | 2050 | 11 | 0 |
| 20 | 128 | 155,726 | 0.5 | 7.8523 | 1.1 | 6.4963 | 16.4 | 0.3700 | 16.4 | 1.00 | 2029 | 285 | 2045 | 145 | 2062 | 19 | 2062 | 19 | 2 |
| 28 | 139 | 100,906 | 0.7 | 7.8359 | 0.7 | 6.3348 | 4.4 | 0.3600 | 4.3 | 0.99 | 1982 | 73 | 2023 | 38 | 2065 | 13 | 2065 | 13 | 4 |
| 16 | 108 | 169,171 | 0.9 | 7.4156 | 0.8 | 7.5051 | 2.1 | 0.4036 | 2.0 | 0.92 | 2186 | 36 | 2174 | 19 | 2162 | 14 | 2162 | 14 | -1 |
| *Rejected Analyses (>10% discordance, >5% reverse discordance, or >10% 2s age uncertainty)* | | | | | | | | | | | | | | | | | | | |
| 24 | 220 | 67,611 | 0.5 | 15.7009 | 11.1 | 0.5287 | 57.0 | 0.0602 | 55.9 | 0.98 | 377 | 205 | 431 | 203 | 731 | 235 | | | |
| 44 | 383 | 265 | 0.8 | 12.9072 | 21.1 | 1.0544 | 21.4 | 0.0987 | 3.7 | 0.17 | 607 | 21 | 731 | 112 | 1133 | 424 | | | |

TABLE 3
*(continued)*

| | | Isotope ratios | | | | | | | | | Apparent ages (Ma) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain # | U (ppm) | $^{206}Pb/^{204}Pb$ | Th/U | $^{206}Pb^*/^{207}Pb^*$ | ± (%) | $^{207}Pb^*/^{235}U^*$ | ± (%) | $^{206}Pb^*/^{238}U$ | ± (%) | error corr. | $^{206}Pb^*/^{238}U^*$ | ± (Ma) | $^{207}Pb^*/^{235}U$ | ± (Ma) | $^{206}Pb^*/^{207}Pb^*$ | ± (Ma) | Best age (Ma) | ± (Ma) | Disc. (%) |
| VL10NB06 (n=35/55) | | | | | | | | | | | | | | | | | | | |
| *Rejected Analyses (>10% discordance, >5% reverse discordance, or >10% 2s age uncertainty)* | | | | | | | | | | | | | | | | | | | |
| 35 | 81 | 13,397 | 0.8 | 15.6985 | 11.8 | 0.9077 | 25.2 | 0.1034 | 22.2 | 0.88 | 634 | 134 | 656 | 122 | 732 | 251 | | | |
| 41 | 64 | 14,110 | 0.5 | 16.3483 | 10.6 | 0.8824 | 12.6 | 0.1046 | 6.9 | 0.54 | 641 | 42 | 642 | 60 | 645 | 228 | | | |
| 55 | 561 | 24,119 | 0.4 | 15.5647 | 1.8 | 0.9338 | 3.1 | 0.1054 | 2.5 | 0.81 | 646 | 15 | 670 | 15 | 750 | 38 | | | |
| 11 | 121 | 19,101 | 0.4 | 15.5781 | 6.3 | 0.9354 | 6.5 | 0.1057 | 1.5 | 0.23 | 648 | 9 | 670 | 32 | 748 | 134 | | | |
| 33 | 253 | 56,041 | 1.3 | 16.4326 | 1.0 | 0.9101 | 2.2 | 0.1085 | 2.0 | 0.89 | 664 | 13 | 657 | 11 | 634 | 22 | | | |
| 54 | 183 | 3,384 | 0.1 | 15.8013 | 4.8 | 0.9572 | 9.6 | 0.1097 | 8.3 | 0.86 | 671 | 53 | 682 | 48 | 718 | 103 | | | |
| 17 | 486 | 93,527 | 0.5 | 16.4388 | 0.7 | 0.9500 | 6.0 | 0.1133 | 5.9 | 0.99 | 692 | 39 | 678 | 30 | 633 | 16 | | | |
| 52 | 113 | 78,183 | 0.7 | 13.1387 | 43.5 | 1.2251 | 49.6 | 0.1167 | 23.7 | 0.48 | 712 | 160 | 812 | 284 | 1098 | 916 | | | |
| 36 | 212 | 81,466 | 0.7 | 14.5239 | 26.4 | 1.1954 | 37.2 | 0.1259 | 26.2 | 0.70 | 765 | 189 | 798 | 209 | 894 | 555 | | | |
| 48 | 143 | 55,503 | 0.6 | 15.7380 | 10.5 | 1.1138 | 29.3 | 0.1271 | 27.3 | 0.93 | 771 | 199 | 760 | 158 | 726 | 223 | | | |
| 6 | 124 | 21,733 | 1.0 | 15.8389 | 7.8 | 1.1119 | 29.4 | 0.1277 | 28.3 | 0.96 | 775 | 207 | 759 | 158 | 713 | 167 | | | |
| 30 | 87 | 37,046 | 0.4 | 15.1703 | 2.9 | 1.2966 | 5.0 | 0.1427 | 4.0 | 0.81 | 860 | 32 | 844 | 28 | 804 | 61 | | | |
| 53 | 886 | 20,363 | 0.2 | 12.1172 | 0.5 | 1.9420 | 22.0 | 0.1707 | 22.0 | 1.00 | 1016 | 207 | 1096 | 149 | 1258 | 10 | | | |
| 32 | 125 | 7,522 | 0.5 | 12.6683 | 3.2 | 2.1342 | 4.9 | 0.1961 | 3.7 | 0.76 | 1154 | 39 | 1160 | 34 | 1171 | 64 | | | |
| 1 | 42 | 5,103 | 0.6 | 12.4966 | 9.0 | 2.3791 | 33.1 | 0.2156 | 31.8 | 0.96 | 1259 | 364 | 1236 | 241 | 1198 | 179 | | | |
| 38 | 57 | 371 | 0.5 | 6.9448 | 23.6 | 5.9312 | 24.4 | 0.2987 | 6.2 | 0.26 | 1685 | 92 | 1966 | 215 | 2276 | 412 | | | |
| 50 | 64 | 60,656 | 0.3 | 6.6652 | 34.5 | 6.6330 | 545 | 0.3206 | 544 | 1.00 | 1793 | - | 2064 | - | 2346 | 611 | | | |
| 43 | 51 | 9,617 | 2.0 | 11.5402 | 27.4 | 4.4623 | 101 | 0.3735 | 97.0 | 0.96 | 2046 | 1741 | 1724 | 1184 | 1353 | 538 | | | |
| 31 | 53 | 9,270 | 0.6 | 13.1440 | 52.2 | 12.7467 | 175 | 1.2151 | 167 | 0.95 | 5127 | - | 2661 | - | 1097 | 1125 | | | |

Table 3
*(continued)*

Notes:
1. Analyses conducted by LA-MC-ICPMS at the Arizona LaserChron Center following methods of Gehrels and others (2008).
2. All uncertainties are reported at the 1-sigma level, and include only measurement errors.
3. Best age is determined from $^{206}Pb/^{238}U$ age for analyses with $^{206}Pb/^{238}U$ age <1200 Ma and from $^{206}Pb/^{207}Pb$ age for analyses with $^{206}Pb/^{238}U$age > 1200 Ma.
4. Discordance for ages >600 Ma is calculated as (100- ($^{206}Pb/^{207}Pb$ age - $^{206}Pb/^{238}U$ age / $^{206}Pb/^{207}Pb$ age). Value is not reported for $^{206}Pb/^{238}U$ ages <600 Ma because of large uncertainty in $^{206}Pb/^{207}Pb$ age.
5. Analyses >600 Ma with >10% discordance or >5% reverse discordance are not included. Analyses <500 Ma that are visually discordant on concordia plot are not included.
6. Analyses with >10% uncertainty (2-sigma) in Best Age are not included.
7. * denotes $^{206}Pb/^{238}U$ ages used in calculation of maximum depositional age (n≥2 and overlap at 1-sigma level).
8. Systematic errors (at 2-sigma level) for 206Pb/238U and 206Pb/207 are 2.1% & 0.9% VL10NB02, 1.3% & 0.8% for sample VL10NB04, 1.6% & 0.8% for sample VL10NB05, and 1.6% & 0.9% for sample VL13NB02.
9. U concentration and U/Th are calibrated relative to Sri Lanka zircon standard and are accurate to ~20%.
10. Common Pb correction is from measured 204Pb with common Pb composition interpreted from Stacey and Kramers (1975).
11. Common Pb composition assigned uncertainties of 1.5 for $^{206}Pb/^{204}Pb$, 0.3 for $^{207}Pb/^{204}Pb$, and 2.0 for $^{208}Pb/^{204}Pb$.
12. U/Pb and $^{206}Pb/^{207}Pb$ fractionation is calibrated relative to fragments of a large Sri Lanka zircon of 563.5 ± 3.2 Ma (2-sigma).
13. U decay constants and composition as follows: $^{238}U$ = 9.8485 x 10-10, $^{235}U$ = 1.55125 x 10-10, $^{238}U/^{235}U$ = 137.88.

(*ca.* 0.9 – 1.2 Ga) grains. All plots display a large gap from *ca.* 500 to 950 Ma, a series of late Paleoproterozoic to Mesoproterozoic peaks between 1.0 and 1.8 Ga, and a few Neoarchean grains in the 2.6 to 3.0 Ga range. In contrast, Neoproterozoic to Cambrian ages (*ca.* 500–1000 Ma) are dominant in zircon grains from the Miramichi Group (VL10-NB06), and the maximum depositional age of the youngest population is 533 ± 8 Ma (fig. 14).

### *Constraints on Detrital Zircon Provenance*

All samples of synaccretionary sedimentary rocks of the Tomogonops, Val Michaud, Elmtree and Duncans Brook formations are dominated by Ordovician zircon populations, but display several peaks in the Mesoproterozoic to late Paleoproterozoic range (*ca.* 1000–1850 Ma) and, except for the Elmtree Formation, small clusters of Neoarchean grains between 2.6 and 3.0 Ga (fig. 13). This age profile has many features in common with Laurentia-derived sedimentary rocks. For example, Cawood and Nemchin (2001) assigned detrital zircons from the eastern Laurentian margin in Newfoundland to four major groups: 1. Archean (2600–2850 Ma), affiliated with the Superior craton; 2. Paleoproterozoic (1750–1950 Ma), associated with the Ungava, New Quebec and Torngat orogenic belts; 3. Mesoproterozoic to early Neoproterozoic (950–1450 Ma), related to the Grenvillian orogenic cycle (see also McLelland and others, 1996; Chiarenzelli and others, 2015); and 4. a local Neoproterozoic population (570–760 Ma) associated with rifting that opened the Iapetus ocean. Furthermore, the age spectra of the New Brunswick samples are almost identical to those documented in the Badger Group of Newfoundland (Waldron and others, 2012) and Southern Uplands of Scotland (Waldron and others, 2008), which were similarly ascribed to Laurentian sources. Conversely, a notable feature of the probability density plots for the synaccretionary rocks (fig. 13) is the near complete absence of Neoproterozoic (550–900 Ma) and early Paleoproterozoic (2.0–2.5 Ga) grains. Zircons that sample these intervals are typical of Amazonian (Gondwanan) sources (Teixeira and others, 1989; Barr and others, 2012), and characterize Neoproterozoic to Early Ordovician sedimentary rock units in New Brunswick (Fyffe and others, 2009). Thus, detrital zircon data strongly favor a Laurentian provenance for the Late Ordovician to mid-Silurian units discussed herein.

Detrital zircon probability density plots for all synaccretionary sedimentary rocks demonstrate that the bulk of constituent zircons range in age from *ca.* 440 to 475 Ma (fig. 13). The probable source of this large influx of eroded material was a tectonically uplifted region created by the (late Taconic) collision between the Popelogan arc and the Laurentian margin (van Staal and others, 1998, 2007; Wilson and others, 2004; Zagorevski and others, 2008; Reusch and van Staal, 2012). In Newfoundland, Late Cambrian to Ordovician detrital zircons in the Badger Group were attributed to a source in the Notre Dame arc (Pollock and others, 2007; Waldron and others, 2012). It is likely that zircons in the New Brunswick rocks were also dominantly sourced from the Notre Dame arc because they exhibit Laurentian inheritance, as discussed above, rather than the Ganderian signature that would be expected if the (Ganderian) Popelogan arc were being sampled (compare Dupuis and others, 2009). Furthermore, except for possible small uplifted areas, the Popelogan arc formed the substrate to much of the Matapedia cover. Another potential source is arc magmatic activity associated with Tetagouche backarc subduction; however, that volcanism is younger than the youngest zircon populations in the sampled units.

No detrital zircon data are available for Middle to early Late Ordovician rocks of the Bathurst and Fournier supergroups except for xenocrystic zircons in conglomerate cobbles at the base of the Tetagouche Group (van Staal and others, 1996). However, detrital zircon data from the Knights Brook Formation (Miramichi Group) (sample Vl10-NB06; table 3 and fig. 14) show a dominance of grains in the Neoproterozoic

interval that is not represented in the synaccretionary (Late Ordovician and younger) rocks. This profile, showing clear Gondwanan/Ganderian inheritance, is very similar to that obtained from correlative rocks of the Ganderian Woodstock Group (fig. 1) in southwestern New Brunswick (Fyffe and others, 2009). Ganderian provenance is also evident in inherited zircons contained in the 473 ± 4 Ma Meridian Brook Granite (fig. 2) in the southwestern part of the Miramichi Highlands (Roddick and Bevier, 1995). Additionally, the evidence of faunal provincialism in the Bathurst Supergroup, including Sandbian conodonts of North Atlantic affinity (Nowlan, 1981; Nowlan and others, 1997), and Floian – Dapingian brachiopods of the Celtic province (Neuman, 1971, 1984) indicate that the dominant influence during the Early to early Late Ordovician was from the Baltic – Gondwanan realm rather than from Laurentia. It is therefore clear that the Late Ordovician in the northern Appalachians is accompanied by a dramatic transition in sedimentary input from primarily east (present coordinates), to primarily west.

## DISCUSSION

Darriwilian – Katian pelagic chert and overlying shale in the upper part of the Bathurst Supergroup are overlain by significantly thicker units of dominantly siliciclastic turbidites that are correlated with turbidites in the Grog Brook and Matapedia groups of the Matapedia forearc basin, and with equivalent rocks of the Badger Group in Newfoundland. This abrupt lithological change signifies sharply contrasting depositional styles and tectonic environments, which we have ascribed to a transition from oceanic conditions far removed from a cratonic source area, to a trench setting (van Staal and others, 2003, 2008). This interpretation is also consistent with the change in sediment provenance indicated by the detrital zircons. Detrital zircon evidence and faunal affinities demonstrate that, before the Late Ordovician, sedimentary rocks of the Bathurst and Fournier supergroups had a Ganderian/Gondwanan provenance. In contrast, the overlying, Upper Ordovician to Wenlockian synaccretionary rocks have a Laurentian provenance, supporting the lithological correlation with the Grog Brook and Matapedia groups, which also have a Laurentian provenance based on fossils (Fyffe and Fricker, 1987; Boucot, 1993; Nowlan and others, 1997) and volcanic detritus (Dupuis and others, 2009). Hence, all were connected to composite Laurentia.

Scarcity of outcrop and fossils, and structural complexities in critical areas of New Brunswick, precludes clear recognition of whether or not the 'pelagic' and 'turbidite' successions are conformable. The pelagic rocks in the upper part of the Little River, Boucher Brook and Elmtree formations contain graptolites that have mainly been assigned to the *N. gracilis* to *Dicranograptus clingani* zones, ranging in age from late Darriwilian to early Katian (Ami, 1905; Alcock, 1935 and references therein; Skinner, 1974; Langton and McDonald, 1995; McCutcheon and others, 1995). Trilobites and conodonts in local occurrences of limestone (Helmstaedt, 1971; Skinner, 1974; Kennedy and others, 1979; Nowlan, 1981) and radiometric ages (*ca.* 457 Ma) of peralkaline rhyolite in the upper part of the Bathurst Supergroup (Sullivan and van Staal, 1996) also indicate a late Darriwilian to early Katian age range. However, a graptolite assemblage from the Little River Formation at a location near Bathurst has been assigned to the *Climacograptus spiniferus* zone by Riva and Malo (1988); this middle Katian age coincides with the oldest age attributed to the Grog Brook Group in the Matapedia forearc basin (Riva and Malo, 1988). Similar relationships are revealed by equivalent successions elsewhere in the northern Appalachians. In Newfoundland, Sandbian to early Katian black shale of the Lawrence Harbour and correlative formations overlies volcanic rocks of the Victoria arc (equivalent to the Popelogan arc) and is overlain conformably by the Badger Group. Basal units of the Badger Group (for example, the Point Leamington Formation) comprise Katian siliciclastic turbidites (Williams and others, 1995; Waldron and others, 2012) very similar to those of the

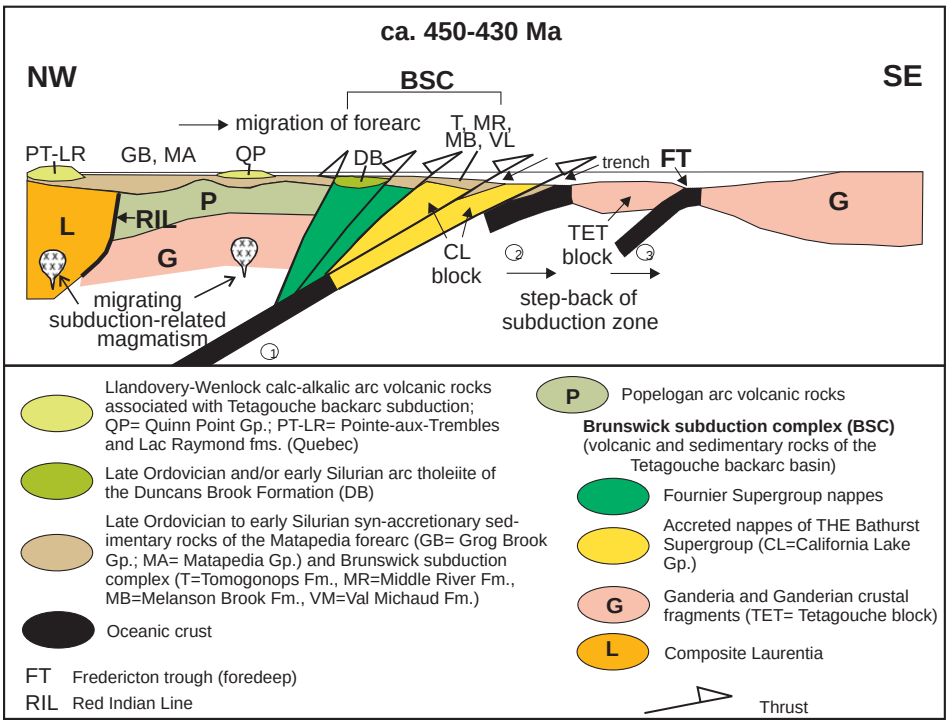


Fig. 15. Schematic tectonic model showing a Late Ordovician stage in the development of the Brunswick subduction complex and associated, Late Ordovician to Wenlockian (*ca.* 450–430 Ma) migrating arc magmatism. Numbers outline the sequential stepping-back of the subduction zone over time concurrent with progressive onlap of Matapedia cover on accreted material.

Grog Brook Group, and by extension, the Tomogonops and Middle River formations in the Bathurst Supergroup. Graptolite assemblages in the Point Leamington Formation are similar to those in the upper part of the Tetagouche Group, and overlap with the mid to late Katian age of graptolites in Grog Brook-equivalent rocks of the Garin Formation in Quebec, which range from the *C. spiniferus* to *Paraclimacograptus manitoulinensis* zones (Riva and Malo, 1988). A conformable transition from pelagic black shale to mid Katian and younger, synaccretionary sedimentary rocks of the Bathurst and Fournier supergroups is therefore probable, at least locally (fig. 3). Elsewhere, relationships may either be tectonic or disconformable (see above).

The oldest, conformable parts of the Tomogonops, Melanson Brook, Middle River and Val Michaud formations are interpreted to have been deposited as wedge-top and foredeep clastic wedges (DeCelles and Giles, 1996) during accretion of the underlying elements of the Tetagouche backarc basin to the leading edge of composite Laurentia (Matapedia forearc basin). The Laurentian provenance and lithological resemblance of synaccretionary deposits of the Bathurst Supergroup to the Grog Brook and Matapedia groups implies that the former represent a 'spillover' of forearc sedimentary material into the trench or onto a progressively deforming subduction complex during, and probably following, exhumation of part of the subduction complex nappes. In other words, the forearc migrated trenchward in lockstep with piecemeal accretion of backarc crustal slivers having Ganderian continental substrates (fig. 15) and consequent, stepwise retreat of the subduction zone (van Staal and others, 2003, 2008; Wilson and others, 2008). A small inlier of dark gray,

Matapedia-like calcilutite located west of the Elmtree inlier (fig. 1) probably represents the remnant of an intermediate depozone between the subduction complex to the east (present coordinates) and the main forearc belt in the Aroostook – Percé Anticlinorium to the west (fig. 1). Once the underlying Tetagouche element was accreted, turbidite sedimentation may have continued, but now as part of an accretionary-wedge slope or an onlapping forearc basin. If so, there may be cryptic unconformities in the turbidite successions, which would be consistent with the apparently conflicting, conformable and unconformable/tectonic field relationships observed between the turbidites and underlying rocks from one locality to another.

Other criteria that potentially can be used to differentiate between syn-accretion (foredeep) and post-accretion depositional settings are differences in metamorphic grade and structural evolution among the various units. However, the heterogeneity of deformation, characterized by marked strain gradients and variations in metamorphic grade ranging locally from prehnite-pumpellyite facies to blueschist and/or high-pressure greenschist facies conditions, compounded by tectonic shuffling as a result of out-of sequence thrusting and normal faulting (van Staal and others, 2001, 2008), render these criteria generally ambiguous. The problem of pre-accretion foredeep/trench deposition vs. post-accretion piggy-back basins is difficult to resolve, given the generally poor exposure and evidence in hand, but five lines of evidence support the interpretation that some turbidites were deposited on a growing and deforming Brunswick subduction complex: 1. The inferred late Ordovician – early Silurian age of the Tomogonops and Val Michaud formations (and indirectly the Middle River and Melanson Brook formations) based on detrital zircons coincides with the formation of $D_1/M_1$ blueschist and high-pressure greenschist facies rocks based on $^{40}Ar/^{39}Ar$ ages of phengite (van Staal and others, 2003); 2. deformation is time-transgressive (van Staal and others, 2003, 2008), and elements of the Tetagouche Group were accreted after those of the Fournier Supergroup and California Lake Group; thus, the Laurentia-derived sediments that formed the basal part of the Tomogonops Formation had to move across the earlier accreted nappes; 3. evidence of tectonic contacts along the western or northwestern margins of the Middle River and Val Michaud formations (fig. 2), such as narrow zones of mélange along the contact between the Boucher Brook and Middle River formations (fig. 9), supports active $D_1$ thrusting as deposition occurred; 4. indications are that some contacts between the turbidites and the underlying rocks are unconformable; and 5. the Duncans Brook arc basalt and underlying sandstone lie unconformably above the Devereaux Complex (fig. 4) of the Fournier Supergroup, which occupies the structurally highest nappe in the Brunswick subduction complex. The trench-proximal location of these volcanic and sedimentary rocks is best explained by southeast-directed migration of the Salinic arc towards its trench, such that the arc basalt now erupted into what was previously part of the arc-trench gap. The foregoing suggests that turbidites in the Brunswick subduction complex that resemble those of the Matapedia forearc basin were probably originally deposited in syn-accretion clastic basins in the wedge-top and proximal foredeep, but over time became part of a trench-migrating accretionary forearc basin as the Tetagouche backarc subduction zone stepped to the southeast behind accreted blocks (compare Dickinson and Seely, 1979; fig. 15). The end of Tetagouche backarc basin subduction at *ca.* 430 Ma coincided with collision of the Gander margin and composite Laurentia, leading to uplift associated with Salinic orogenesis and inversion of the Matapedia forearc basin.

## CONCLUSIONS

Upper Ordovician to Llandoverian synaccretionary, mainly turbiditic sedimentary rocks of the Bathurst and Fournier supergroups were deposited, at least in part, conformably above Sandbian – Katian pelagic sediments (chert and black shale) during incorporation of their substrate of backarc basin rocks into the Brunswick

subduction complex. Accretion started shortly after the initiation of northwest-directed Salinic subduction of the Tetagouche backarc basin at *ca.* 450 Ma, because the backarc basin contained several buoyant blocks of extended continental backarc crust, as well as basaltic seamounts that resisted deep subduction (van Staal and others, 2008). Detrital zircon analysis indicates that the youngest zircon populations in the Tomogonops and Val Michaud formations are Sandbian to Katian, implying that deposition of these units was coeval with deposition of lithologically similar, Late Ordovician to Silurian rocks in the Matapedia cover sequence.

The age of the Duncans Brook Formation is latest Ordovician to early Silurian, based on detrital zircon populations in underlying and interlayered sedimentary rocks, confirming the hypothesis of Winchester and others (1992) that these rocks are significantly younger than other basalt in the Elmtree inlier. Hence, the Duncans Brook Formation is interpreted to unconformably overlie the Middle Ordovician rocks of the Devereaux Complex. The Duncans Brook basalt has arc tholeiitic compositions and is probably tectonically related to somewhat younger (late Llandoverian) calc-alkaline basalt in the Weir Formation (Quinn Point Group) farther to the northwest (Wilson and others, 2008).

All age constraints show that deposition of the Matapedia cover sequence took place while northwest-directed subduction and deformation within the Brunswick subduction complex was occurring farther east in the adjacent Tetagouche backarc basin; that is, the depositional setting of the Matapedia cover sequence was a forearc basin. The implication of this 'spillover' of forearc rocks into and onto the adjacent trench and accretionary wedge is that the forearc progressively expanded toward the southeast between *ca.* 450 and 430 Ma; this is attributed to Late Ordovician – Llandoverian (Salinic) accretion of buoyant blocks in the Tetagouche backarc basin to composite Laurentia, and concomitant stepping back of the subduction zone. The foregoing demonstrates the complex interplay between accretion, sedimentation and exhumation in a large accretionary forearc system. Accretion ended with the arrival of the leading edge of the Gander margin no later than 430 Ma, marking the culmination of Salinic orogenesis.

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